JEPPIAAR INSTITUTE OF TECHNOLOGY

Self Belief | Self Discipline | Self Respect

QUESTION BANK

ACADEMIC YEAR : 2019-2020

REGULATION: 2017

III YEAR – 06th SEMESTER

DEPARTMENT OF MECHANICAL ENGINEERING

INSTITUTION VISION

Jeppiaar Institute of Technology aspires to provide technical education in futuristic technologies with the perspective of innovative, industrial and social application for the betterment of humanity.

INSTITUTION MISSION

- To produce competent and disciplined high quality professionals with the practical skills necessary to excel as innovative professionals and entrepreneurs for the benefit of the society.
- To improve the quality of education through excellence in teaching and learning, research, leadership and by promoting the principles of scientific analysis, and creative thinking.
- To provide excellent infrastructure, serene and stimulating environment that is most conducive to learning.
- To strive for productive partnership between the Industry and the Institute for research and development in the emerging fields and creating opportunities for employability.
- To serve the global community by instilling ethics, values and life skills among the students needed to enrich their lives.

DEPARTMENT VISION

To be the most sought-after Department in the field of Mechanical Engineering for imparting Technical Education for the upliftment of the society.

DEPARTMENT MISION

- To provide innovative solutions for industrial problems which helps in societal development.
- To inculcate students for a successful career in engineering and technology.
- To promote excellence in engineering and technology by motivating students for higher studies.
- To motivate self-employment thereby reducing migration to urban areas.
- To maintain ethical values while assimilating diverse culture without compromising with Indian value system.
- To motivate lifelong learning

PROGRAM OUTCOMES (POs) (Given in SAR)

Engineering Graduates will be able to:

1. **Engineering knowledge**: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
2. **Problem analysis**: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
3. **Design/development of solutions**: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
4. **Conduct investigations of complex problems**: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
5. **Modern tool usage**: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
6. **The engineer and society**: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
7. **Environment and sustainability**: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
8. **Ethics**: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
9. **Individual and team work**: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
10. **Communication**: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
11. **Project management and finance**: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
12. **Life-long learning**: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

BLOOM'S TAXONOMY

Definition:

Bloom's taxonomy is a classification system used to define and distinguish different levels of human cognition like thinking, learning and understanding.

Objectives:

- To classify educational learning objectives into levels of complexity and specification. The classification covers the learning objectives in cognitive, affective and sensory domains.
- To structure curriculum learning objectives, assessments and activities.

Levels in Bloom's Taxonomy:

- **BTL 1 – Remember** - The learner recalls, restate and remember the learned information.

- **BTL 2 – Understand** - The learner embraces the meaning of the information by interpreting and translating what has been learned.

- **BTL 3 – Apply** - The learner makes use of the information in a context similar to the one in which it was learned.

- **BTL 4 – Analyze** - The learner breaks the learned information into its parts to understand the information better.

- **BTL 5 – Evaluate** - The learner makes decisions based on in-depth reflection, criticism and assessment.

- **BTL 6 – Create** - The learner creates new ideas and information using what has been previously learned.

REGULATION : 2017 ACADEMIC YEAR : 2019-20

TABLE OF CONTENT

ME8694 – Hydraulics and Pneumatics

ME8091 – Automobile Engineering

ME8651 DESIGN OF TRANSMISSION SYSTEMS L TPC

3 0 0 3

OBJECTIVES:

- To gain knowledge on the principles and procedure for the design of Mechanical power Transmission components.
- To understand the standard procedure available for Design of Transmission of Mechanical elements.
- To learn to use standard data and catalogues.

UNIT I DESIGN OF FLEXIBLE ELEMENTS 9

Design of Flat belts and pulleys - Selection of V belts and pulleys – Selection of hoisting wire ropes and pulleys – Design of Transmission chains and Sprockets.

UNIT II SPUR GEARS AND PARALLEL AXIS HELICAL GEARS 9

Speed ratios and number of teeth-Force analysis -Tooth stresses - Dynamic effects – Fatigue strength - Factor of safety - Gear materials – Design of straight tooth spur & helical gears based on strength and wear considerations – Pressure angle in the normal and transverse plane- Equivalent number of teeth-forces for helical gears.

UNIT III BEVEL, WORM AND CROSS HELICAL GEARS 9

Straight bevel gear: Tooth terminology, tooth forces and stresses, equivalent number of teeth. Estimating the dimensions of pair of straight bevel gears. Worm Gear: Merits and demerits terminology. Thermal capacity, materials-forces and stresses, efficiency, estimating the size of the worm gear pair. Cross helical: Terminology-helix angles-Estimating the size of the pair of cross helical gears.

UNIT IV GEAR BOXES 9

Geometric progression - Standard step ratio - Ray diagram, kinematics layout -Design of sliding mesh gear box - Design of multi speed gear box for machine tool applications - Constant mesh gear box -Speed reducer unit. – Variable speed gear box, Fluid Couplings, Torque Converters for automotive applications.

UNIT V CAMS, CLUTCHES AND BRAKES 9

Cam Design: Types-pressure angle and under cutting base circle determination-forces and surface stresses. Design of plate clutches –axial clutches-cone clutches-internal expanding rim clutches-Electromagnetic clutches. Band and Block brakes - external shoe brakes – Internal expanding shoe brake.

TOTAL : 45 PERIODS

OUTCOMES:

- Upon completion of this course, the students can able to successfully design transmission components used in Engine and machines

TEXT BOOKS:

1. Bhandari V, “Design of Machine Elements”, 3rd Edition, Tata McGraw-Hill Book Co, 2010.
2. Joseph Shigley, Charles Mischke, Richard Budynas and Keith Nisbett “Mechanical Engineering Design”, 8th Edition, Tata McGraw-Hill, 2008.

REFERENCES:

1. Sundararajamoorthy T. V, Shanmugam .N, “Machine Design”, Anuradha Publications, Chennai, 2003.
2. Gitin Maitra, L. Prasad “Hand book of Mechanical Design”, 2nd Edition, Tata McGraw-Hill,2001.

3. Prabhu. T.J., “Design of Transmission Elements”, Mani Offset, Chennai, 2000.
4. C.S.Sharma, Kamlesh Purohit, “Design of Machine Elements”, Prentice Hall of India, Pvt. Ltd.,2003.
5. Bernard Hamrock, Steven Schmid, Bo Jacobson, “Fundamentals of Machine Elements”,2nd Edition, Tata McGraw-Hill Book Co., 2006.
6. Robert C. Juvinall and Kurt M. Marshek, “Fundamentals of Machine Design”, 4th Edition, Wiley,2005
7. Alfred Hall, Halowenko, A and Laughlin, H., “Machine Design”, Tata McGraw-HillBookCo.(Schaum’s Outline), 2010
8. Orthwein W, “Machine Component Design”, Jaico Publishing Co, 2003.
9. Ansel Ugural, “Mechanical Design – An Integral Approach", 1st Edition, Tata McGraw-HillBook Co, 2003.
10. Merhyle F. Spotts, Terry E. Shoup and Lee E. Hornberger, “Design of Machine Elements”8th Edition, Printice Hall, 2003.
11. U.C.Jindal : Machine Design, "Design of Transmission System", Dorling Kindersley, 2010

Subject Code:ME8651 **Year/Semester: III /06**
Subject Name: Design Of Transmission Systems **Subject Handler: Mr.S.Kanna & S.Vignesh**

UNIT I –DESIGN OF FLEXIBLE ELEMENTS

Design of Flat belts and pulleys - Selection of V belts and pulleys – Selection of hoisting wire ropesand pulleys – Design of Transmission chains and Sprockets.

PART * A

Q.No.	Questions
1	**Give an expression for ratio of tensions in a flat belt drive.** BTL3 $\frac{T_1}{T_2} = e^{\mu\theta}$ Where, T_1=Tension in tight side in N; T_2=Tension in slack side in N; μ=Coefficient of friction; θ=Angle of contact of driving pulley in radians.
2	**How is a V-belt specified?**BTL2 A typical example of its specification “C2032 IS 2494: 1964”. Here the ‘C’ denotes the section type of the belt, ‘2032’ represents the nominal inside length of the belt and 1964 is referred to as year of coding. The power transmitting capacity of section’C’ type of the belt is 1 kW to 12 kW.
3	**What is meant by “Chordal action of chain”? Also name a company that produces driving chains. (April/May 2015)**BTL1 When chain passes over a sprocket, it moves as a series of chords instead of a continuous arc as in the case of a belt drive. It results in varying speed of the chain drive. This phenomenon is known as chordal action. Some of the company names producing chains are: Roto mechanical equipment Chennai: Monal Chains Limited, Mumbai; Innotech Engineers Ltd., New Delhi.
4	**Why tight-side of the belt should be at the bottom side of the pulley?**BTL4 The positions of input and output pulleys are such that the tight side of the belt must be on the bottom and slack side on the top of the pulleys. Otherwise, the angle of contact between the belt and rim of the pulley reduces, decreasing the power transmission capacity of the belt.
5	**Definethe term “Crowning of pulley”. (Nov/Dec-2016, May/June 2014)**BTL1 The pulley rims are tapered slightly towards the edges. This slight convexity is known as crowning. The crowning tends to keep the belt in centre on a pulley rim while in motion. These flat belts stayed centered on pulleys without any guides or flanges. The key to keeping them tracking centered on the pulleys is the use of "crowned pulleys"
6	**A longer belt will last more than a shorter belt. Why? (Apr/May 2017)**BTL4 The life of a belt is a function of the centre distance between the driver and driven shafts and diameter of driver and driven pulleys. The shorter the belt, the more often it will be subjected to additional bending stresses while running around the pulleys at a given speed. And also it will be destroyed quickly due to fatigue. Hence the increased centre distance and diameter of pulley

	will increase the belt life. Hence, a longer belt will last more than a shorter belt.
7	**Mention the losses in belt drives. (Nov/Dec 2014)**BTL2 The losses in a belt drive are due to: ➢ Slip and creep of the belt on the pulleys (about 3%) ➢ Bending of the belt over the pulleys (about 1%) ➢ Friction in the bearings of pulley (about 1%) and ➢ Windage or air resistance to the movement of belt and pulleys (usually negligible)
8	**In what ways the timing belts are superior to ordinary V-belts? (April/May 2015)**BTL4 Flat belt and V-belt drives cannot provide a precise speed ratio, because slippage occurs at the sheaves. But certain applications require an exact output to input speed ratio. In such situations, timing belts are used. Since the timing belts (aka. synchronous belts) possess toothed shape in their -inner side, engagement with toothed pulley will provide positive drive without, belt-slip where as in the case of ordinary V-belts, chances of slip are and hence positive drive is not possible at all times. Hence toothed belts (I timing belts) are superior to ordinary V-belts.
9	**Why are idler pulleys used in a belt drive?**BTL4 Idler pulleys are used to take up slack, change the direction of transmission, or provide clutching action in any industry, material handling or any other mechanical purpose. But they don't provide any mechanical advantage, nor does it transmit power. One such example of its application is to improve belt drive performances as they reduce vibration by supporting a segment of belt which is prone to vibration/oscillation. They are also used in car engines for positive clutching action by running the idler pulley on the slack side of the flat-belt drive from engine to transmission.
10	**Name the few materials for belt drives. (May/June 2016)**BTL2 ➢ Leather ➢ Fabric and cotton ➢ Rubber ➢ Balata and ➢ Nylon.
11	**State the law of belting.**BTL1 Law of belting states that the centre line of the belt as it approaches the pulley must lie in a plane perpendicular to the axis of that pulley or must lie in the plane of the pulley, otherwise the belt will run off the pulley. "The centreline of the belt when it approaches a pulley must lie in the midplane of the pulley".
12	**What is wipping? How it can be avoided in belt drives?**BTL3 If the centre distances between two pulleys are too long then the belt begins to vibrate in a direction perpendicular to the direction of motion of belt. This phenomenon is called as wipping. Wipping can be avoided by using idler pulleys.
13	**How are wire ropes designated? Give an example? (Nov/Dec 2012)**BTL2 Wire ropes are designated (or specified) by the number of strands and the number of wires in each strand. Standard Wire Rope, 6x7 Class Wire Rope, Strands: 6, Wires per Strand: 7, Core: Fiber Core, Standard Grade(s): Improved Plow (IPS), Lay: Regular or Lang, Finish: Bright or

	Galvanized
14	**What do you understand by 6 x 19 constructions in wire ropes? (Nov/Dec 2014)**BTL2 A 6 x 19 wire rope means a rope is made from 6 strands with 19 wires in each strand.
15	**Give any three applications of chain drives. What are they limitations? (April/May 2011)**BTL2 Chain drives are widely used in transportation industry, agricultural machinery, metal and wood working machines. Limitations: heavy height, sudden failure, intensive wear of the links in the joints susceptibility to jerks and overloads.
16	**What is the effect of chordal action in chain drives? How can you reduce that effect? (April/May 2015)**BTL4 As the chain enters and exits, it rises and falls as each pitch engages and disengages the sprockets. This movement, called chordal action, causes chain speed variations (drive roughness) that may be objectionable in some applications. These speed variations can normally be minimized by increasing the size of the sprockets. Chordal action results in a pulsating and jerk motion of a chain. In order to reduce the variation in chain speed, the number of teeth on the sprocket should be increased.
17	**What do you mean by galling of roller chains? (May/June 2012)**BTL3 Galling is a stick-slip phenomenon between the pin and the bushing. When the load is heavy and the speed is high, the high spots (i.e. joints) of the contacting surfaces are welded together. This phenomenon of welding is called as galling of roller chains. Use high quality, high pressure lubricants and ensure that the lubricant regime is such that the film of lubricant is constantly maintained between the surfaces.
18	**Under what circumstances chain drives are preferred over V belt drives? (May/June 2016)**BTL4 The popularity of chain drives stems from their ability to transmit high torque levels in a small package, at relatively low cost, while utilizing readily available stock components. While initial costs of standard roller chain drives can be quite low, the cost of maintaining them can be substantial. The ability to create any length of chain with connecting links. The availability of a large selection of chains and sprockets.
19	**What factors will affect the working conditions of chain drive? (Nov/Dec-2016)**BTL2 ➢ Tension in the chains ➢ Sizes of the pulley/gear ➢ Number of pulley/gear ➢ Length of the chain drive ➢ Friction between chains & pulley/gear ➢ Angle of contact.
20	**List the advantages of wire ropes compared to chains.(Apr/May-2017)**BTL1 ➢ More reliable in operation ➢ Silent operation even at high working speeds ➢ Less danger for damage due to jerks.

21 **What is centrifugal effect on belts? (Nov/Dec 2015)**BTL4

As the belt moves round the pulley, it would experience a centrifugal force which has a tendency to separate the belt from the pulley surface. To maintain contact between the pulley and belt, the centrifugal force produce additional tension in the belt, which is known as centrifugal tension ($T_C=mv^2$).

22 **What are the factors upon which the coefficient of friction between the belt and pulley depends? (May/June 2014, 2012)**BTL2

The coefficient of friction between the belt material and pulley surface depends upon the belt material, material of the pulley surfaces, belt speed and belt slip.

23 **Name the types of belts used for transmission of power.(May/June 2013)**BTL2

- Flat belts
- V-belts
- Ribbed belts
- Toothed or timing belts

24 **List out the various stresses induced in the wire ropes. (May/June 2013)**BTL1

- Direct stress due to the weight of the load to be lifted.
- Bending stress when the rope passes over the sheave
- Stress due to acceleration
- Stress due to starting and stopping
- Effective stress.

25 **Mention the parts of roller chains.**(**Nov/Dec 2012)**BTL2

- Inner (pin link or coupling link) and outer link plates (roller link)
- Pin
- Bushing and rollers.

PART * B

1 **Design a flat belt drive to transmit 110 kW for a system consisting of two pulleys of diameters 0.9m and 1.2m for a centre distance of 3.6m, belt speed of 20 m/s and coefficient of friction is 0.3. There is a slip of 1.2% at each pulley and 5% friction loss at each shaft with 20% overload. (13M)(Nov/Dec 2016)** BTL5

Pulley diameters: d = 0.9m, D = 1.2m

Answer: Page: 1.31 – Dr.A.Baskar

Design power:(2M)

$$Design\ power = \frac{Rated\ power\ X\ Load\ correction\ factor}{Arc\ of\ contact\ factor} = 135882\ W$$

Type of belt: (2M)

Considering heavy duty and medium belt speed; Dunlop FORT 949 g belt is selected.

Load rating = 0.0578 kW per mm per ply

No. of plies = 8.

Standard belt width:(2M)

$$Belt\ width = \frac{Design\ power}{load} = 294\ mm$$

Pulley width:(2M)

Pulley width above 250 mm upto including 375 mm is to be wider than belt width by 38 mm.

Pulley width = 343 mm.

Length of belt:(2M)

$$L = 2C + \frac{\pi}{2}(D + d) + \frac{(D - d)}{4C} = 10505\,mm$$

Other pulley dimensions:(3M)

Number of arms = 6

Cross section of arms = elliptical

Radius of cross section of arm, r = 52.5 mm (small) & r = 57 mm (large).

Minimum length of bore, l = 230 mm (small) & l = 230 mm (large).

Speed of driver pulley = 430 rpm.

Speed of driven pulley = 319 rpm.

2 **A V-belt drive is to transmit 15 kW to a compressor. The motor runs at 115 rpm and the compressor is to run at 400 rpm. Determine (i) Belt specification, (ii) Number of belts, (iii) Correct centre distance, (iv) Drive pulley diameters. (13M)(Nov/Dec 2015)** BTL5

Answer: Page: 1.69 – Dr.A.Baskar

Belt cross section:(1M)

Nominal top width, W = 17 mm.

Nominal thickness, T = 11 mm.

Pulley diameters:(1M)

$$speed\ ratio, i = \frac{D}{d} = \frac{n_1}{n_2}$$

Standard pulley diameter, D = 400 mm.

Centre distance, C;(1M)

Centre distance is assumed to be equal to 400 mm.

Nominal pitch length:(2M)

$$L = 2C + \frac{\pi}{2}(D + d) + \frac{(D - d)}{4C} = 1671.93\,mm$$

Minimum power transmitting capacity in kW:(2M)

$$kW = \left(0.79 \times 7.53^{-0.09} - \frac{50.8}{142.5} - 1.32 \times 10^{-4} \times 7.53^2\right) 7.53 = 2.22\,kW$$

Number of belts:(2M)

$$Arc\ of\ contact = 180° - 60° \times \frac{D - d}{C} = 138.75°$$

$$no. of\ belts = \frac{P \times F_a}{kW \times F_c \times F_d} = 11\,belts$$

Actual centre distance, C:(2M)

$$A = \frac{L}{4} - \frac{\pi(D + d)}{8} = 217.33$$

$$B = \frac{(D + d)^2}{8} = 9453.125$$

$$C = A + \sqrt{A^2 - B} = 411.7\ mm$$

Dimensions of V grooved pulley:(2M)

Pitch width, l_p = 14 mm.

Minimum distance down to pitch line, b = 4.2 mm.

Centre to centre distance, e = 19 mm.

Edge of pulley to first groove, f = 12.5 mm.

3 **At the construction site, 1 tonne of steel is to be lifted upto a height of 20 m with the help of 2 wire ropes of 6x19 size, nominal diameter 12 mm and breaking load 75 kN. Determine the factor of safety if the sheave diameter is 56d and wire rope is suddenly stopped in 1 second while travelling at a speed of 1.2 m/s. What is the factor of safety if bending load is neglected? (13M)(Nov/Dec 2014)**BTL5

Answer: Page: 1.126 – Dr.A.Baskar

Wire rope type: 6 x 19 group.(2M)

Design load: Not required

Wire rope diameter, d and weight of rope, W_r:(2M)

D = 12 mm (given), W_r = 106 N.

Drum diameter, D = 56d = 672 mm.

Useful cross section area, A = 45.24 mm^2.

Wire diameter, d_w:(3M)

$$d_w = \frac{Rope\ diameter, d}{1.5 \times \sqrt{No.of\ strands \times No.of\ wires\ per\ strand}} = 0.7493\ mm$$

Effective load, W_{eq}:(4M)

$$W_d = W + W_r = 9916\ N$$

$$W_b = E \times \frac{d_w}{D} \times A = 3959\ N$$

$$W_a = \frac{W + W_r}{g} \times a = 1213\ N$$

$$W_{eq} = W_d + W_b + W_a$$

Actual factor of safety:(2M)

$$Working\ factor\ of\ safety = \frac{Breaking\ load\ of\ the\ selected\ rope}{Effective\ load} = 10.34$$

4 **A bucket elevator is to be driven by a geared motor and a roller chain drive with the information given below:**

Motor output = 3 kW; speed of motor shaft = 100 rpm; elevator drive shaft speed = 42 rpm; load = even; distance between centres of sprockets approximately = 1.2m; period of operation = 16 hours/day; geared motor is mounted on an auxiliary bed for centre distance adjustments. Design the chain drive. (13M)(Nov/Dec 2016)BTL5

Answer: Page: 1.151 – Dr.A.Baskar

Type of chain: Roller chain.(1M)

Preferred transmission ratio, i;(2M)

$$i = \frac{z_2}{z_1} = \frac{n_1}{n_2} = 2.38$$

Number of teeth, z;(1M)

Z_1 = 27; Z_2 = 100 to 120 satisfied.

Standard pitch, p:(1M)

$$p = \frac{a}{30}\ to\ \frac{a}{50} = 40\ to\ 24\ mm$$

The standard pitch of 15.875 mm is selected.

Minimum factor of safety, n:(2M)

$$N = \frac{Q.v}{102nk_s}\ in\ kW$$

Chain velocity, v = 0.7144 m/s.

Service factor, k_s = 1.0

$$Breaking\ load, Q = \frac{N \times 102 \times n \times k_s}{v} = 3341\ kgf$$

Selection of chain:(1M)

Chain no.10 A-2 DR 50 is selected; Breaking area, A = 140 mm^2

Check for actual factor of safety, [n]:(1M)

$$[n] = \frac{Q}{\sum P} = 10.06$$

Actual factor of safety is larger than assumed factor of safety. Hence the design is safe.

Check for bearing stress:(1M)

$$\sigma = \frac{N \times 102 \times k_s}{A.v} = 3.15\ kgf/mm^2$$

Actual bearing stress is less than the allowable bearing stress. Hence the design is safe.

Actual length of chain, l:(1M)

$$l_p = 2a_p + \frac{(z_1 + z_2)}{2} + \frac{\left(\frac{z_2 - z_1}{2\pi}\right)^2}{a_p} = 198\ mm$$

$$l = l_p.p = 3143.25\ mm$$

Exact centre distance, a;(1M)

$$a = \frac{e + \sqrt{e^2 - 8m}}{4}.p = 1202.67\ mm$$

Chain wheel profile dimensions:(1M)

Pitch diameter of small sprocket, d_1 = 136.74 mm.

Tooth side radius, F = 15.88 mm.

Side relief, G = 1.60 mm.

Shroud depth, J = 3.43 mm.

Shroud radius, K = 0.76 mm.

5 **A compressor is to run by a motor pulley running at 1440 rpm, speed ratio 2.5. Choose a flat belt crossed drive. Centre distance between pulleys is 3.6 m. Take belt speed as 16 m/s. Load factor is 1.3. Take a 5-ply, flat Dunlop belt. Power to be transmitted is 12 kW. High**

speed load rating is 0.0118 kW/ply/mm width at v = 5 m/s. Determine the width and length of the belt. (13M)(Nov/Dec 2014)BTL5

Answer: Page: 1.39 – Dr.A.Baskar

Pulley diameters: (2M)

$$Speed\ ratio, i = \frac{D}{d} = \frac{n}{N} = 2.5$$

d = 224 mm, D = 560 mm

Design power:(3M)

$$Design\ power = \frac{Rated\ power\ X\ Load\ correction\ factor}{Arc\ of\ contact\ factor} = 16.28\ kW$$

Type of belt: (3M)

For high speeds, Dunlop HI-SPEED 878 g fabric belting is selected.

Load rating = 0.03776 kW/mm/ply

No. of plies = 5 (give).

Standard belt width:(3M)

$$Belt\ width = \frac{Design\ power}{load} = 87\ mm$$

Length of belt:(2M)

$$L = 2C + \frac{\pi}{2}(D + d) + \frac{(D + d)}{4C} = 8474\ mm$$

PART * C

1 **Design a V-belt drive and calculate the actual belt tensions and average stress for the following data:**

Power to be transmitted = 7.5 kW; Speed of driving wheel = 1000 rpm; Speed of driven wheel = 300 rpm; Diameter of driven wheel = 500 mm; Diameter of driver pulley = 150 mm and centre distance = 925 mm. (15M)(April/May 2015)BTL5

Answer: Page: 1.75 – Dr.A.Baskar

Belt cross section:(1M)

Nominal top width, W = 17 mm.

Nominal thickness, T = 11 mm.

Pulley diameters:(1M)

d = 150 mm (given); D = 500 mm (given).

Centre distance, C = 925 mm (given)

Nominal pitch length:(2M)

$$L = 2C + \frac{\pi}{2}(D + d) + \frac{(D - d)}{4C} = 2904.13\ mm$$

Minimum power transmitting capacity in kW:(3M)

$$kW = \left(0.79S^{-0.09} - \frac{50.8}{d_e} - 1.32 \times 10^{-4}s^2\right)S = 2.7561\ kW$$

Number of belts:(2M)

$$Arc\ of\ contact = 180° - 60° \times \frac{D - d}{C} = 157.3°$$

$$no.of\ belts = \frac{P \times F_a}{kW \times F_c \times F_d} = 4\ belts$$

Actual centre distance, C:(3M)

$$A = \frac{L}{4} - \frac{\pi(D+d)}{8} = 517.496$$

$$B = \frac{(D+d)^2}{8} = 15312.5$$

$$C = A + \sqrt{A^2 - B} = 1019.98\ mm$$

Actual belt tensions:(3M)

$$Power\ transmitted\ per\ belt = \frac{Total\ power\ transmitted}{Number\ of\ belts} = 1875\ W$$

$$\frac{T_1}{T_2} = e^{\left(\frac{\mu\theta}{\sin\beta}\right)}$$

Tension on slack side, T_1 = 15.19 N;

Tension on tight side, T_2 = 254.04 N.

2 **The transporter of a heat treatment furnace is driven by a 4.5 kW, 1440 rpm induction motor through a chain drive with a speed reduction ratio of 2.4. The transmission is horizontal with both type of lubrication. Rating is continuous with 3 shifts per day. Design the complete chain drive.(15M)(Nov/Dec 2013)**BTL5

Answer: Page: 1.145 – Dr.A.Baskar

Type of chain: Roller chain. (1M)

Preferred transmission ratio, i = 2.4 (given)

Number of teeth, z:(1M)

Z_1 = 27 (assumed); Z_2 = 65.

Standard pitch, p:(1M)

$$p = \frac{a}{30}\ to\ \frac{a}{50} = 16.6667\ to\ 10\ mm$$

Available standard pitches are: 9.525 mm, 12.7 mm & 15.875 mm.

The standard pitch of 12.7 mm is selected.

Minimum factor of safety, n:(2M)

$$N = \frac{Q.v}{102nk_s}\ in\ kW$$

Chain velocity, v = 8.229 m/s.

Service factor, k_s = 1.5

$$Breaking\ load, Q = \frac{N\times102\times n\times k_s}{v} = 1104.33\ kgf$$

Selection of chain:(1M)

Chain no.08 B-3 R 1278H is selected;

Breaking load, Q = 2100 kgf;

Weight per meter = 0.75 kgf;

Breaking area, A = 54 mm^2

Check for actual factor of safety, [n]:(1M)

$$[n] = \frac{Q}{\sum P} = 33.23$$

Actual factor of safety is larger than assumed factor of safety. Hence the design is safe.

Check for bearing stress:(2M)

$$\sigma = \frac{N \times 102 \times k_s}{A.v} = 1.55\ kgf/mm^2$$

Actual bearing stress is less than the allowable bearing stress. Hence the design is safe.

Actual length of chain, l:(2M)

$$l_p = 2a_p + \frac{(z_1 + z_2)}{2} + \frac{\left(\frac{z_2 - z_1}{2\pi}\right)^2}{a_p} = 125.669\ mm$$

$$l = l_p.p = 1600.2\ mm$$

Exact centre distance, a:(2M)

$$a = \frac{e + \sqrt{e^2 - 8m}}{4}.p = 502.12\ mm$$

Chain wheel profile dimensions:(2M)

Pitch diameter of small sprocket, d_1 = 109.4 mm.

Tooth side radius, F = 12.70 mm.

Side relief, G = 1.25 mm.

Shroud depth, J = 2.79 mm.

Shroud radius, K = 0.76 mm.

3 **A 7.5 kW electric motor running at 1400 rpm is used to drive the input shaft of the gear box of a special purpose machine. Design a suitable roller chain to connect the motor shaft to the gear box shaft to give an exact speed ratio of 10 to 1. Assume the minimum centre distance between driver and driven shafts as 600 mm.(15M)(May/June 2016)**BTL5

Answer: Page: 1.156 – Dr.A.Baskar

Type of chain: Roller chain.(1M)

Preferred transmission ratio, i = 10 (given);

Number of teeth, z: (1M)

Z_1 = 11 (assumed); Z_2 = 110.

Standard pitch, p:(1M)

$$p = \frac{a}{30}\ to\ \frac{a}{50} = 20\ to\ 12\ mm$$

The standard pitch of 15.875 mm is selected.

Minimum factor of safety, n:(1M)

$$N = \frac{Q.v}{102nk_s}\ in\ kW$$

Chain velocity, v = 4.07 m/s.

Service factor, k_s = 1.5625

$$Breaking\ load, Q = \frac{N \times 102 \times n \times k_s}{v} = 3877\ kgf$$

Selection of chain:(1M)

Chain no.10 B-2 DR 1595 is selected;
Breaking load, Q = 4540 kgf;
Weight per meter = 1.82 kgf;
Breaking area, A = 134 mm^2

Check for actual factor of safety, [n]:(2M)

$$[n] = \frac{Q}{\sum P} = 10.06$$

Actual factor of safety is larger than assumed factor of safety. Hence the design is safe.

Check for bearing stress:(2M)

$$\sigma = \frac{N \times 102 \times k_s}{A.v} = 3.15\, kgf/mm^2$$

Actual bearing stress is less than the allowable bearing stress. Hence the design is safe.

Actual length of chain, l:(2M)

$$l_p = 2a_p + \frac{(z_1 + z_2)}{2} + \frac{\left(\frac{z_2 - z_1}{2\pi}\right)^2}{a_p} = 198$$

$$l = \ l_p.p = 3143.25\, mm$$

Exact centre distance, a:(2M)

$$a = \frac{e + \sqrt{e^2 - 8m}}{4}.p = 1202.67\, mm$$

Chain wheel profile dimensions:(2M)
Pitch diameter of small sprocket, d_1 = 136.74 mm.
Tooth side radius, F = 15.88 mm.
Side relief, G = 1.60 mm.
Shroud depth, J = 3.43 mm.
Shroud radius, K = 0.76 mm.

4 **A V-belt drive is to be arranged between two shafts with 1.2 m as centre distance. The driving pulley is of 250 mm effective diameter and is to be supplied with 20 kW power at 960 rpm. The follower pulley is to run at 460 rpm. Determine the number of belts required from the following:**
Arc of the belt cross section = 143 mm^2; Mass density of the belt material = 100 kg/m^3; Permissible tensile stress = 2 N/mm^2; Coefficient of friction = 0.3; Groove angle of the pulley, 2β = 40°. (15M)(Nov/Dec 2015)BTL5

Note: since all the data are available, problem can be solved using basic equations.

Diameter of the driven pulley, D:(2M)

$$Speed\ ratio, i = \frac{D}{d} = \frac{n_1}{n_2}$$

$$D = \frac{960\ X\ 0.25}{460} = 522\, mm$$

Mass of the belt per meter length:(2M)

$$m = Density\ \times cross\ section\ area = 0.143\, \frac{kg}{m}$$

Centrifugal tension, T_c:(2M)

$$T_c = mv^2 = 22.58\ N$$

Angle contact, θ:(2M)

$$Arc\ of\ contact = 180° - 60° \times \frac{D-d}{C} = 166.4°$$

Maximum tension in the belt, T_{max}:(2M)

$$T_{max} = \sigma \times cross\ section\ area = 286\ N$$

Belt tensions:(2M)

$$\frac{T_1}{T_2} = e^{\left(\frac{\mu\theta}{\sin\beta}\right)}$$

Tension at tight side, $T_1 = T_{max} - T_c$ = 263.42 N.

Tension at slack side, T_2 = 20.63 N.

Number of belts:(3M)

$$Power\ transmitted = (T_1 - T_2)v = 3050.9\ W$$

$$Number\ of\ belts = \frac{Total\ power\ transmitted}{Power\ transmitted\ by\ one\ belt} = 7\ belts$$

UNIT II–SPUR GEARS AND PARALLEL AXIS HELICAL GEARS

Speed ratios and number of teeth-Force analysis -Tooth stresses - Dynamic effects – Fatigue strength-Factor of safety - Gear materials – Design of straight tooth spur & helical gears based on strengthand wear considerations – Pressure angle in the normal and transverse plane- Equivalent number ofteeth-forces for helical gears.

PART * A

Q.No.	Questions
1	**Specify the conditions based on which gear cutters are selected.**BTL4 ➢ The capacity of the machine size and shape of the gear ➢ Proper material selection ➢ The magnitude of production range ➢ The production time ➢ The technical experience of the machinist ➢ The economic viability of the machine ➢ The cutting forces
2	**Define backlash. What factors influence backlash in gear drives? (Nov/Dec 2016)**BTL1 Shortest distance between the non-contacting surfaces of the adjacent teeth is referred to as backlash. ➢ Module and ➢ Pitch line velocity influence the backlash in gear drives.
3	**What are the advantages of the helical gear over spur gear?**BTL2 ➢ Helical gears produce less noise than spur gears of equivalent quality because the total contact ratio is increased. ➢ Helical gears have a greater load carrying capacity than equivalent size of spur gears. ➢ A limited number of standard cutters are used to cut a wide variety of helical gears simply by varying the helix angle. ➢ Smoother engagement of the gear teeth. ➢ More teeth carry load at a given time so that they are more efficient – carry more load for a given size.
4	**What are the main types of gear tooth failure? (May/June2013, 2012)**BTL1 ➢Tooth breakage (due to static and dynamic loads). ➢Tooth wear (or surface deterioration): (a) Abrasion; (b) Pitting and(c) Scoring or seizure.
5	**What are the assumptions made in deriving Lewis equation?**BTL3 ➢ The effect of radial component, which induces compressive stresses, is negligible. ➢ The tangential component is uniformly distributed across the full face width. ➢ The tangential force is applied to the tip of a single tooth.

	➢ Stress concentration in the tooth fillet is negligible.
6	**Why is pinion made harder than gear? (Nov/Dec 2012)**BTL4 Since the teeth of pinion undergo more number of cycles than gear and hence quicker wear.
7	**List out the various methods of manufacturing a gear.**BTL2 ➢ Gear milling, ➢ Gear generating, ➢ Gear hobbing, ➢ Gear shaping, ➢ Gear molding, ➢ Injection molding, ➢ Die casting and ➢ Investment casting.
8	**What are the common forms of gear tooth profile? (Apr/May 2011)**BTL1 ➢ Involute tooth profile and ➢ Cycloidal tooth profile.
9	**What are the standard interchangeable tooth profiles?**BTL2 ➢ $14½^0$ composite system ➢ $14½^0$ full depth involute system ➢ 20^0 full depth involute system and ➢ 20^0 stub involute system.
10	**What are the effects of increasing and decreasing the pressure angle in gear design? (April/May 2015, 2017&2014, Nov/Dec 2014)**BTL4 ➢ Increasing the pressure angle will increase the beam and surface strengths of tooth. But gear becomes noisy. ➢ Decreasing the pressure angle will increase the minimum number of teeth required on the pinion to avoid interference/ undercutting.
11	**A helical gear has a normal pressure angle of 20 degrees, a helix angle of 45 degrees, normal module of 4mm and has 20 teeth. Find the pitch diameter. (Nov/Dec 2016)**BTL5 Solution : Pitch circle diameter (d) = (m_n x Z)/ cosβ, = (4x20)/cos45 = 113.3 = 114mm
12	**Differentiate double helical and herringbone gears. (Nov/Dec 2015, Apr/May 2017)** BTL4 When there is groove in between the gears, then the gears are specifically known as double helical gears. When there is no groove in between the gears, then the gears is known as herringbone gears.
13	**Write short notes on stub tooth system. (May/June2012)**BTL1 In this system, the thickness of tooth at top surface and its root is more compare to full depth tooth system. Also this kind of tooth possesses shorter addendum and larger pressure angle, usually 20^0 and thus interference problem may be eliminated. For standard stub tooth system, the tooth proportion are as Whole depth=1.8*module; Addendum==0.8*module; Dedendum=1.0*module; Working Depth=1.6*module; Clearance=0.2*module;
14	**What are the advantages of helical gears? [(Nov/Dec 2012)**BTL2 ➢ Transmit more power

	➢ Provide smooth and ➢ Soundless operation.
15	**What are the profiles of a spur gear? (May/June 2016)**BTL1 Two constant velocity tooth profiles are the most commonly used in modern times: the cycloid and the involute.
16	**What is herringbone gear? (May/June 2016)**BTL1 Herringbone gears, also called double helical gears, are gear sets designed to transmit power through parallel or, less commonly, perpendicular axes. The unique tooth structure of a herringbone gear consists of two adjoining, opposite helixes that appear in the shape of the letter 'V'.Double helical gears are used in many applications such as cranes, fluid pumps and power transmission to the propulsion screws in military ships for a quieter and less vibration operation.
17	**State the advantages of Herringbone gear. (April/May 2015, 2013)**BTL1 Herringbone gears eliminate the existence of axial thrust load in the helical gears. Because, in herringbone gears, the thrust force of the right hand is balanced by that of the left hand helix.
18	**Why is a gear tooth subjected to dynamic load? (Nov/Dec 2014)**BTL4 Dynamic loads are due to ➢ In accuracies of tooth spacing ➢ Irregularities in tooth profiles ➢ Elasticity of parts ➢ Misalignment between bearings ➢ Deflection of teeth under load ➢ Dynamic unbalance of rotating masses.
19	**Compare the features of spur and helical gears. (Nov/Dec 2012)**BTL4 **Advantages of the spur gear**: ➢ Spur gears are simplest, hence easiest to design and manufacture. ➢ A spur gear is more efficient if you compare it with helical gear of same size. ➢ Easy to assemble **Advantages of the helical gear**: ➢ Silent operation ➢ Helical gears can be used for transferring power between non-parallel shafts. ➢ For same tooth size (module) and equivalent width, helical gears can handle more load than spur gears because the helical gear tooth is effectively larger since it is diagonally positioned.
20	**Define the various pitch in a helical gear. (May/June 2012)**BTL1 ➢ Transverse circular pitch (P_t) ➢ Normal circular pitch (P_n) ➢ Axial Pitch (P_a) ➢ Normal diametral pitch (P_d)
21	**State the law of gearing. (or) State the conditions of correct gearing. (Nov/Dec2012, April /May 2015)(or) What conditions must be satisfied in order that a pair of spur gears may**

	have constant velocity ratio?(May/June 2014)BTL1 The law of gearing states that for obtaining a constant velocity ratio, at any instant of teeth the common normal at each point of contact should always pass through a pitch point (fixed point), situated on the line joining the centres of rotation of the pair of mating gears. The angular velocity ratio of the gears of a gear-set must remain constant throughout the mesh.
22	**State some materials used for manufacturing of gears. (May/June 2013)**BTL1 Metallic gears: steel, cast iron and bronze. Non-metallic gears: wood, compressed paper and synthetic resins.
23	**Define module. (April/May 2011, May/June 2013, Nov/Dec 2015)**BTL1 Module, m this indicates the tooth size and is the number of mm of pitch circle diameter (p.c.d.) per tooth. For gears to mesh, their modules must be equal. Gear ISO standards and design methods are now normally based on the module. EG a gear of module 3 has 16 teeth, its pitch circle diameter is: 3 x 16 = 48 mm. In a pair of spur gears, the module is 6 mm.
24	**What are the advantages of toothed gears over the other types of transmission systems?**BTL2 Advantages of gear drives over other drives, i.e. belt, rope and chain drives are ➢ It is very compact and need less space. ➢ It has a very high efficiency which is very useful in transmitting motion. ➢ The main advantage of gear drive is that it transmit same velocity ratio. ➢ Again a good advantage is that it is a very good reliable service. ➢ And last is that it can be used to transmit a very large power.
25	**What is pressure angle? (April /May 2015 & 2014, Nov/Dec 2014)**BTL1 It is the angle which the line of action makes with the common tangent to pitch circles of mating gears. Simply refers to the angle through which forces are transmitted between meshing gears. Ideally 20° of pressure angle (involute system) is preferred because the tooth acting as a beam is wider at the base.
	PART * B
1	**A speed reducing unit using spur gear is to be designed. Power to be transmitted is 60 hp and is continuous with moderate shock loads. The speeds of the shafts are 720 rpm and 144 rpm respectively. The centre distance is kept as small as possible. Select a suitable material and design the gears. Give the details of the gears.(13M)(May/June 2016)**BTL5 **Answer: Page: 2.59 – Dr.A.Baskar** **Gear ratio, i:**(1M) $$i = \frac{N_1}{N_2} = 5$$ **Material:**(1M) C45 is selected for both pinion and wheel. Design bending stress, $[\sigma_b]$ = 13734 X 10^4 N/m^2 Design surface contact stress, $[\sigma_c]$ = 49050 X 10^4 N/m^2 **Gear life:** Not Given **Design torque, $[M_t]$:**(1M)

$$Torque\ transmitted, M_t = \frac{60 \times Power\ in\ watts}{2\pi N} = 593.648\ N - m$$

$$[M_t] = M_t . k_d . k = 771.742\ N - m$$

Calculation of E_{eq}, $[\sigma_b]$ and $[\sigma_c]$:(1M)

$E_{eq} = 210915 \text{ X } 10^6 \text{ N/m}^2$

$[\sigma_b] = 13734 \text{ X } 10^4 \text{ N/m}^2$

$[\sigma_c] = 49050 \text{ X } 10^4 \text{ N/m}^2$

Centre distance, a:(1M)

$$a \geq (i + 1) \sqrt[3]{\left(\frac{0.74}{[\sigma_c]}\right)^2 \frac{E \times [M_t]}{i \times \psi}}$$

$$Assume, \frac{b}{a} = 0.3$$

$$a_{min} = 376\ mm$$

Number of teeth Z_1 and Z_2:(1M)

Z_1 = 20 (assumed)

Z_2 = i. Z_1 = 100.

Module, m:(1M)

$$m \geq 1.26 \sqrt[3]{\frac{[M_t]}{y[\sigma_b]\psi Z_1}} = 6\ mm$$

Revised centre distance, a and number of teeth:(1M)

$$a = \frac{m(Z_1 + Z_2)}{2}$$

Z_1 = 25 teeth; Z_2 = 105 teeth; a = 378 mm.

Face width, pitch circle diameter, pitch line velocity:(1M)

Face width, b = ψ . a = 113.4 mm

Pitch circle diameter, $d_1 = mZ_1$ = 126 mm.

Pitch line velocity, v = 4.75 m/s.

Quality of gear:(1M)

IS quality 8 is selected.

Revision of design torque:

$$[M_t] = M_t . k_d . k = 865.539\ N - m$$

Check for maximum induced bending stress, σ_b:(1M)

$$\sigma_b = \frac{(i + 1)}{amby} \times [M_t] \leq [\sigma_b]$$

$$\sigma_b = 13734 \times 10^4 N/m^2$$

Design is safe.

Check for maximum induced compressive stress, σ_c:(1M)

$$\sigma_c = 0.74 \times \frac{(i + 1)}{a} \times \sqrt{\frac{(i + 1)E[M_t]}{i . b}} \leq [\sigma_c]$$

$$\sigma_c = 49050 \times 10^4 N/m^2$$

Design is safe.

Basic dimensions of pinion and wheel:(1M)

Pinion:

$$Pitch\ circle\ diameter, d_1 = 126\ mm$$
$$Height\ factor, f_0 = 1\ (for\ full\ depth)$$
$$Tip\ circle\ diameter, d_{c1} = (Z_1 + 2f_0)m = 138\ mm$$
$$Root\ circle\ diameter, d_{f1} = (Z_1 + 2f_0)m - 2c = 111\ mm$$
$$Top\ depth, h = 2.25m = 13.5\ mm$$

Wheel:

$$Pitch\ circle\ diameter, d_2 = 630\ mm$$
$$Tip\ circle\ diameter, d_{c2} = (Z_2 + 2f_0)m = 642\ mm$$
$$Root\ circle\ diameter, d_{f2} = (Z_2 + 2f_0)m - 2c = 615\ mm$$
$$Top\ depth, h = 2.25m = 13.5\ mm$$

2 **In a spur gear drive for a stone crusher, the gears are made of C40 steel. The pinion is transmitting 30 kW at 1200 rpm. The gear ratio is 3. Gear is to work 8 hours per day, six days a week and for 3 years. Design the drive.(13M)(Nov/Dec 2016)**BTL5

Answer: Page: 2.65 – Dr.A.Baskar

Gear ratio, i:(1M)

$$i = \frac{N_1}{N_2} = 3\ (given)$$

Material:(1M)

C40 is selected for both pinion and wheel (given).

Gear life: N = 53.9136 X 10^7 cycles.

Design torque, [M_t]:(1M)

$$Torque\ transmitted, M_t = \frac{60 \times Power\ in\ watts}{2\pi N} = 238.732\ N - m$$
$$[M_t] = M_t . k_d . k = 310.352\ N - m$$

Calculation of E_{eq}, [σ_b] and [σ_c]:(1M)

E_{eq} = 210915 X 10^6 N/m^2

$$[\sigma_b] = \frac{1.4 k_{bl} \sigma_{-1}}{n . k_\sigma} = 15525 \times 10^4 N/m^2$$
$$[\sigma_c] = C_R HRC k_{cl} = 62697 \times 10^4 N/m^2$$

Centre distance, a:(1M)

$$a \geq (i + 1) \sqrt[3]{\left(\frac{0.74}{[\sigma_c]}\right)^2 \frac{E \times [M_t]}{i \times \psi}}$$
$$Assume, \frac{b}{a} = 0.3$$
$$a_{min} = 187\ mm$$

Number of teeth Z_1 and Z_2:(1M)

Z_1 = 20 (assumed)

Z_2 = i. Z_1 = 60.

Module, m:(1M)

$$m \geq 1.26\sqrt[3]{\frac{[M_t]}{y[\sigma_b]\psi Z_1}} = 4\,mm$$

Revised centre distance, a and number of teeth:(1M)

$$a = \frac{m(Z_1 + Z_2)}{2}$$

Z_1 = 24 teeth; Z_2 = 72 teeth; a = 192 mm.

Face width, pitch circle diameter, pitch line velocity:(1M)

Face width, b = ψ . a = 57.6 mm

Pitch circle diameter, $d_1 = mZ_1$ = 96 mm.

Pitch line velocity, v = 6.03 m/s.

Quality of gear:(1M)

IS quality 8 is selected.

Revision of design torque:

$$[M_t] = M_t.k_d.k = 334.416\,N - m$$

Check for maximum induced bending stress, σ_b:(1M)

$$\sigma_b = \frac{(i+1)}{amby} \times [M_t] \leq [\sigma_b]$$

$$\sigma_b = 15525 \times 10^4 N/m^2$$

Design is safe.

Check for maximum induced compressive stress, σ_c:(1M)

$$\sigma_c = 0.74 \times \frac{(i+1)}{a} \times \sqrt{\frac{(i+1)E[M_t]}{i.b}} \leq [\sigma_c]$$

$$\sigma_c = 62697 \times 10^4 N/m^2$$

Design is safe.

Basic dimensions of pinion and wheel:(1M)

Pinion:

$$Pitch\ circle\ diameter, d_1 = 96\,mm$$

$$Height\ factor, f_0 = 1\ (for\ full\ depth)$$

$$Tip\ circle\ diameter, d_{c1} = (Z_1 + 2f_0)m = 104\,mm$$

$$Root\ circle\ diameter, d_{f1} = (Z_1 + 2f_0)m - 2c = 86\,mm$$

$$Top\ depth, h = 2.25m = 9\,mm$$

Wheel:

$$Pitch\ circle\ diameter, d_2 = 288\,mm$$

$$Tip\ circle\ diameter, d_{c2} = (Z_2 + 2f_0)m = 296\,mm$$

$$Root\ circle\ diameter, d_{f2} = (Z_2 + 2f_0)m - 2c = 278\,mm$$

$$Top\ depth, h = 2.25m = 9\,mm$$

3 **Design a pair of straight gear drive for a stone crusher, the pinion and wheel are made of C15 steel and cast iron grade 30 respectively. The pinion is to transmit 22 kW power at 900 rpm. The gear ratio is 2.5. Take pressure angle of 20º and working life of gear as 10000 hours.(13M)(Nov/Dec 2016)**BTL5

Answer: Page: 2.76 – Dr.A.Baskar

Gear ratio, i:(1M)

$$i = \frac{N_1}{N_2} = 2.5\ (given)$$

Material:(1M)

Pinion – C15

Wheel – Cast iron, grade 30 (given).

Gear life: N = 10000 hrs (given)

Design torque, $[M_t]$:(1M)

$$Torque\ transmitted, M_t = \frac{60 \times Power\ in\ watts}{2\pi N} = 233.427\ N-m$$

$$[M_t] = M_t.k_d.k = 303.4554\ N-m$$

Calculation of E_{eq}, $[\sigma_b]$ and $[\sigma_c]$:(1M)

$$E_{eq} = \frac{2E_1E_2}{E_1+E_2}$$

$E_{eq} = 143.226 \text{ X } 10^9\ N/m^2$

$$[\sigma_b] = \frac{1.4k_{bl}\sigma_{-1}}{n.k_\sigma} = 10379 \times 10^4 N/m^2$$

$$[\sigma_c] = C_R HRC k_{cl} = 74487 \times 10^4 N/m^2$$

Centre distance, a:(1M)

$$a \geq (i+1)\sqrt[3]{\left(\frac{0.74}{[\sigma_c]}\right)^2 \frac{E \times [M_t]}{i \times \psi}}$$

$$Assume, \frac{b}{a} = 0.3$$

$$a_{min} = 241\ mm$$

Number of teeth Z_1 and Z_2:(1M)

$Z_1 = 20$ (assumed)

$Z_2 = i.\ Z_1 = 50.$

Module, m:(1M)

$$m \geq 1.26\sqrt[3]{\frac{[M_t]}{y[\sigma_b]\psi Z_1}} = 5\ mm$$

Revised centre distance, a and number of teeth:(1M)

$$a = \frac{m(Z_1+Z_2)}{2}$$

$Z_1 = 28$ teeth; $Z_2 = 70$ teeth; a = 245 mm.

Face width, pitch circle diameter, pitch line velocity: (1M)

Face width, $b = \psi \cdot a = 73.5$ mm

Pitch circle diameter, $d_1 = mZ_1 = 140$ mm.

Pitch line velocity, v = 6.6 m/s.

Quality of gear:(1M)

IS quality 8 is selected.

Revision of design torque:

$$[M_t] = M_t.k_d.k = 329.389\ N-m$$

Check for maximum induced bending stress, σ_b:(1M)

$$\sigma_b = \frac{(i+1)}{amby} \times [M_t] \le [\sigma_b]$$

$$\sigma_b = 2711 \times 10^4 N/m^2$$

Design is safe.

Check for maximum induced compressive stress, σ_c:(1M)

$$\sigma_c = 0.74 \times \frac{(i+1)}{a} \times \sqrt{\frac{(i+1)E[M_t]}{i.b}} \le [\sigma_c]$$

$$\sigma_c = 30375 \times 10^4 N/m^2$$

Design is safe.

Basic dimensions of pinion and wheel:(1M)

Pinion:

$$Pitch\ circle\ diameter, d_1 = 140\ mm$$

$$Height\ factor, f_0 = 1\ (for\ full\ depth)$$

$$Tip\ circle\ diameter, d_{c1} = (Z_1 + 2f_0)m = 150\ mm$$

$$Root\ circle\ diameter, d_{f1} = (Z_1 + 2f_0)m - 2c = 127.5\ mm$$

$$Top\ depth, h = 2.25m = 11.25\ mm$$

Wheel:

$$Pitch\ circle\ diameter, d_2 = 350\ mm$$

$$Tip\ circle\ diameter, d_{c2} = (Z_2 + 2f_0)m = 360\ mm$$

$$Root\ circle\ diameter, d_{f2} = (Z_2 + 2f_0)m - 2c = 337.5\ mm$$

$$Top\ depth, h = 2.25m = 11.25\ mm$$

4 **A pair of helical gears subjected to moderate shock loading is to transmit 30 kW at 1500 rpm of the pinion. The speed reduction ratio is 4 and the helix angle is 20°. The service is continuous and the teeth are 20° FD in the normal plane. For gear life of 10,000 hours, design the gear drive.(13M)(May/June 2016)**BTL5

Answer: Page: 2.156 – Dr.A.Baskar

Gear ratio, i:(1M)

$$i = \frac{N_1}{N_2} = 4\ (given)$$

Material:(1M)

Assume 40 Ni2 Cr1 Mo 28 for both pinion and wheel (given).

Design bending stress, $[\sigma_b] = 4000$ kgf/cm^2

Design surface contact stress, $[\sigma_c] = 11000$ kgf/cm^2

Gear life: (1M)

Equivalent mean life, N = 60nT = 90 X 10^7 cycles.

Design torque, $[M_t]$:(1M)

$$Torque\ transmitted, M_t = \frac{60 \times Power\ in\ watts}{2\pi N} = 190.99\ N - m$$

$$[M_t] = M_t . k_d . k = 248.28\ N - m$$

Calculation of E_{eq}, $[\sigma_b]$ and $[\sigma_c]$:(1M)

$E_{eq} = 210915 \times 10^6$ N/m^2

$$[\sigma_b] = \frac{1.4 k_{bl} \sigma_{-1}}{n. k_\sigma} = 240.345 \times 10^6 N/m^2$$

$$[\sigma_c] = C_R HRC k_{cl} = 1049.64 \times 10^6 N/m^2$$

Centre distance, a:(1M)

$$a \geq (i+1) \sqrt[3]{\left(\frac{0.7}{[\sigma_c]}\right)^2 \frac{E \times [M_t]}{i \times \psi}}$$

$$Assume, \frac{b}{a} = 0.3$$

$$a_{min} = 268.7\ mm$$

Number of teeth Z_1 and Z_2:(1M)

$Z_1 = 20$ (assumed)

$Z_2 = i. Z_1 = 80.$

Module, m:(1M)

$$m \geq 1.15 \cos\beta \sqrt[3]{\frac{[M_t]}{y[\sigma_b]\psi Z_1}} = 3\ mm$$

Revised centre distance, a and number of teeth:

$$a = \frac{m(Z_1 + Z_2)}{2 \cos\beta}$$

$Z_1 = 34$ teeth; $Z_2 = 136$ teeth; a = 271.37 mm.

Face width, pitch circle diameter, pitch line velocity:(1M)

Face width, b = ψ . a = 82 mm

Pitch circle diameter, $d_1 = mZ_1 / \text{Cos}\beta = 108.55$ mm.

Pitch line velocity, v = 8.525 m/s.

Quality of gear:(1M)

IS quality 8 is selected.

Revision of design torque:

$$[M_t] = M_t . k_d . k = 280.75\ N - m$$

Check for maximum induced bending stress, σ_b:(1M)

$$\sigma_b = \frac{0.7 \times (i+1) \times [M_t]}{amby} \leq [\sigma_b]$$

$$\sigma_b = 31.65 \times 10^6 N/m^2$$

Design is safe.

Check for maximum induced compressive stress, σ_c:(1M)

$$\sigma_c = \frac{0.74 \times (i+1)}{a} \times \sqrt{\frac{(i+1)E[M_t]}{i.b}} \leq [\sigma_c]$$

$$\sigma_c = 387.5 \times 10^6 N/m^2$$

Design is safe.

Basic dimensions of pinion and wheel:(1M)

Pinion:

$$Pitch\ circle\ diameter, d_1 = 108.55\ mm$$

$$Height\ factor, f_0 = 1\ (for\ full\ depth)$$

$$Tip\ circle\ diameter, d_{c1} = \left(\frac{Z_1}{\cos\beta} + 2f_0\right) m = 114.55\ mm$$

$$Root\ circle\ diameter, d_{f1} = \left(\frac{Z_1}{\cos\beta} + 2f_0\right) m - 2c = 101.05\ mm$$

$$Top\ depth, h = 2.25m = 6.75\ mm$$

Wheel:

$$Pitch\ circle\ diameter, d_2 = \frac{m_n}{\cos\beta} \times Z_2 = 434.18\ mm$$

$$Tip\ circle\ diameter, d_{c2} = \left(\frac{Z_2}{\cos\beta} + 2f_0\right) m = 440.18\ mm$$

$$Root\ circle\ diameter, d_{f2} = \left(\frac{Z_2}{\cos\beta} + 2f_0\right) m - 2c = 426.68\ mm$$

$$Top\ depth, h = 2.25m = 6.75\ mm$$

5

Design a helical gear drive to transmit a power of 15 kW at 1440 rpm to the following specifications: Speed reduction is 3, pressure angle is 20º, helix angle is 15º, material of both gears is C45 steel, allowable static stress is 180 N/mm^2, Young's modulus = 2 X 10^5 N/mm^2.(13M)(Nov/Dec 2010)BTL5

Answer: Page: 2.175 – Dr.A.Baskar

Material:(1M)

C45 Steel (given)

Number of teeth Z_1 and Z_2:(1M)

Z_1 = 20 (assumed)

Z_2 = i. Z_1 = 60.

Tangential load, F_t:(1M)

$$F_t = \frac{Design\ power\ in\ watts}{v_m} = \frac{12.488}{m}$$

Dynamic Load, F_d:(1M)

$$F_d = F_t.C_V$$

$$F_d = \frac{12.488}{m} \times (1 + 260.25m)$$

Beam strength, F_s:(1M)

$$F_s = [\sigma_b]m.b.Y = 594\ \times 10^6 m^2$$

Module, m:(1M)

$$F_s \geq F_d\ for\ safe\ design$$

$$\frac{12.488}{m} \times (1 + 260.25m) =\ 594\ \times 10^6 m^2$$

Module, m = 4 mm.

Face width, pitch circle diameter, pitch line velocity:(1M)

Face width, b = 10 X m = 40 mm

Pitch circle diameter of pinion, $d_1 = mZ_1/\cos\beta = 82.82$ mm.

Pitch circle diameter of wheel, $d_2 = mZ_2/\cos\beta = 248.47$ mm.

Pitch line velocity, v = 6.032 m/s.

Revision of beam strength, F_s:(1M)

$$F_s = [\sigma_b]m.b.Y = 9504\ N$$

Buckingham's dynamic load, F_d:(1M)

$$F_d = F_t + \left[\frac{0.164V_m(cbcos^2\beta + F_t)\cos\beta}{0.164V_m + 1.485\sqrt{cbcos^2\beta + F_t}}\right] = 7942.96\ N$$

Check for the design:

(F_d = 7942.96 N) < (F_s = 9504 N)

The design is safe.

Check for wear:(2M)

$$Wear\ load, F_w = \frac{bd_1Qk}{cos^2\beta} = 3130.4\ N$$

(F_w = 3130.4 N) < (F_d = 7942.96 N)

The design is not safe.

For increasing wear load, it is preferable to increase the $[\sigma_c]$ by heat treatment to 9000 kgf/cm^2.

Therefore, F_w = 8829 N

Now, (F_w = 8829 N) > (F_d = 7942.96 N)

Hence, the design is safe.

Basic dimensions of pinion and wheel:(2M)

Pinion:

$$Pitch\ circle\ diameter, d_1 = 82.82\ mm$$

$$Height\ factor, f_0 = 1\ (for\ full\ depth)$$

$$Tip\ circle\ diameter, d_{c1} = \left(\frac{Z_1}{\cos\beta} + 2f_0\right)m = 90.82\ mm$$

$$Root\ circle\ diameter, d_{f1} = \left(\frac{Z_1}{\cos\beta} + 2f_0\right)m - 2c = 72.82\ mm$$

$$Top\ depth, h = 2.25m = 9\ mm$$

Wheel:

$$Pitch\ circle\ diameter, d_2 = \frac{m_n}{\cos\beta} \times Z_2 = 248.47\ mm$$

$$Tip\ circle\ diameter, d_{c2} = \left(\frac{Z_2}{\cos\beta} + 2f_0\right)m = 256.47\ mm$$

$$Root\ circle\ diameter, d_{f2} = \left(\frac{Z_2}{\cos\beta} + 2f_0\right)m - 2c = 238.47\ mm$$

$$Top\ depth, h = 2.25m = 9\ mm$$

PART * C

1 **Design a straight spur gear drive to transmit 8 kW. The pinion speed is 720 rpm and the speed ratio is 2. Both the gears are made of the same surface hardened carbon steel with 55 RC and core hardness less than 350 BHN. Ultimate strength is 720 N/mm^2 and yield strength is360 N/mm^2.(15M)(Nov/Dec 2015)**BTL5

Answer: Page: 2.71 – Dr.A.Baskar

Gear ratio, i:(1M)

$$i = \frac{N_1}{N_2} = 2\ (given)$$

Material:(1M)

Surface hardened carbon steel (given)

Gear life: Not given

Design torque, [M$_t$]:(1M)

$$Torque\ transmitted, M_t = \frac{60 \times Power\ in\ watts}{2\pi N} = 106.1\ N - m$$

$$[M_t] = M_t.k_d.k = 137.93\ N - m$$

Calculation of E$_{eq}$, [σ$_b$] and [σ$_c$]:(1M)

$E_{eq} = 21095 \text{ X } 10^6 \text{ N/m}^2$

$$[\sigma_b] = \frac{1.4k_{bl}\sigma_{-1}}{n.k_\sigma} = 13802.88 \times 10^4 N/m^2$$

$$[\sigma_c] = C_R HRC k_{cl} = 85837.5 \times 10^4 N/m^2$$

Centre distance, a:(1M)

$$a \geq (i+1)\sqrt[3]{\left(\frac{0.74}{[\sigma_c]}\right)^2 \frac{E \times [M_t]}{i \times \psi}}$$

$$Assume, \frac{b}{a} = 0.3$$

$$a_{min} = 46\ mm$$

Number of teeth Z$_1$ and Z$_2$:(1M)

Z$_1$ = 12 (assumed)

Z$_2$ = i. Z$_1$ = 24.

Module, m:(1M)

$$m \geq 1.26\sqrt[3]{\frac{[M_t]}{y[\sigma_b]\psi Z_1}} = 4\ mm$$

Revised centre distance, a and number of teeth:(1M)

$$a = \frac{m(Z_1 + Z_2)}{2}$$

Z_1 = 12 teeth; Z_2 = 24 teeth; a = 72 mm.

Face width, pitch circle diameter, pitch line velocity:(1M)

Face width, b = ψ . a = 21.6 mm

Pitch circle diameter, $d_1 = mZ_1$ = 48 mm.

Pitch line velocity, v = 1.8096 m/s.

Quality of gear:(1M)

IS quality 8 is selected.

Revision of design torque:(1M)

$$[M_t] = M_t.k_d.k = 334.41\ N - m$$

Check for maximum induced bending stress, σ_b:(1M)

$$\sigma_b = \frac{(i+1)}{amby} \times [M_t] \leq [\sigma_b]$$

$$\sigma_b = 7012 \times 10^4 N/m^2$$

Design is safe.

Check for maximum induced compressive stress, σ_c:(1M)

$$\sigma_c = 0.74 \times \frac{(i+1)}{a} \times \sqrt{\frac{(i+1)E[M_t]}{i.b}} \leq [\sigma_c]$$

$$\sigma_c = 29486 \times 10^4 N/m^2$$

Design is safe.

Basic dimensions of pinion and wheel:(2M)

Pinion:

$$Pitch\ circle\ diameter, d_1 = 140\ mm$$
$$Height\ factor, f_0 = 1\ (for\ full\ depth)$$
$$Tip\ circle\ diameter, d_{c1} = (Z_1 + 2f_0)m = 150\ mm$$
$$Root\ circle\ diameter, d_{f1} = (Z_1 + 2f_0)m - 2c = 127.5\ mm$$
$$Top\ depth, h = 2.25m = 11.25\ mm$$

Wheel:

$$Pitch\ circle\ diameter, d_2 = 350\ mm$$
$$Tip\ circle\ diameter, d_{c2} = (Z_2 + 2f_0)m = 360\ mm$$
$$Root\ circle\ diameter, d_{f2} = (Z_2 + 2f_0)m - 2c = 337.5\ mm$$
$$Top\ depth, h = 2.25m = 11.25\ mm$$

2 **Design a spur gear drive required to transmit 45 kW at a pinion speed of 800 rpm. The velocity ratio is 3.5:1. The teeth are 20º full depth involute with 18 teeth on the pinion. Both the pinion and gear are made of steel with a maximum safe static stress of 180 N/mm^2. Assume medium shock conditions.(15M)(Nov/Dec 2015)**BTL5

Answer: Page: 2.98 – Dr.A.Baskar

Material:(1M)

Steel for both pinion and wheel (given)

Number of teeth Z_1 and Z_2:(1M)

Z_1 = 18 (given)

Z_2 = i. Z_1 = 63.

Tangential load, F_t:(1M)

$$F_t = \frac{Design\ power\ in\ watts}{v_m} = \frac{77.586}{m}$$

Dynamic Load, F_d:(1M)

$$F_d = F_t . C_V$$

$$F_d = \frac{77.586}{m} \times (1 + 125.7m)$$

Beam strength, F_s:(1M)

$$F_s = [\sigma_b]m.b.Y = 584.1\ \times 10^6 m^2$$

Module, m:(2M)

$$F_s \geq F_d\ for\ safe\ design$$

$$\frac{77.586}{m} \times (1 + 125.7m) = \ 584.1\ \times 10^6 m^2$$

Module, m = 8 mm.

Face width, pitch circle diameter, pitch line velocity:(2M)

Face width, b = 10 X m = 80 mm

Pitch circle diameter, $d_1 = mZ_1$ = 144 mm.

Pitch line velocity, v = 6.032 m/s.

Revision of beam strength, F_s:(1M)

$$F_s = [\sigma_b]m.b.Y = 37382\ N$$

Buckingham's dynamic load, F_d:(1M)

$$F_d = F_t + \left[\frac{0.164V_m(cb + F_t)}{0.164V_m + 1.485\sqrt{cb + F_t}}\right] = 26417\ N$$

Check for the design:

(F_d = 26417 N) < (F_s = 37382 N)

The design is safe.

Check for wear:(1M)

$$Wear\ load, F_w = d_1 Qkb = 36056\ N$$

(F_w = 36056 N) > (F_d = 26417 N)

The design is safe.

Basic dimensions of pinion and wheel:(3M)

Pinion:

$$Pitch\ circle\ diameter, d_1 = 144\ mm$$

$$Height\ factor, f_0 = 1\ (for\ full\ depth)$$

$$Tip\ circle\ diameter, d_{c1} = (Z_1 + 2f_0)m = 160\ mm$$

$$Root\ circle\ diameter, d_{f1} = (Z_1 + 2f_0)m - 2c = 124\ mm$$

$$Top\ depth, h = 2.25m = 18\ mm$$

Wheel:

$$Pitch\ circle\ diameter, d_2 = 504\ mm$$

$$Tip\ circle\ diameter, d_{c2} = (Z_2 + 2f_0)m = 520\ mm$$

$$Root\ circle\ diameter, d_{f2} = (Z_2 + 2f_0)m - 2c = 484\ mm$$

$$Top\ depth, h = 2.25m = 18\ mm$$

3 **Design a pair of helical gears to transmit 10 kW at 1000 rpm of the pinion. Reduction ratio of 5 is required. Pressure angle is 20º and the helix angle is 15º. The material for both the gears is 40Ni2 Cr1 Mo28. Give the details of the drive in a tabular form.(15M)(Nov/Dec 2016)**BTL5

Answer: Page: 2.149 – Dr.A.Baskar

Gear ratio, i:(1M)

$$i = \frac{N_1}{N_2} = 5\ (given)$$

Material:(1M)

40 Ni2 Cr1 Mo 28 for both pinion and wheel (given).

Design bending stress, $[\sigma_b] = 392.4 \text{ X } 10^6 \text{ N/m}^2$

Design surface contact stress, $[\sigma_c] = 1079.1\text{X } 10^6 \text{ N/m}^2$

Gear life: Not Given

Design torque, $[M_t]$:(1M)

$$Torque\ transmitted, M_t = \frac{60 \times Power\ in\ watts}{2\pi N} = 95.493\ N - m$$

$$[M_t] = M_t.k_d.k = 124.141\ N - m$$

Calculation of E_{eq}, $[\sigma_b]$ and $[\sigma_c]$:(1M)

$E_{eq} = 210915 \text{ X } 10^6 \text{ N/m}^2$

$[\sigma_b] = 392.4 \text{ X } 10^6 \text{ N/m}^2$

$[\sigma_c] = 1079.1 \text{ X } 10^6 \text{ N/m}^2$

Centre distance, a:(1M)

$$a \geq (i + 1)\sqrt[3]{\left(\frac{0.7}{[\sigma_c]}\right)^2 \frac{E \times [M_t]}{i \times \psi}}$$

$$Assume, \frac{b}{a} = 0.3$$

$$a_{min} = 105\ mm$$

Number of teeth Z_1 and Z_2:(1M)

$Z_1 = 20$ (assumed)

$Z_2 = i.\ Z_1 = 100.$

Module, m:(1M)

$$m \geq 1.15 \cos\beta \sqrt[3]{\frac{[M_t]}{y[\sigma_b]\psi Z_1}} = 2\ mm$$

Revised centre distance, a and number of teeth:(1M)

$$a = \frac{m(Z_1 + Z_2)}{2\cos\beta}$$

Z_1 = 18 teeth; Z_2 = 90 teeth; a = 111.8 mm.

Face width, pitch circle diameter, pitch line velocity:(1M)

Face width, b = ψ . a = 33.54 mm

Pitch circle diameter, $d_1 = mZ_1 / \text{Cos}\beta$ = 37.27 mm.

Pitch line velocity, v = 1.951 m/s.

Quality of gear:(1M)

IS quality 8 is selected.

Revision of design torque:(1M)

$$[M_t] = M_t.k_d.k = 113.45\ N - m$$

Check for maximum induced bending stress, σ_b:(1M)

$$\sigma_b = \frac{0.7 \times (i+1) \times [M_t]}{amby} \leq [\sigma_b]$$

$$\sigma_b = 163.331 \times 10^6 N/m^2$$

Design is safe.

Check for maximum induced compressive stress, σ_c:(1M)

$$\sigma_c = \frac{0.74 \times (i+1)}{a} \times \sqrt{\frac{(i+1)E[M_t]}{i.b}} \leq [\sigma_c]$$

$$\sigma_c = 1076 \times 10^6 N/m^2$$

Design is safe.

Basic dimensions of pinion and wheel:(2M)

Pinion:

$$Pitch\ circle\ diameter, d_1 = 37.27\ mm$$

$$Height\ factor, f_0 = 1\ (for\ full\ depth)$$

$$Tip\ circle\ diameter, d_{c1} = \left(\frac{Z_1}{\cos\beta} + 2f_0\right)m = 41.27\ mm$$

$$Root\ circle\ diameter, d_{f1} = \left(\frac{Z_1}{\cos\beta} + 2f_0\right)m - 2c = 32.27\ mm$$

$$Top\ depth, h = 2.25m = 4.5\ mm$$

Wheel:

$$Pitch\ circle\ diameter, d_2 = \frac{m_n}{\cos\beta} \times Z_2 = 186.35\ mm$$

$$Tip\ circle\ diameter, d_{c2} = \left(\frac{Z_2}{\cos\beta} + 2f_0\right)m = 190.35\ mm$$

$$Root\ circle\ diameter, d_{f2} = \left(\frac{Z_2}{\cos\beta} + 2f_0\right)m - 2c = 181.35\ mm$$

$$Top\ depth, h = 2.25m = 4.5\ mm$$

UNIT III–BEVEL, WORM AND CROSS HELICAL GEARS

Straight bevel gear: Tooth terminology, tooth forces and stresses, equivalent number of teeth.Estimating the dimensions of pair of straight bevel gears. Worm Gear: Merits and demeritsterminology.Thermal capacity, materials-forces and stresses, efficiency, estimating the size of theworm gear pair. Cross helical: Terminology-helix angles-Estimating the size of the pair of cross helicalgears.

PART * A

Q.No.	Questions
1	**What is virtual or formative number of teeth in bevel gears? (Nov/Dec 2014, April/May 2017, May/June 2014)**BTL1 An imaginary spur gear considered in a plane perpendicular to the tooth of the bevel gear at the larger end is known as virtual spur gear. The number of teeth z_v on this imaginary spur gear is called virtual number of teeth in bevel gears. $z_v = z/\cos \delta$ where z = actual number of teeth on the bevel gear and δ = pitch angle.
2	**Define the following terms: (a) Cone distance (b) Face angle. (May/June 2014)**BTL1 (a)Cone distance: In bevel gears, cone distance is the length of the pitch cone element. (b) Face angle: It is the angle subtended by the face of the tooth at the cone centre.
3	**Why is the efficiency of worm gear drive comparatively low?**BTL4 The efficiency of worm gear drive is lower because of power loss due to friction caused by sliding.
4	**In which gear drive, self-locking is available? (April/May 2015, 2013)**BTL3 In the worm gear drive, self-locking is available.
5	**Write the conditions of self-locking of worm gears in terms of lead and pressure angle in gear design. And also write the condition for over running drives. (Apr/May 2017)**BTL3 ➢ The drive is called self-locking, if $\mu \geq \cos \alpha . \tan \gamma$ ➢ The drive is called overrunning, if $\mu < \cos \gamma . \tan \gamma$
6	**Why is multistart worm more efficient than the single start one?**BTL4 The efficiency of the worm depends mainly on pressure angle (also known as pitch angle of the worm). For a single start worm this pressure angle will be less. In a multi start worm, this pressure angle can be increased (of the order 45^0). That's why multi start worm is more efficient.
7	**What is the difference between an angular gear and a miter gear? (Nov/Dec 2015)**BTL4 ➢ When the bevel gears connect two shafts whose axes intersect at an angle other than a right angle, then they are known as angular bevel gears. ➢ When equal bevel gears (having equal teeth and equal pitch angles) connect two shafts whose axes intersect at right angle, then they are known as miter gears.
8	**A pair of worm gears is designated as 2/54/10/5. Find the gear ratio.** BTL5

	Solution: (2/54/10/5): ($z_1/z_2/q/m_x$)Therefore, Gear ratio, i = z_2/z_1 = 54/2 = 27
9	**Why phosphor bronze is widely used for worm gears?**BTL4 Phosphor bronze has high antifriction properties to resist seizure. Because in worm gear drive, the failure due to seizure is more.
10	**List out the main types of failure in worm gear drive. (Nov/Dec 2012)**BTL2 ➢ Seizure ➢ Pitting and rupture.
11	**For transmitting large power, worm reduction gears are not generally preferred. Why?**BTL4 In worm drive, meshing occurs with sliding action. Since sliding occurs, the amount of heat generation and power loss are quite high.
12	**In worm gear drive, only the wheel is designed. Why? (Apr/May 2011)**BTL4 Since always the strength of the worm is greater than the worm wheel, therefore only the worm wheel is designed.
13	**What are the forces acting on bevel gear? (May/June 2013)**BTL2 ➢ Tangential force ➢ Separating force: It is resolved into two components, they are axial radial force.
14	**Under what situation, bevel gears are used? (Apr/May 2011)**BTL3 Bevel gears are used to transmit power between two intersecting shafts.
15	**Write some applications of worm gear drive. (Nov-Dec 2016)**BTL2 **Where do we use worm gears? (May/June2013)** It is commonly used in automotive differentials**,** Tuning Instruments , Elevators/Lifts, Gates and Conveyor Belts
16	**What are the main types of failures in worm gear drives?(Nov/Dec2012)**BTL2 ➢ Seizure ➢ Pitting ➢ Surface wear
17	**What is the helical angle of worm? (May/June 2016)**BTL1 In mechanical engineering, a helix angle is the angle between any helix and an axial line on its right, circular cylinder or cone. Common applications are screws, helical gears, and worm gears. The helix angle references the axis of the cylinder, distinguishing it from the lead angle, which references a line perpendicular to the axis. Naturally, the helix angle is the geometric complement of the lead angle. The helix angle is measured in degrees.
18	**What is a crown gear? (Nov/Dec 2016, May/June 2013)**BTL1 A crown gear (or a contrate gear) is a gear which has teeth that project at right angles to the face of the wheel. In particular, a crown gear is a type of bevel gear where the pitch cone angle is 90 degrees.
19	**How bevel gears are manufactured**? (**May/June 2016)**BTL1 Bevel gears can be manufactured through the gear hobbing and machining process.
20	**What kind of contact is required between worm and worm wheel? How does this differ from other gears? (Nov/Dec 2015)**BTL4

	Sliding contact is required between worm and worm wheel. For other gears Line contact is required for other gears.
21	**What is a Zero Bevel Gears? (April/May 2015)**BTL1 Spiral bevel gears with curved teeth but with a zero degree spiral angle are known as zero bevel gears.
22	**Mention the advantages of worm gear drive. (Nov/Dec 2014)**BTL2 Worm gears are used to transmit power between two non-intersecting, non-parallel shafts. Worm gears can be used for high speed reduction ratios as high as 300:1.
23	**When do we employ crossed helical gear? (Nov/Dec 2012)**BTL4 Crossed helical gear sets are used to transmit power and motion between non-intersecting and non-parallel axes. Both of the gears that mesh with each other are involute helical gears, and a point contact is made between them. They can stand a small change in the center distance and the shaft angle without any impairment in the accuracy of transmitting motion.
24	**List the various types of Bevel gears. (May/June 2012)**BTL2 ➢ Straight bevel gears ➢ Spiral bevel gears ➢ Zero bevel gears ➢ Hypoid gears
25	**What are the various losses in the worm gear drive? (May/June 2012)**BTL2 Worm drives have high power losses. A disadvantage is the potential for considerable sliding action, leading to low efficiency. They produce a lot of heat. High-ratio units have a smaller gear-tooth lead (helix) angle, which causes more surface contact between them. This higher contact causes higher friction and lower efficiency. Typical worm-gear efficiencies range from 49% for a 300:1, double-reduction ratio, up to 90% for a 5:1, single-reduction ratio. For this reason, these units are usually more suitable for low ratios.
	PART * B
1	**Design a bevel gear drive to transmit 3.5 kW with driving shaft speed is 200 rpm. Speed ratio required is 4. The drive is non-reversible. Pinion is made of steel and wheel made of CI. Assume a life of 25,000 hrs. (13M)(Nov/Dec 2016)**BTL5 **Answer: Page: 3.26 – Dr.A.Baskar** **Gear ratio, i:**(1M) $i = \frac{N_1}{N_2} = 4\ (given)$ $\tan \delta_2 = i$ $\delta_2 = 75.96°;\ \delta_1 = 14.04°$ **Material:**(1M) Pinion: C45, Hardened steel. Tensile strength, $\sigma_u = 700 \text{ X } 10^6 \text{ N/m}^2$ Yield strength, $\sigma_y = 360 \text{ X } 10^6 \text{ N/m}^2$ Wheel: CI Grade 30. Tensile strength, $\sigma_u = 300 \text{ X } 10^6 \text{ N/m}^2$

Gear life, N:(1M)

Life in number of cycles, N = 60 X (rpm, n) X (Life in hrs, T) = 30 X 10^7 cycles

Design torque, [M$_t$]:(1M)

$$Torque\ transmitted, M_t = \frac{60 \times Power\ in\ watts}{2\pi N} = 167.11\ N-m$$

$$[M_t] = M_t.k_d.k = 217.25\ N-m$$

Calculation of E$_{eq}$, [σ$_b$] and [σ$_c$]:(1M)

E_{eq} = 166.77 X 10^9 N/m^2

$$Pinion, [\sigma_b] = \frac{1.4k_{bl}\sigma_{-1}}{n.k_\sigma} = 836.66\ kgf/cm^2$$

$$Pinion, [\sigma_c] = C_R HRC k_{cl} = 6054.75\ kgf/cm^2$$

$$Wheel, [\sigma_b] = \frac{1.4k_{bl}\sigma_{-1}}{n.k_\sigma} = 513.1\ kgf/cm^2$$

$$Wheel, [\sigma_c] = C_R HRC k_{cl} = 3782.35\ kgf/cm^2$$

Minimum value is selected.

$[\sigma_b]$ = 513.1 kgf/cm^2

$[\sigma_c]$ = 3782.35 kgf/cm^2

Cone distance, R:(1M)

$$R \geq \psi\sqrt{i^2+1}\sqrt[3]{\left(\frac{0.72}{(\psi-0.5)[\sigma_c]}\right)^2 \frac{E \times [M_t]}{i}}$$

$$Assume, \psi = \frac{R}{b} = 3$$

$$R = 218\ mm$$

Number of teeth Z$_1$ and Z$_2$:(1M)

Z_1 = 18 (assumed)

Z_2 = i. Z_1 = 72.

Transverse Module, m$_t$:(1M)

$$m_{av} \geq 1.28\sqrt[3]{\frac{[M_t]}{y[\sigma_b]\psi Z_1}} = 5.096\ mm$$

$$m_t = m_{av} + \frac{b}{z}\sin\delta = 6\ mm$$

Revision of cone distance, R and number of teeth:

$$R = 0.5 m_t Z_1 \sqrt{i^2+1} = 222.65\ mm$$

Z_1 = 18 teeth; Z_2 = 72 teeth;

Face width, pitch circle diameter, pitch line velocity:(1M)

Face width, b = 10.m$_t$ = 60 mm

Pitch circle diameter,

$$d_{1av} = m_t Z_1\left(\frac{R-0.5b}{R}\right) = 93.45\ mm$$

Pitch line velocity, v = 0.98 m/s.

Quality of gear:(1M)

IS quality 8 is selected.

Revision of design torque:

$$[M_t] = M_t.k_d.k = 217.25\ N - m$$

Check for maximum induced bending stress, σ_b:(1M)

$$\sigma_b = \frac{R\sqrt{i^2+1}.[M_t]}{(R-0.5b)^2 mby}.\frac{1}{\cos\alpha} \le [\sigma_b]$$

$$\sigma_b = 41.8 \times 10^6 N/m^2$$

Design is safe.

Check for maximum induced compressive stress, σ_c:(1M)

$$\sigma_c = \frac{0.72}{(R-0.5b)} \times \sqrt{\frac{(i^2+1)^3 E[M_t]}{i.b}} \le [\sigma_c]$$

$$\sigma_c = 365 \times 10^6 N/m^2$$

Design is safe.

Basic dimensions of pinion and wheel:(1M)

Pinion:

$$Reference\ angle, \delta_1 = 14.04°$$

$$Pitch\ circle\ diameter, d_1 = 108\ mm$$

$$Tip\ circle\ diameter, d_{a1} = m_t(Z_1 + 2cos\delta_1) = 138\ mm$$

Wheel:

$$Reference\ angle, \delta_2 = 75.96°$$

$$Pitch\ circle\ diameter, d_2 = 432\ mm$$

$$Tip\ circle\ diameter, d_{a2} = m_t Z_2 = 642\ mm$$

2 **A pair of cast iron bevel gears connects two shafts at right angles. The pitch diameters of the pinion and gear are 80 mm and 100 mm respectively. The tooth profiles of the gears are 14½° composite form. The allowable static stress for both gears is 55 MPa. If the pinion transmits 2.75 kW at 1100 rpm, find the module and number of teeth on each gear and check the design. Take surface endurance limits as 630 MPa and modulus of elasticity for cast iron as 84 kN/mm^2.(13M)(Nov/Dec 2009)**BTL5

Answer: Page: 3.55 – Dr.A.Baskar

Material:(1M)

Cast Iron (given) for both pinion and wheel.

We have to design pinion.

Gear ratio, i:(1M)

$$i = \frac{N_1}{N_2} = 1.25$$

$$\tan\delta_2 = i$$

$$\delta_2 = 51.34°;\ \delta_1 = 38.66°$$

Tangential load, F$_t$:(1M)

$$F_t = \frac{Design\ power\ in\ watts}{v_m} = \frac{3575}{4.608} = 775.82\ N$$

Dynamic Load, F_d:(1M)

$$F_d = F_t.N_{sf}.k_m.C_V = 1251\ N$$

Strength of gear tooth, F_s:(1M)

$$F_s = [\sigma_b]m_t.b.Y\left(1-\frac{b}{R}\right)$$

$$F_s = 0.294\times10^6\ \times m_t - 15.86\times10^6\ \times m_t^2$$

Transverse Module, m_t:(1M)

$$F_s \geq F_d\ for\ safe\ design$$

$$0.294\times10^6\ \times m_t - 15.86\times10^6\ \times m_t^2 = \ 1251$$

Module, m = 7 mm.

Face width, pitch circle diameter, pitch line velocity:(1M)

Face width, b = 10 X m = 20 mm

No. of teeth, mZ_1 = 12, Z_2 = 15.

Pitch circle diameter of pinion, $d_1 = mZ_1$ = 80 mm.

Pitch circle diameter of wheel, $d_2 = mZ_2$ = 100 mm (given).

Pitch line velocity, v = 4.608 m/s.

Revision of beam strength, F_s:(1M)

$$F_s = [\sigma_b]m.b.Y\left(1-\frac{b}{R}\right) = 1287\ N$$

Buckingham's dynamic load, F_d:(2M)

$$F_d = F_t + \left[\frac{0.164V_m(cb+F_t)}{0.164V_m + 1.485\sqrt{cb+F_t}}\right] = 2516.5\ N$$

Check for the design:

(F_d = 2616.5 N) > (F_s = 1287 N)

The design is not safe.

- d_1 and d_2 are given, and limited to 80 mm and 100 mm.
- No. of teeth $Z_1$to be minimum 12 and hence 'm_t' cannot be increased.
- B cannot be increased much, it will reduce 'Fs'. 'R' is also fixed 64 mm given.
- It is difficult to re-deign.

Check for wear:(1M)

$$Wear\ load, F_w = \frac{bd_1Qk}{\cos\delta_1} = 4225\ N$$

(F_w = 4225N) > (F_d = 2516.5 N)

Basic dimensions of pinion and wheel:(2M)

Pinion:

$$Reference\ angle, \delta_1 = 38.66°$$

$$Pitch\ circle\ diameter, d_1 = 80\ mm$$

$$Tip\ circle\ diameter, d_{a1} = m_t(Z_1 + 2cos\delta_1) = 94.93\ mm$$

	Wheel: $Reference\ angle, \delta_2 = 51.34^\circ$ $Pitch\ circle\ diameter, d_2 = 100\ mm$ $Tip\ circle\ diameter, d_{a2} = m_t Z_2 = 113.75\ mm$ The design is safe.
3	**Design a pair of straight bevel gears for two shafts whose axes are at right angle. The power transmitted is 25 kW. The speed of pinion is 300 rpm and the gear is 120 rpm. Assume 15 Ni2 Cr1 Mo15 steel for both the pinion and wheel. Use Hertz stresses method.(13M)**BTL5 **Answer: Page: 3.42 – Dr.A.Baskar** **Gear ratio, i:**(1M) $i = \frac{N_1}{N_2} = 2.5$ $\tan\delta_2 = i$ $\delta_2 = 68.2^\circ;\ \delta_1 = 21.8^\circ$ **Material:**(1M) Assumed: 15 Ni2 Cr1 Mo15 steel for both pinion and wheel. $[\sigma_b]$= 313.92 X 10^6 N/m^2 $[\sigma_c]$= 931.95 X 10^6 N/m^2 **Gear life, N:** Not available. **Design torque, $[M_t]$:**(1M) $Torque\ transmitted, M_t = \frac{60 \times Power\ in\ watts}{2\pi N} = 795.77\ N - m$ $[M_t] = M_t.k_d.k = 1034.51\ N - m$ **Calculation of E_{eq}, $[\sigma_b]$ and $[\sigma_c]$:**(1M) E_{eq} = 210.915 X 10^9 N/m^2 $[\sigma_b]$= 313.92 X 10^6 N/m^2 $[\sigma_c]$= 931.95 X 10^6 N/m^2 **Cone distance, R:**(1M) $R \geq \psi\sqrt{i^2+1}\sqrt[3]{\left(\frac{0.72}{(\psi - 0.5)[\sigma_c]}\right)^2 \frac{E \times [M_t]}{i}}$ $Assume, \psi = \frac{R}{b} = 3$ $R = 164\ mm$ **Number of teeth Z_1 and Z_2:**(1M) Z_1 = 20 (assumed) Z_2 = i. Z_1 = 50. **Transverse Module, m_t:**(1M) $m_{av} \geq 1.28\sqrt[3]{\frac{[M_t]}{y[\sigma_b]\psi Z_1}} = 4.42\ mm$

$$m_t = m_{av} + \frac{b}{z}\sin\delta = 6\ mm$$

Revision of cone distance, R and number of teeth:

$$R = 0.5 m_t Z_1 \sqrt{i^2+1} = 177.71\ mm$$

Z_1 = 22 teeth; Z_2 = 55 teeth;

Face width, pitch circle diameter, pitch line velocity:(1M)

Face width, b = 10.m_t = 60 mm

Pitch circle diameter,

$$d_{1av} = m_t Z_1 \left(\frac{R-0.5b}{R}\right) = 129.77\ mm$$

Pitch line velocity, v = 2.04 m/s.

Quality of gear:(1M)

IS quality 8 is selected.

Revision of design torque:

$$[M_t] = M_t.k_d.k = 1782.52\ N-m$$

Check for maximum induced bending stress, σ_b:(1M)

$$\sigma_b = \frac{R\sqrt{i^2+1}.[M_t]}{(R-0.5b)^2 mby}.\frac{1}{\cos\alpha} \le [\sigma_b]$$

$$\sigma_b = 279 \times 10^6 N/m^2$$

Design is safe.

Check for maximum induced compressive stress, σ_c:(2M)

$$\sigma_c = \frac{0.72}{(R-0.5b)} \times \sqrt{\frac{(i^2+1)^3 E[M_t]}{i.b}} \le [\sigma_c]$$

$$\sigma_c = 1077.8 \times 10^6 N/m^2$$

Design is not safe.

Increase face width, b = 1,

$$\therefore [M_t] = M_t.k_d.k = 1336.89\ N-m$$

$$\sigma_c = \frac{0.72}{(R-0.5b)} \times \sqrt{\frac{(i^2+1)^3 E[M_t]}{i.b}} \le [\sigma_c]$$

$$\sigma_c = 830.9 \times 10^6 N/m^2$$

Hence, design is safe.

Basic dimensions of pinion and wheel:(1M)

Pinion:

$$Reference\ angle, \delta_1 = 21.8°$$

$$Pitch\ circle\ diameter, d_1 = 132\ mm$$

$$Tip\ circle\ diameter, d_{a1} = m_t(Z_1 + 2cos\delta_1) = 143.14\ mm$$

Wheel:

$$Reference\ angle, \delta_2 = 68.2°$$

$$Pitch\ circle\ diameter, d_2 = 330\ mm$$

$$Tip\ circle\ diameter, d_{a2} = m_t Z_2 = 334.46\ mm$$

4 **2 kW power is applied to a worm shaft at 720 rpm. The worm is of quadruple start with 50 mm as pitch circle diameter. The worm gear has 40 teeth with 5 mm module. The pressure angle in the diametral plane is 20°. Determine: (i) the lead angle of the worm, (ii) velocity ratio and, (iii) centre distance. Also calculate efficiency of the worm gear drive and power lost in friction.(13M)(May/June 2014)**BTL5

Answer: Page: 3.94 – Dr.A.Baskar

Lead angle of the worm, γ:(3M)

$$Diameter\ factor, q = \frac{d_1}{m_x} = 10$$

$$\gamma = \tan^{-1}\frac{Z}{q} = 21.8°$$

Velocity ratio, i:(2M)

$$Gear\ ratio, i = \frac{z}{Z} = 10$$

Centre distance, a:(2M)

$$a = 0.5m_x(q + z + 2x) = 125\ mm$$

Efficiency of the worm drive, η:(2M)

$$\eta = \frac{\tan\gamma}{\tan(\gamma + \rho)} = 87.11\%$$

Power lost in friction:(2M)

$$Power\ lost\ in\ friction = (1 - \eta)P = 257.79\ Watts$$

5 **Design a worm gear drive to transmit 20 kW at 1440 rpm, speed of worm wheel is 60 rpm.(13M)(May/June 2016)**BTL5

Answer: Page: 3.111 – Dr.A.Baskar

Gear ratio, i:(1M)

$$i = \frac{n}{n_1} = 24$$

Material; No. of threads on worm, Z; No.of teeth on worm wheel, z:(1M)

Worm – steel

Worm wheel – bronze (assumed)

Z = 3 (assumed)

Z = i.Z = 72 teeth.

Design of worm wheel torque, [M$_t$]:(1M)

$$Torque\ transmitted, M_t = \frac{60 \times P}{2\pi n_1} \times \eta = 2546.48\ N - m$$

$$[M_t] = M_t . k_d . k = 2546.48\ N - m$$

Design bending stress, [σ$_b$] and surface compressive stress, [σ$_c$]:(1M)

For steel and bronze combination, [σ_c] = 156 X 10^6 N/m^2

For bronze wheel chill casting, [σ_b] = 53.955 X 10^6 N/m^2

Minimum centre distance, a:(1M)

$$a = \left(\frac{z}{q}+1\right)\sqrt[3]{\left(\frac{540}{\frac{z}{q}\times[\sigma_c]}\right)^2\{[M_t]\times 10^5\}}$$

$$Assume, q = 11\ (assumed)$$

$$a = 312.8\ mm$$

Axial Module, m_x:(1M)

$$m_x = 1.24\sqrt[3]{\frac{[M_t]}{yqz[\sigma_b]}} = 8\ mm$$

Revision of centre distance, a:(1M)

$$a = 0.5m_x(q+z+2x) = 332\ mm$$

Pitch diameters, pitch line velocity of worm, sliding velocity:(1M)

Pitch diameter-worm,

$$d_1 = qm_x = 88\ mm$$

Pitch diameter-worm wheel,

$$d_2 = zm_x = 576\ mm$$

Pitch line velocity, v = 6.635 m/s.

Sliding velocity,

$$v_s = \frac{v_1}{\cos\gamma} = 6.877\ m/s$$

Revision of [σ_c]:(1M)

For steel-bronze combination, v_s = 6.877 m/s.

Assume [σ_c] = 146.2 X 10^6 N/m^2

Revision of design torque:

$$[M_t] = M_t.k_d.k = 2546.5\ N-m$$

Check for induced bending stress, σ_b:(1M)

$$\sigma_b = \frac{1.9[M_t]}{m_x^3 qzy} \le [\sigma_b]$$

$$\sigma_b = 23.9\times 10^6 N/m^2$$

Design is safe.

Check for induced compressive stress, σ_c:(1M)

$$\sigma_c = \frac{540}{(\frac{z}{b})}\times\sqrt{\left[\frac{\frac{z}{b}+1}{a}\right]^3\{[M_t]\times 10^5\}} \le [\sigma_c]$$

$$\sigma_c = 146.2\times 10^6 N/m^2$$

Design is safe.

Check for efficiency, η:(1M)

$$\eta = \frac{\tan\gamma}{\tan(\gamma+\rho)} = 92.63\%$$

Basic dimensions of pinion and wheel:(1M)

Worm:

$$No.of\ starts, Z = 3$$
$$Pitch\ diameter, d_1 = 88\ mm$$
$$Height\ factor, f_0 = 1$$
$$Tip\ circle\ diameter, d_{a1} = d_1 + 2f_0m_x = 104\ mm$$
$$Root\ circle\ diameter, d_{f1} = d_1 - 2f_0m_x - 2c = 68.8\ mm$$
$$Min\ Length, L = (12.5 + 0.09z)m_x = 154.24\ mm$$

Worm Wheel:

$$No.of\ teeth, z = 72$$
$$Pitch\ diameter, d_2 = 576\ mm$$
$$Tip\ circle\ diameter, d_{a2} = (z + 2f_0 + 2x)m_x = 592\ mm$$
$$Root\ circle\ diameter, d_{f2} = (z - 2f_0)m_x - 2c = 556.8\ mm$$
$$Top\ depth, h = 2.25m = 13.5\ mm$$

PART * C

1 **Design a pair of right angle bevel gears to transmit 15 kW at 75 rpm to another gear to run at 250 rpm. Not less than 20 teeth are to be used on either gear. The pressure angle is 20º. Assume a gear life of 12000 hrs.(15M)(Nov/Dec 2015)**BTL5

Answer: Page: 3.35 – Dr.A.Baskar

Gear ratio, i:(1M)

$$i = \frac{N_1}{N_2} = 3$$
$$\tan\delta_2 = i$$
$$\delta_2 = 75.57°;\ \delta_1 = 14.43°$$

Material:(1M)

C45 steel for both pinion and wheel (assumed).

Tensile strength, $\sigma_u = 700 \text{ X } 10^6$ N/m^2

Yield strength, $\sigma_y = 360 \text{ X } 10^6$ N/m^2

Gear life, N:(1M)

Life in number of cycles, N = 60 X (rpm, n) X (Life in hrs, T) = 54X 10^7 cycles

Design torque, [M$_t$]:(1M)

$$Torque\ transmitted, M_t = \frac{60 \times Power\ in\ watts}{2\pi N} = 190.99\ N - m$$
$$[M_t] = M_t.k_d.k = 248.28\ N - m$$

Calculation of E$_{eq}$, [σ$_b$] and [σ$_c$]:(1M)

$E_{eq} = 210.915 \text{ X } 10^9$ N/m^2

$$[\sigma_b] = \frac{1.4k_{bl}\sigma_{-1}}{n.k_\sigma} = 82.076 \times 10^6\ \ N/m^2$$
$$[\sigma_c] = C_R HRC k_{cl} = 593.97 \times 10^6\ N/m^2$$

Cone distance, R:(1M)

$$R \geq \psi\sqrt{i^2+1}\sqrt[3]{\left(\frac{0.72}{(\psi-0.5)[\sigma_c]}\right)^2\frac{E\times[M_t]}{i}}$$

$$Assume, \psi = \frac{R}{b} = 3$$

$$R = 152\ mm$$

Number of teeth Z_1 and Z_2:(1M)

Z_1 = 20 (assumed)

Z_2 = i. Z_1 = 60.

Transverse Module, m_t:(1M)

$$m_{av} \geq 1.28\sqrt[3]{\frac{[M_t]}{y[\sigma_b]\psi Z_1}} = 4.33\ mm$$

$$m_t = m_{av} + \frac{b}{z}\sin\delta = 6\ mm$$

Revision of cone distance, R and number of teeth:(1M)

$$R = 0.5m_tZ_1\sqrt{i^2+1} = 187.74\ mm$$

Z_1 = 20 teeth; Z_2 = 60 teeth;

Face width, pitch circle diameter, pitch line velocity:(1M)

Face width, b = 10.m_t = 60 mm

Pitch circle diameter,

$$d_{1av} = m_tZ_1\left(\frac{R-0.5b}{R}\right) = 101\ mm$$

Pitch line velocity, v = 3.966 m/s.

Quality of gear:(1M)

IS quality 6 is selected.

Revision of design torque:(1M)

$$[M_t] = M_t.k_d.k = 412.54\ N-m$$

Check for maximum induced bending stress, σ_b:(1M)

$$\sigma_b = \frac{R\sqrt{i^2+1}.[M_t]}{(R-0.5b)^2mby}.\frac{1}{\cos\alpha} \leq [\sigma_b]$$

$$\sigma_b = 73.527\times10^6N/m^2$$

Design is safe.

Check for maximum induced compressive stress, σ_c:(1M)

$$\sigma_c = \frac{0.72}{(R-0.5b)}\times\sqrt{\frac{(i^2+1)^3E[M_t]}{i.b}} \leq [\sigma_c]$$

$$\sigma_c = 557.27\times10^6N/m^2$$

Design is safe.

Basic dimensions of pinion and wheel:(1M)

Pinion:

$$Reference\ angle, \delta_1 = 14.43°$$

$$Pitch\ circle\ diameter, d_1 = 120\ mm$$

$$Tip\ circle\ diameter, d_{a1} = m_t(Z_1 + 2cos\delta_1) = 131.62\ mm$$

Wheel:

$$Reference\ angle, \delta_2 = 75.57°$$

$$Pitch\ circle\ diameter, d_2 = 360\ mm$$

$$Tip\ circle\ diameter, d_{a2} = m_t Z_2 = 363\ mm$$

2 **A hardened steel worm rotates at 1440 rpm and transmits 12 kW to a phosphor bronze gear. The speed of the worm gear should be 60 rpm. Design the worm gear drive if an efficiency of atleast 82% is desired.(15M)(Nov/Dec 2016)**BTL5

Answer: Page: 3.128 – Dr.A.Baskar

Material:(1M)

Worm-hardened steel (given)

Worm gear-phosphor bronze (given)

No.of threads on worm, Z and teeth on worm wheel, z:(1M)

Z = 3 (assumed)

$$Gear\ ratio, i = \frac{n}{n_1} = 24$$

No. of teeth on wheel, z = i.Z = 72 teeth.

Diameter factor, q and Lead angle, γ:(1M)

Q = 11 (assumed)

$$\gamma = \tan^{-1}\left(\frac{Z}{q}\right) = 15.255°$$

Tangential load, F_t:(1M)

$$F_t = \frac{Design\ power\ in\ watts}{Pitch\ line\ velocity\ of\ worm\ gear} = \frac{68.967}{m_x}\ N$$

Dynamic Load, F_d:(1M)

$$F_d = F_t\frac{6 + v_{mg}}{6} = \frac{68.967}{m_x} + 2600$$

Beam strength, F_s:(1M)

$$F_s = [\sigma_b]m_x.b.Y$$

$$F_s = 253.8 \times 10^6 \times m_x^2, N$$

Axial Module, m_x:(1M)

$$F_s \geq F_d\ for\ safe\ design$$

$$253.8 \times 10^6 \times m_x^2 = \frac{68.967}{m_x} + 2600$$

Module, m_x = 8 mm.

Face width, b; Pitch diameter, d_1; pitch line velocity of worm:(2M)

Face width, b = 8.25 X m_x = 66 mm

Pitch diameter,

$$d_1 = qm_x = 88\ mm$$

Pitch line velocity of worm,

$$v_{mg} = 226.195 m_x = 1.81\ m/s$$

Revision of beam strength, F_s:(1M)

$$F_s = 253.8 \times 10^6 \times m_x^2 = 16243.2\ N$$

Revision of dynamic load, F_d:(1M)

$$F_d = \left[\frac{68.967}{m_x}\right] + 2600 = 11220.9\ N$$

Check for the design:

(F_s = 16243.2 N) > (F_d = 11220.9 N)

Wear load, F_w:(1M)

$$F_w = D_g.b.k_w = 32818.5\ N$$

Check for the design:

(F_w = 32818.5 N) > (F_d = 11220.9 N)

The design is safe.

Check for efficiency, η:(1M)

$$\eta = \frac{\tan\gamma}{\tan(\gamma+\rho)} = 82\%$$

Design is satisfactory.

Basic dimensions of pinion and wheel:(2M)

Worm:

$$No.of\ starts, Z = 3$$
$$Pitch\ diameter, d_1 = 88\ mm$$
$$Height\ factor, f_0 = 1$$
$$Tip\ circle\ diameter, d_{a1} = d_1 + 2f_0 m_x = 104\ mm$$
$$Root\ circle\ diameter, d_{f1} = d_1 - 2f_0 m_x - 2c = 68.8\ mm$$
$$Min\ Length, L = (12.5 + 0.09z)m_x = 154.24\ mm$$

Worm Wheel:

$$No.of\ teeth, z = 72$$
$$Pitch\ diameter, d_2 = 576\ mm$$
$$Tip\ circle\ diameter, d_{a2} = (z + 2f_0 + 2x)m_x = 592\ mm$$
$$Root\ circle\ diameter, d_{f2} = (z - 2f_0)m_x - 2c = 556.8\ mm$$
$$Top\ depth, h = 2.25m = 13.5\ mm$$

3 **The input to worm gear shaft is 18 kW at 600 rpm, speed ratio is 20. The worm is to be of hardened steel and the wheel is made of chilled phosphor bronze. Considering wear and strength, design worm and worm wheel.(15M)(Nov/Dec 2015)**BTL5

Answer: Page: 3.134 – Dr.A.Baskar

Material:(1M)

Worm-hardened steel (given)

Worm wheel – chilled phosphor bronze (given)

Design bending stress (worm wheel) for chilled bronze, $[\sigma_b] = 98.1 \times 10^6\ N/m^2$

No. of threads on worm, Z and teeth on worm wheel, z:(1M)

Z = 3 (assumed)

$$Gear\ ratio, i = \frac{n}{n_1} = 20\ (given)$$

No. of teeth on wheel, z = i.Z = 60 teeth.

Diameter factor, q and Lead angle, γ:(1M)

Q = 11 (assumed)

$$\gamma = \tan^{-1}\left(\frac{Z}{q}\right) = 15.255°$$

Tangential load, F_t:(1M)

$$F_t = \frac{Design\ power\ in\ watts}{Pitch\ line\ velocity\ of\ worm\ gear} = \frac{124.14}{m_x}\ N$$

Dynamic Load F_d:(1M)

$$F_d = F_t\frac{6 + v_{mg}}{6} = \frac{124.14 + 3900.065m_x}{m_x}, N$$

Beam strength, F_s:(1M)

$$F_s = [\sigma_b]m_x.b.Y$$

$$F_s = 317.25 \times 10^6 \times m_x^2, N$$

Axial Module, m_x:(1M)

$$F_s \geq F_d\ for\ safe\ design$$

$$317.25 \times 10^6 \times m_x^2 = \frac{124.14 + 3900.065m_x}{m_x}$$

Module, m_x = 8 mm.

Face width, b; Pitch diameter, d_1; pitch line velocity of worm:(2M)

Face width, b = 8.25 X m_x = 66 mm

Pitch diameter,

$$d_1 = qm_x = 88\ mm$$

Pitch line velocity of worm,

$$v_{mg} = 226.195m_x = 1.508\ m/s$$

Revision of beam strength, F_s:(1M)

$$F_s = 317 \times 10^6 \times m_x^2 = 20304.32\ N$$

Revision of dynamic load, F_d:(1M)

$$F_d = \frac{124.14 + 3900.065m_x}{m_x} = 19417.565\ N$$

Check for the design:

(F_s = 20304.32 N) > (F_d = 19417.565 N)

Wear load, F_w:(1M)

$$F_w = D_g.b.k_w = 27348.71\ N$$

Check for the design:

(F_w = 27348.71 N) > (F_d = 19417.565 N)

The design is safe.

Check for efficiency, η:(1M)

$$\eta = \frac{\tan\gamma}{\tan(\gamma+\rho)} = 87.78\%$$

Design is satisfactory.

Basic dimensions of pinion and wheel:(2M)

Worm:

$$No.of\ starts, Z = 3$$

$$Pitch\ diameter, d_1 = 88\ mm$$

$$Height\ factor, f_0 = 1$$

$$Tip\ circle\ diameter, d_{a1} = d_1 + 2f_0 m_x = 104\ mm$$

$$Root\ circle\ diameter, d_{f1} = d_1 - 2f_0 m_x - 2c = 68.8\ mm$$

$$Min\ Length, L = (12.5 + 0.09z)m_x = 143.2\ mm$$

Worm Wheel:

$$No.of\ teeth, z = 60$$

$$Pitch\ diameter, d_2 = 480\ mm$$

$$Tip\ circle\ diameter, d_{a2} = (z + 2f_0 + 2x)m_x = 496\ mm$$

$$Root\ circle\ diameter, d_{f2} = (z - 2f_0)m_x - 2c = 380.8\ mm$$

$$Top\ depth, h = 2.25m = 13.5\ mm$$

REGULATION: 2017 **ACADEMIC YEAR: 2019-2020**

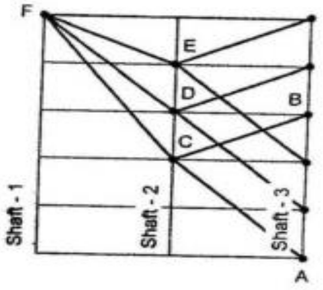
Subject Code:ME8651 **Year/Semester: III /06**

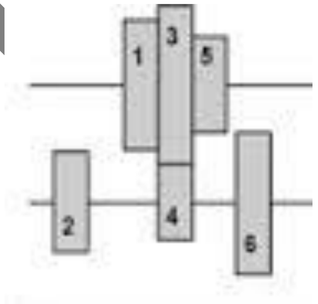
Subject Name: Design Of Transmission Systems **Subject Handler: Mr.S.Kanna & S.Vignesh**

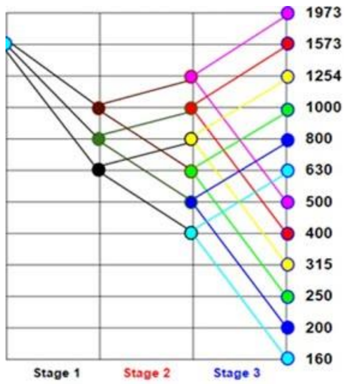
UNIT IV–GEAR BOXES

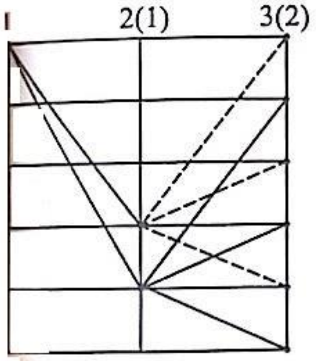
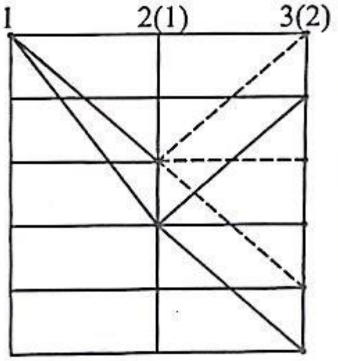
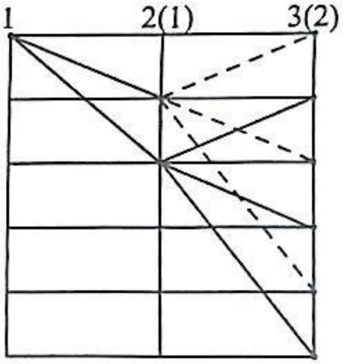
Geometric progression - Standard step ratio - Ray diagram, kinematics layout -Design of sliding mesh gear box - Design of multi speed gear box for machine tool applications - Constant mesh gear box -Speed reducer unit–Variable speed gear box, Fluid Couplings, Torque Converters for automotive applications.

PART * A

Q.No.	Questions
1	**Calculate standard step ratio for six speed gear box with speed ranging between 100 and 560rpm.**BTL5 $\phi = [N_{Max}/N_{Min}]^{1/n-1}$ $= [560/100]^{1/6-1}$ $=1.411$ 
2	**Comment on the number of gears to be used in the output shaft. (May/June 2012)**BTL3 It is practiced in the gear box that output shaft is fixed with maximum of three gears.
3	**What are the methods of lubrication in speed reducers?**BTL2 ➢ Splash or spray lubricating method and ➢ Pressure lubrication method.
4	**List any two methods used for changing speeds in gear boxes. (Nov/Dec 2016)**BTL2 ➢ Sliding mesh gear box and ➢ Constant mesh gear box
5	**Write any two requirements of a speed gear box.**BTL2 ➢ Gear box should provide the designed series of spindle speeds. ➢ Gear box should transmit the required amount of power to the spindle.
6	**Differentiate ray diagram and structural diagram. (or) What does the ray diagram of gear box indicates? (May/June 2012, Nov/Dec 2016)**BTL4 The ray diagram is a graphical representation of the drive arrangement in general form. It serves the specific values of all the transmission ratios and speed of all the shafts in the drive. The structural diagrams are drawn from the structural formulae which is a graphical tool used to find the range ratio of transmission groups. The structural diagram gives information about the

	number of shafts and the number of gears on each shaft.
7	**Write the structural formula for a six speed gear box.**BTL3 A typical ray diagram for a six speed gear box, for the preferred structural formula 3(1) 2(3), is shown below.
8	**Select 3 pairs of gears with total teeth for each pair 60 and speed ratios 1, 1.41, and 2.**BTL4 $z_1+ z_2=z_3+ z_4= z_5+ z_6=60$; $i= z_2/ z_1=1$; $i=z_4/ z_3=1.41$; $i= z_6/ z_5=2$ $z_1=30$; $z_2=30$; $z_3=25$: $z_4=36$: $z_5=20$: $z_6=40$
9	**State any three basic rules to be followed while designing a gear box.**BTL1 ➢ The transmission ratio in a gear box is limited by ¼ ≤ i ≤ 2. ➢ For stable operation, the speed ratio of any stage should not be greater than 8. i.e., $N_{max}/ N_{min} \leq 8$. ➢ In all stages except in the first stage, $N_{max} \geq N_{input} > N_{min}$
10	**What is the function of spacers in a gear-box?**BTL1 The function of spacers is to provide the necessary distance between the gears and the bearings.
11	**List out the possible arrangements to achieve 16 speed gear box.**BTL2 ➢ 4 x 2 x 2 scheme ➢ 2 x 4 x 2 scheme and ➢ 2 x 2 x 4 schemes
12	**What are the possible arrangements to achieve 12 speeds from a gear box? (April/May 2011, May/June 2013)**BTL3 The possible arrangements are: ➢ 3 x 2 x 2 scheme ➢ 2 x 3 x 2 scheme and ➢ 2 x 2 x 3 scheme.
13	**Sketch the kinematics layout of gears for 3 speeds between two shafts.**BTL3 
14	**What are preferred numbers? (Apr/May 2011,2013, Nov/Dec 2014)**BTL2 **Name the series in which speeds of multi speed gear box are arranged. [May/June 2014]** Preferred numbers are the conventionally rounded off values derived from geometric series. There are five basic series, denoted as R 5, R 10, R 20, R 40 and R 80 series.
15	**What does the ray-diagram of gear box indicates? (May/June 2012, Apr/May 2017)**BTL3 The ray diagram is a graphical representation of the drive arrangement in general form. It serves to determine the specific values of all the transmission ratios and speeds of all the shafts

	in the drive.
16	**What is step ratio? (or) Define progression ratio. (Nov/Dec 2015, May/June 2014)**BTL1 When the spindle speeds are arranged in geometric progression, then the ratio between the two adjacent speeds is known as step ratio or progression ratio.
17	**Draw the ray diagram for 12 speed gear box. (May/June 2013)**BTL3 
18	**What is a speed reducer?**BTL1 Speed reducer is a gear mechanism with a constant speed ratio, to reduce the angular speed of output shaft as compared with that of input shaft.
19	**Specify four types of gear box.(Nov/Dec 2014)**BTL2 ➢ Sliding mesh gear box, ➢ constant mesh gear box, ➢ synchromesh gearbox, ➢ planetary gearbox.
20	**What is multispeed gear box? (May/June 2016)**BTL1 A gearbox that converts a high speed input into a number of different speed output it is called a multi-speed gear box. Multi speed gear box has more than two gears and shafts. A multi speed gearbox reduces the speed in different stages.
21	**Why geometric progression is selected for arranging the speeds in gear box? (Apr/May 2017)**BTL2 When the speeds are arranged in G.P, it has the following advantages over the other progressions. ➢ The speed loss is minimum ➢ No.of gears to be employed is minimum ➢ G.P provides a more even range of spindle speeds at each step. ➢ The lay out is comparatively very compact. ➢ G.P m/c tool spindle speeds can be selected easily from preferred numbers, because preferred numbers are in geometric progression.
22	**What is R20 series? (May/June 2016)**BTL1 In industrial design, preferred numbers (also called preferred values, preferred series or convenient numbers are standard guidelines for choosing exact product dimensions within a given set of constraints. Product developers must choose numerous lengths, distances,

	diameters, volumes, and other characteristic quantities. Preferred numbers represent preferences of simple numbers (such as 1, 2, and 5) and their powers of a convenient basis, usually 10. The R5, R10 and R20 series refers to the Renard 5 (first-choice sizes 60 % increments), Renard 10 (second-choice sizes 25 % increments) and Renard 20 (third-choice sizes 12 % increments) series of preferred numbers standardized in ISO3.
23	**Write the significance of structural formula. (Nov/Dec 2015)**BTL1 Structural formula is used to find the number of speeds (n) available at the spindle and through no. Stages it can be achieved. $n = p_1 (X_1) .p_2 (X_2).p_2 (X_3)$ p= stages in the gear box, X = Characteristic of the stage.
24	**List four application where constant mesh gear box is used. (Nov/Dec 2012)**BTL2 Vehicles which use this type of gearboxes are farm trucks, motorcycles, and heavy machinery. The availability of such mechanisms like constant mesh gearbox which create less noise and are cost effective.
25	**What are the conditions required for interchangeability of toothed Gears? (Nov/Dec 2012)**BTL3 For interchangeability of all gears, the set must have the same circular pitch, module, diameter pitch, pressure, angle, addendum and dedendum and tooth thickness must be one half of the circular pitch.
	PART * B
1	**Sketch three possible ray diagrams for a 6 speed gearbox with 2x3 arrangement. Choose the best possible ray diagram. Give suitable explanation for the same. (13M)(April/May 2010)**BTL5 **Answer: Page: 4.13 – Dr.A.Baskar**  *Ray diagram (i)*  *Ray diagram (ii)*  *Ray diagram (iii)* (6M) ➢ Three ray diagrams are drawn keeping the input speed same.(6M) ➢ Ray diagram (ii): Two output speeds are same as input speed in stage 2. This is not preferable.

- Ray diagram (i): One speed reduction is very high in stage 1. This is not preferable.
- Ray diagram (iii): Do not have any such speeds and hence this is the preferable ray diagram.

$$\frac{N_{min}}{N_{Input}} \geq \frac{1}{4} and\ \frac{N_{max}}{N_{Input}} \leq 2\ should\ be\ satisfied\ at\ each\ stage$$

Overlapping speed gearbox:(1M)

- Maximum possible speeds = Required number of speeds.
- Sometimes: Required number of speeds < Maximum possible speeds.

2 **A sliding mesh gearbox is to be used for 4 forward and 1 reverse speeds. First gear speed ratio is 5.5 and reverse gear ratio is 5.8. Clutch gear on clutch shaft and gear (in constant mesh) on lay shaft has speed ratio of 2. Calculate the number of teeth on all the gears. Assume that the minimum number of teeth on any gear should not be less than 18. Calculate actual gear ratios. Assume that the geometric progression for gear ratios, top gear (fourth), third gear, second and first gear is 1:x:x^2:x^3. (13M)(Nov/Dec 2014)**BTL5

Answer: Page: 4.33 – Dr.A.Baskar

The GP ratio:(1M)

$i_1 = x^3 = 5.5$; x = 1.765.

Gear ratios are:

1:1.765:3.116:5.5

$$Speed\ ratio, i = \frac{Speed\ of\ the\ first\ driver\ gear}{Spead\ of\ last\ driven\ gear}$$

Max gear ratio, i_{max}:(1M)

$$i_{max} = \frac{Z_2}{Z_1} \times \frac{Z_8}{Z_7}$$

Zmin = 18 (given)

Let, Z_7 = 18 and Z_8 = 50.

$Z_1 + Z_2 = Z_7 + Z_8 = 69$

Z_1 = 23 and Z_2 = 46

Second gear ratio, i_2:(1M)

$$i_2 = \frac{Z_2}{Z_1} \times \frac{Z_6}{Z_5} = 3.116$$

$Z_1 + Z_2 = Z_7 + Z_8 = Z_5 + Z_6 = 69$

Z_5 = 27 and Z_6 = 42

Third gear ratio, i_3:(1M)

$$i_3 = \frac{Z_2}{Z_1} \times \frac{Z_4}{Z_3} = 1.765$$

$Z_1 + Z_2 = Z_7 + Z_8 = Z_5 + Z_6 = Z_3 + Z_4 = 69$

Z_3 = 37 and Z_4 = 32

Reverse gear ratio, i_R:(1M)

$$i_R = \frac{Z_2}{Z_1} \times \frac{Z_8}{Z_9} = 5.8$$

Z_8 = 51 (already found) and Z_9 = 18.

Actual gear ratios:(5M)

$$Constant\ gear\ ratio, i_{constant} = \frac{Z_2}{Z_1} = 2$$

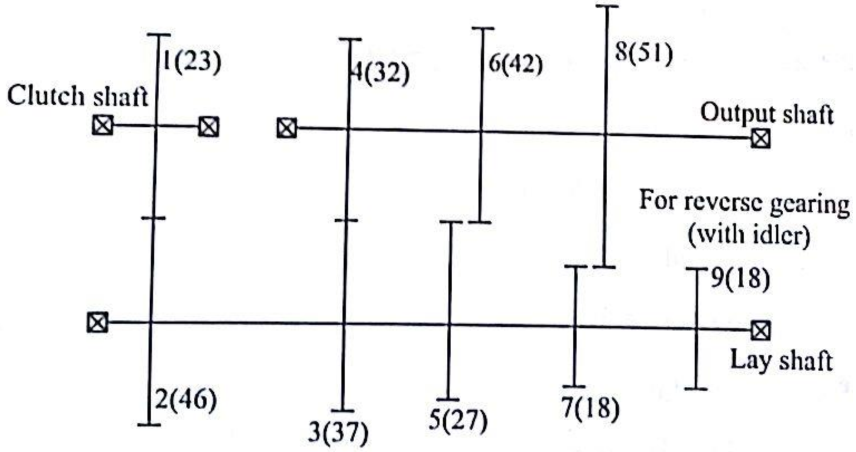
$$First\ gear\ ratio, i_1 = \frac{Z_2}{Z_1} \times \frac{Z_8}{Z_7} = 5.6667$$

$$Second\ gear\ ratio, i_2 = \frac{Z_2}{Z_1} \times \frac{Z_6}{Z_5} = 3.1111$$

$$Third\ gear\ ratio, i_3 = \frac{Z_2}{Z_1} \times \frac{Z_4}{Z_3} = 1.7297$$

$$Reverse\ gear\ ratio, i_R = \frac{Z_2}{Z_1} \times \frac{Z_8}{Z_9} = 5.6667$$

Kinematic Layout:(3M)



3 **Design a four speed gearbox to have following speed ratio. First gear is 5:1, second gear is 3:1, third gear is 1.5:1 and the top gear is 1:1. The centre distance between the input and output shafts is 150 mm. All gears are of 4 mm module, Determine the number of teeth of all wheels, pitch circle diameter of all wheels and sketch the diagrammatic arrangement of the gear box. (Assume number of teeth not less than 20 and pressure angle 20º.(13M)(Nov/Dec 2015)**BTL5

Answer: Page: 4.38 – Dr.A.Baskar

$$Speed\ ratio, i = \frac{Speed\ of\ the\ first\ driver\ gear}{Spead\ of\ last\ driven\ gear}$$

Max gear ratio, i_{max}:(2M)

$$i_{max} = \frac{Z_2}{Z_1} \times \frac{Z_8}{Z_7} = 5$$

Assuming same ratio between any pair of gears;

$$\frac{Z_2}{Z_1} = \frac{Z_8}{Z_7} = \sqrt{5}$$

Given centre distance, a:(2M)

$$a = \frac{m(Z_1 + Z_2)}{2} = 150$$

$Z_1 + Z_2 = 75$.

$Z_2 = 2.2361Z_1$ and $Z_8 = 2.2361Z_7$

Also, $Z_1 + Z_2 = Z_7 + Z_8 = Z_5 + Z_6 = Z_3 + Z_4 = 75$

$Z_1 = 23$ and $Z_2 = 52$.

Also, $Z_8 = 2.2361Z_7$ and $Z_7 + Z_8 = 75$

$Z_7 = 23$ & $Z_8 = 52$.

Second gear ratio, i_2:(1M)

$$i_2 = \frac{Z_2}{Z_1} \times \frac{Z_6}{Z_5} = 3$$

$Z_5 = 32$ and $Z_6 = 43$.

Third gear ratio, i_3:(1M)

$$i_3 = \frac{Z_2}{Z_1} \times \frac{Z_4}{Z_3} = 1.5$$

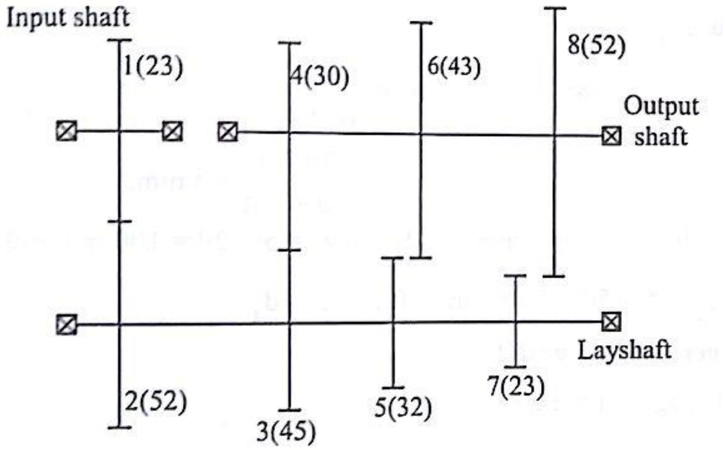
$Z_3 = 45$ and $Z_4 = 30$.

Pitch circle diameter of all gears:(4M)

$d_1 = mZ_1 = 92$ mm ; $d_2 = mZ_2 = 208$ mm; $d_3 = mZ_3 = 180$ mm; $d_4 = mZ_4 = 120$ mm

$d_5 = mZ_5 = 128$ mm; $d_6 = mZ_6 = 172$ mm; $d_7 = mZ_7 = 92$ mm; $d_8 = mZ_8 = 208$ mm

Kinematic layout:(3M)



4 **A gear box is to give 18 speeds for a spindle of a milling machine. Maximum and minimum speeds of the spindle are to be around 650 and 35 rpm respectively. Find the speed ratios which will give the desired speeds and draw the structural diagram and kinematic arrangement of the drive.(13M)(Nov/Dec 2015)**BTL5

Answer: Page: 4.50 – Dr.A.Baskar

$$Step\ ratio, \emptyset = \left(\frac{N_{max}}{N_{min}}\right)^{\left(\frac{1}{n-1}\right)} = 1.1875(2M)$$

Range of speeds:(1M)

R40 Series:

35.5, 42.5, 50, 60, 71, 85, 100, 118, 140, 170, 200, 236, 280, 335, 400, 475, 560, 670 rpm.

Structural formula:(1M)

$$1 \times 3(1) \times 3(3) \times 2(9)$$

Ray Diagram:(2M)

$$Condition\ to\ be\ satisfied, \frac{N_{min}}{N_{Input}} \geq \frac{1}{4} and\ \frac{N_{max}}{N_{Input}} \leq 2$$

At stage 3:

$$N_{min} = 35.5\ rpm;\ N_{input} = 142\ rpm; N_{max} = 170\ rpm$$

At stage 2:

$$N_{min} = 85\ rpm;\ N_{input} = 340\ rpm; N_{max} = 236\ rpm$$

At stage 1:

$$N_{min} = 280\ rpm;\ N_{input} = 670\ rpm; N_{max} = 400\ rpm$$

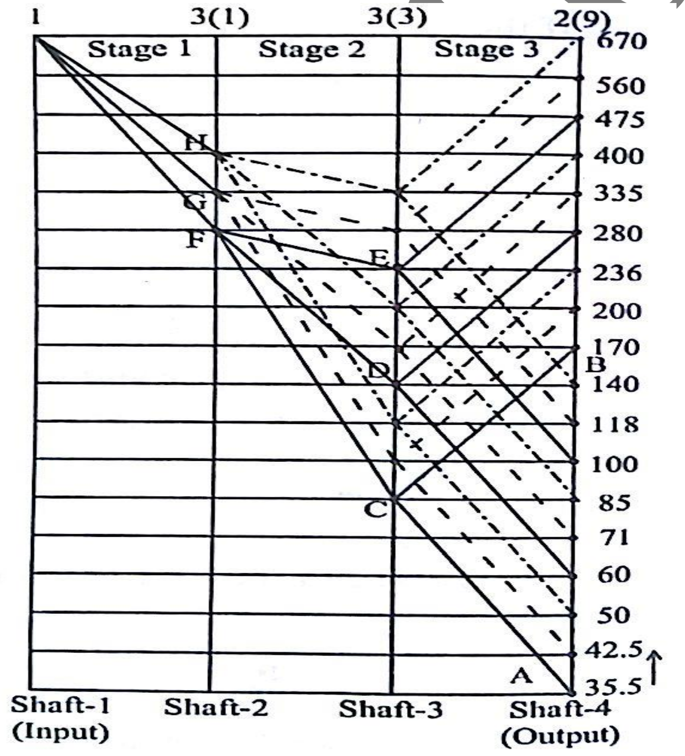
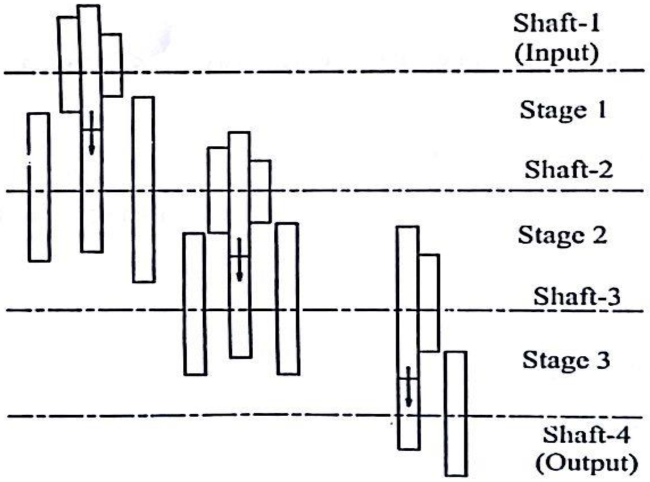


Diagram: (5M)

Kinematic arrangement:(2M)



5

A nine speed gear box, used as a head stock gearbox for a turret lathe, is to provide a speed range of 180 rpm to 1800 rpm. Using standard step ratio, draw the speed diagram and kinematic layout.(13M)(May/June 2011)BTL5

Answer: Page: 4.45 – Dr.A.Baskar

$Step\ ratio, \emptyset = \left(\frac{N_{max}}{N_{min}}\right)^{\left(\frac{1}{n-1}\right)} = 1.3335$(2M)

Range of speeds:(1M)

R40 Series:

180, 236, 315, 425, 560, 750, 1000, 1320, 1800 rpm.

Structural formula:(1M)

$$1 \times 3(1) \times 3(3)$$

Ray diagram:(2M)

$$At\ any\ stage, \frac{N_{min}}{N_{Input}} \geq \frac{1}{4} and\ \frac{N_{max}}{N_{Input}} \leq 2$$

At stage 2:

$$N_{min} = 180\ rpm;\ N_{input} = 560\ rpm; N_{max} = 1000\ rpm$$

At stage 1:

$$N_{min} = 560\ rpm;\ N_{input} = 1800\ rpm; N_{max} = 1000\ rpm$$

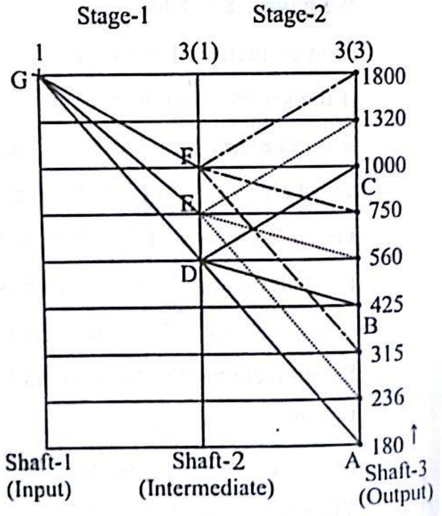
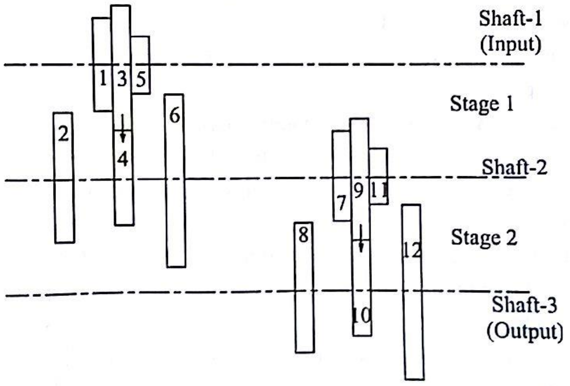


Diagram: (5M)

Kinematic Arrangement:(2M)



PART * C

1 **Draw the kinematic diagram and speed diagram of the head stock gearbox of a turret lathe arrangement for 9 spindle speeds, ranging from 31.5 rpm to 1050 rpm. Calculate the number of teeth on each gear. Minimum number of teeth on a gear is 25. Also calculate the percentage deviation of the obtainable speeds.(15M)(May/June 2016)**BTL5

Answer: Page: 4.57 – Dr.A.Baskar

$Step\ ratio, \emptyset = \left(\frac{N_{max}}{N_{min}}\right)^{\left(\frac{1}{n-1}\right)} = 1.5501(1M)$

Range of speeds:(1M)

R40 Series:

31.5, 50, 80, 125, 200, 315, 500, 800, 1250 rpm.

Structural formula:(1M)

$$1 \times 3(1) \times 3(3)$$

Ray diagram:(1M)

$$At\ any\ stage, \frac{N_{min}}{N_{Input}} \geq \frac{1}{4} and\ \frac{N_{max}}{N_{Input}} \leq 2$$

At stage 2:

$$N_{min} = 31.5\,rpm;\ N_{input} = 125\,rpm; N_{max} = 500\,rpm$$

At stage 1:

$$N_{min} = 125\,rpm;\ N_{input} = 800\,rpm; N_{max} = 315\,rpm$$

Number of teeth on each gear:(2M)

$Z_1 = 37$;	$Z_2 = 148$;	$Z_3 = 52$;	$Z_4 = 133$
$Z_5 = 25$;	$Z_6 = 160$;	$Z_7 = 63$;	$Z_8 = 62$
$Z_9 = 100$;	$Z_{10} = 25$;	$Z_{11} = 25$;	$Z_{12} = 100$

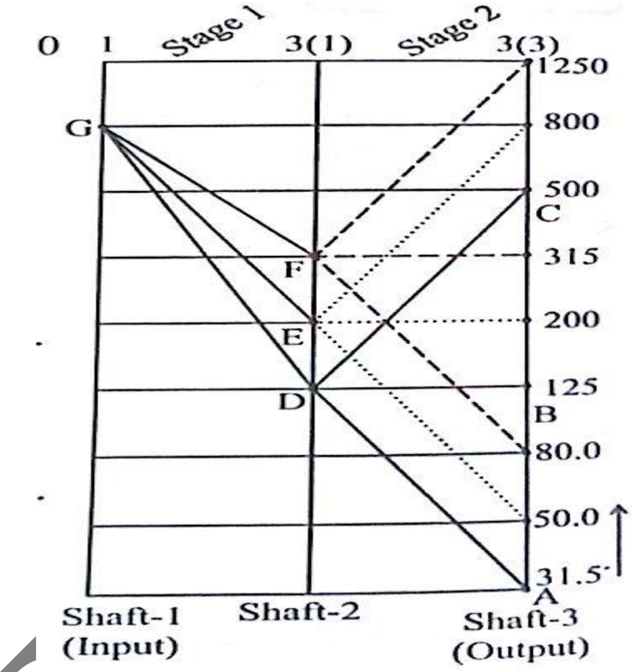
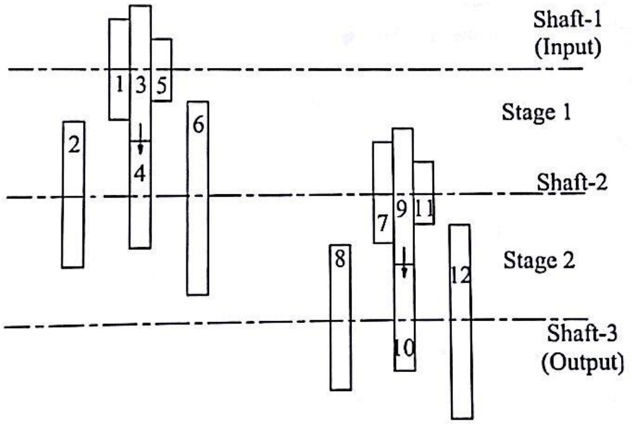


Diagram: (4M)

Kinematic Arrangement:(2M)



Obtainable speeds:(2M)

Input speed, N = N_G = 800 rpm.

$N_1 = N \times \frac{Z_1}{Z_2} \times \frac{Z_7}{Z_8} = 203.23\,rpm$	$N_2 = N \times \frac{Z_1}{Z_2} \times \frac{Z_9}{Z_{10}} = 800\,rpm$

$N_3 = N \times \frac{Z_1}{Z_2} \times \frac{Z_{11}}{Z_{12}} = 50\, rpm$	$N_4 = N \times \frac{Z_3}{Z_4} \times \frac{Z_7}{Z_8} = 317.83\, rpm$
$N_5 = N \times \frac{Z_3}{Z_4} \times \frac{Z_9}{Z_{10}} = 1251.13\, rpm$	$N_6 = N \times \frac{Z_3}{Z_4} \times \frac{Z_{11}}{Z_{12}} = 78.20\, rpm$
$N_7 = N \times \frac{Z_5}{Z_6} \times \frac{Z_7}{Z_8} = 127.02\, rpm$	$N_8 = N \times \frac{Z_5}{Z_6} \times \frac{Z_9}{Z_{10}} = 500\, rpm$
$N_9 = N \times \frac{Z_5}{Z_6} \times \frac{Z_{11}}{Z_{12}} = 31.25\, rpm$	

Arranging in ascending order;

Obtained speeds; 31.25, 50, 78.2, 127.02, 203.23, 317.83, 500, 800, 1251.13 rpm.

Percentage deviation of obtainable speeds from the calculated speeds (1M)

$$\%deviation = \frac{N_{obt} - N_{Cal}}{N_{Cal}} \times 100$$

Speed No	N_{obt} (rpm)	N_{cal} (rpm)	% deviation
1	31.25	31.5	-0.79
2	50	50	0
3	78.2	80	-2.25
4	127.02	125	1.62
5	203.23	200	1.62
6	317.83	315	0.90
7	500	500	0
8	800	800	0
9	1251.13	1250	0.09

2 **Sketch the arrangements of a six speed gearbox. The minimum and maximum speeds required are around 460 and 1400 rpm. Drive speed is 1440 rpm. Construct speed diagram of the gearbox and obtain various reduction ratios. Use standard output speeds and standard step ratio. Calculate number of teeth in each gear and verify whether the actual output speeds are within ±2% of standard speeds.(15M)(May/June 2014)**BTL5

Answer: Page: 4.63 – Dr.A.Baskar

$Step\ ratio, \emptyset = \left(\frac{N_{max}}{N_{min}}\right)^{\left(\frac{1}{n-1}\right)} = 1.2493$(1M)

Range of speeds:(1M)

R40 Series:

450, 560, 710, 900, 1120, 1400 rpm.

Structural formula:(1M)

$$1 \times 2(1) \times 3(2)$$

Ray diagram:(1M)

$$At\ any\ stage, \frac{N_{min}}{N_{Input}} \geq \frac{1}{4} and\ \frac{N_{max}}{N_{Input}} \leq 2$$

At stage 2:

$$N_{min} = 450\ rpm;\ N_{input} = 1800\ rpm; N_{max} = 1120\ rpm$$

At stage 1:

$$N_{min} = 710\ rpm;\ N_{input} = 1400\ rpm; N_{max} = 900\ rpm$$

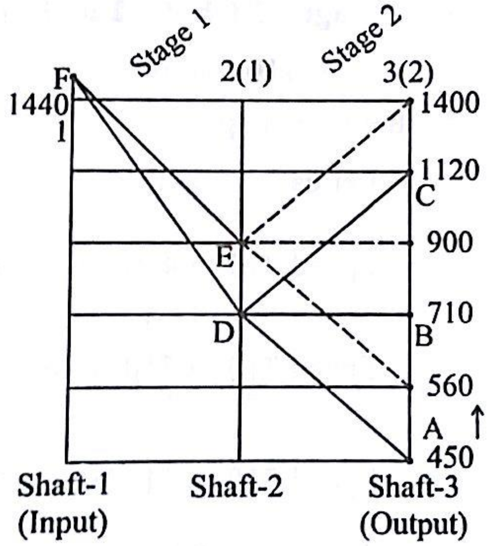


Diagram: (3M)

Number of teeth on each gear:(2M)

Z_1 = 37; Z_2 = 148; Z_3 = 52; Z_4 = 133; Z_5 = 25;

Z_6 = 160; Z_7 = 63; Z_8 = 62; Z_9 = 100; Z_{10} = 25.

Obtainable speeds:(2M)

Input speed, N = N_F = 1440 rpm.

$$N_1 = N \times \frac{Z_1}{Z_2} \times \frac{Z_5}{Z_6} = 871.58\ rpm$$

$$N_2 = N \times \frac{Z_1}{Z_2} \times \frac{Z_7}{Z_8} = 1394.53\ rpm$$

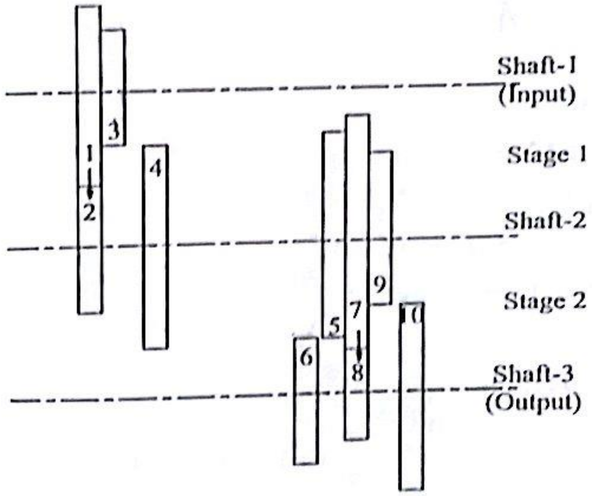
$$N_3 = N \times \frac{Z_1}{Z_2} \times \frac{Z_9}{Z_{10}} = 544.74\ rpm$$

$$N_4 = N \times \frac{Z_3}{Z_4} \times \frac{Z_5}{Z_6} = 702.44\ rpm$$

$$N_5 = N \times \frac{Z_3}{Z_4} \times \frac{Z_7}{Z_8} = 1123.90\ rpm$$

$$N_6 = N \times \frac{Z_3}{Z_4} \times \frac{Z_9}{Z_{10}} = 439.02\ rpm$$

Kinematic Arrangement:(2M)



Arranging in ascending order;

Obtained speeds; 439.02, 544.74, 702.44, 871.58, 1123.90, 1394.53 rpm.

Percentage deviation of obtainable speeds from the calculated speeds (2M)

$$\%deviation = \frac{N_{obt} - N_{Cal}}{N_{Cal}} \times 100$$

Speed No	N_{obt} (rpm)	N_{cal} (rpm)	% deviation
1	439.02	450	-2.44
2	544.74	560	-2.725
3	702.44	710	-1.065
4	871.58	900	-3.158
5	1123.90	1120	0.348
6	1394.53	1400	-3.907

3 **A six speed gearbox is required to provide output speeds in the range of 125 to 400 rpm, with a step ratio of 1.25 and transmit a power 5 kW at 710 rpm. Draw the speed diagram and kinematic diagram. Determine the number of teeth, module and face width of all gears, assuming materials for gears. Determine the length of the gearbox along the axis of the gear shaft.(15M)(May/June 2016)**BTL5

Answer: Page: 4.69 – Dr.A.Baskar

Range of speeds:(1M)

R40 Series:

125, 160, 200, 250, 315, 400 rpm.

Structural formula:(1M)

$$1 \times 2(1) \times 3(2)$$

Ray diagram:(1M)

$$At\ any\ stage, \frac{N_{min}}{N_{Input}} \geq \frac{1}{4} and\ \frac{N_{max}}{N_{Input}} \leq 2$$

At stage 2:

$$N_{min} = 125\ rpm;\ N_{input} = 500\ rpm; N_{max} = 315\ rpm$$

At stage 1:

$$N_{min} = 200\ rpm;\ N_{input} = 400\ rpm; N_{max} = 250\ rpm$$

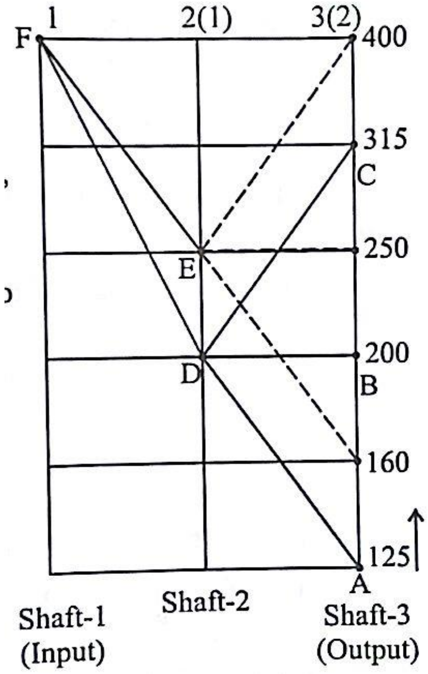


Diagram: (3M)

Number of teeth on each gear:(2M)

Z_1 = 23; Z_2 = 37; Z_3 = 20; Z_4 = 40; Z_5 = 26;
Z_6 = 26; Z_7 = 32; Z_8 = 20; Z_9 = 20; Z_{10} = 32.

Minimum module, m:(3M)

$$m \geq 1.26 \times \sqrt[3]{\frac{[M_t]}{y[\sigma_b]\omega_m Z_1}}$$

$$Design\ torque, [M_t] = M_t \times k \times k_2 = 3.10349 \times 10^5 N - mm$$

$$m \geq 3.873\ mm$$

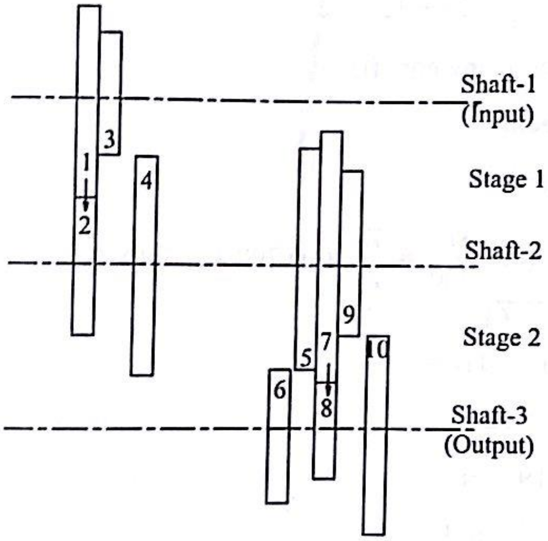
Taking higher standard, m = 5 mm.

Face width, b = 50 mm.

Length of gear box, L:(2M)

$$L = 2\delta + 4b + c + 7b + width\ of\ bearing\ assumed = 645\ mm$$

Kinematic Arrangement:(2M)

	Shaft-1 (Input) Stage 1 Shaft-2 Stage 2 Shaft-3 (Output) 1 2 3 4 5 6 7 8 9 10

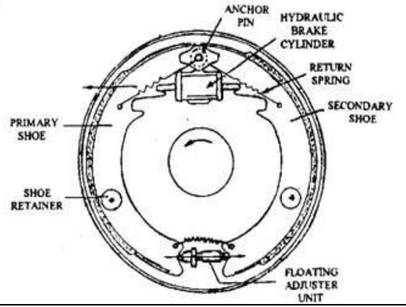
UNIT V – CAM, CLUTCHES AND BRAKES

Cam Design: Types-pressure angle and under cutting base circle determination-forces and surfacestresses. Design of plate clutches –axial clutches-cone clutches-internal expanding rim clutches-Electromagnetic clutches. Band and Block brakes - external shoe brakes - Internal expanding shoebrake.

PART * A

Q.No.	Questions
1	**What are the desirable properties of friction material to be used for clutches?**BTL2 ➢ A high and uniform coefficient of friction. ➢ Good resiliency ➢ The ability to withstand high temperatures, together with good heat conductivity. ➢ High resistance to wear, scoring and galling. ➢ Friction materials are basically composite materials made up of strands and fiber composites.
2	**Classify clutches based on the coupling methods. (May/June 2014)**BTL2 ➢ Positive contact clutches ➢ Frictional clutches ➢ Overrunning clutches ➢ Magnetic clutches and ➢ Fluid couplings.
3	**What is fade? (May/June 2012, May/June 2013)**BTL1 When the brake is applied continuously over a period of time, the brake becomes overheated and the coefficient of friction drops. This results in sudden fall of efficiency of the brake. This phenomenon is known as ‘fade’ of ‘fading’.
4	**Distinguish between coupling and a clutch. (Nov/Dec 2012)**BTL4 Couplings are used as permanent connecting elements between two power transmitting elements whereas clutches are used as temporary connecting elements. Thus periodical engagement is possible in clutch connection.
5	**Why in automobiles, braking action when travelling in reverse is not as effective as when moving forward? (April/May 2015)**BTL2 When an automobile moves forward, the braking force acts in the opposite direction to the direction of motion of the vehicle Whereas in reverse travelling the braking force acts in the same direction to the direction of motion of the vehicle. So it requires more braking force to apply brake.
6	**What is the axial force required at the engagement and disengagement of cone clutch? (May/June2013)**BTL2 ➢ For engagement: $W_e = W_n (1 + \mu \cot \alpha)$,

	➢ For disengagement: W_d= W_n (1 - μ cot α).
7	**What is the function of a clutch in a transmission systems? (May/June 2016)**BTL1 The clutch is a mechanical device which is used to connect or disconnect the source of power at the operator's will.
8	**What is a self-locking brake? (Apr/May 2011**, **May/June 2013, Nov/Dec 2012)**BTL1 When the frictional force is sufficient enough to apply the brake with no external force, then the brake is said to be self-locking brake.
9	**What you meant by self-energizing brake? (Nov/Dec 2016, May/June 2014, 2013)**BTL1 When the moment of applied force (F. l) and the moment of the frictional force (μ . R_N . c) are in the same direction, then frictional force helps in applying the brake. This type of brake is known as a self-energizing brake.
10	**How can pressure angle be reduced in cam design? (May/June 2012)**BTL2 It can be reduced by increasing the cam size or by adjusting the offset. Higher the pressure angle higher the side thrust and higher the chances of jamming the translating follower in its guide ways.
11	**If a multidisc clutch has 8 discs in driving shaft and 9 discs in driven shaft, then how many number of contact surfaces it will have? (April/May 2015)**BTL5 Given data : n_1 = 8; n_2 = 9 Solution : Number of pair of contact surface, n = n_1 + n_2 -1 = 8+9-1 = 16
12	**Name different types of clutch.** BTL2 ➢ Single Plate clutch ➢ Multi plate Clutch ➢ Cone Clutch ➢ Centrifugal Clutch
13	**How does the function of a brake differ from that of a clutch?** BTL4 Clutch used to engage and disengage the engine from the transmission system when applied. Brake is used to stop the vehicle when applied due to frictional power.
14	**What is the significance of pressure angle in CAM design? (May/June 2016)**BTL3 It is the measure of steepness of the cam profile. The angle between the direction of the follower movement and the normal to the pitch curve at any point is called pressure angle. Pressure angle varies from maximum to minimum during complete rotation.
15	**Mention a few applications of Cams.(Nov/Dec 2016)**BTL2 Cam mechanisms are used in various areas of machine building, such as internal-combustion engines, metal-cutting machines, and machines of the food industry, in which the cam mechanism performs a programmed operation, as well as in automated machines, in which cam mechanisms perform control functions, connecting and disconnecting working parts at the proper moment.
16	**Differentiate between uniform pressure and uniform wear theories adopted in the design of clutches.(Nov/Dec 2014)**BTL4 ➢ For uniform pressure theory Mean radius of friction surface (R) = $2/3[r_1^3 – r_2^3/r_1^2-r_2^2]$ ➢ For uniform wear theory Mean radius of friction surface (R) = $[r_1 +r_2] /2$

	r_1 = External radius of frictional surface r_2 = Internal radius of frictional surface
17	**Double shoe brakes are preferred than single shoe brakes. Why? (April /May 2017)**BTL4 If only one block is used for braking, then there will be side thrust on the bearing of wheel shaft. This drawback can be removed by providing two blocks on the two sides of the drum. The double shoes on the drum reduce the unbalanced force on the shaft.
18	**What are the effects of temperature rise in clutches? (May/June 2013)**BTL2 Because the temperature rise beyond the permissible range in brakes will cause: ➢ Excessive wear ➢ Distortion of the brake linings and ➢ Surface cracks due to thermal stresses.
19	**Differentiate a brake and a dynamometer.(April /May 2017)**BTL4 ➢ Brake is a mechanical device by means of a body is retarded for slowing down or to bring it to rest, by applying artificial frictional resistance. ➢ A dynamometer is a brake incorporating a device to measure the frictional resistance applied. This is used for measuring the driving forces or torque transmitted and hence the power developed by the machine.
20	**Name four materials used for lining of friction surfaces in clutches. (or) Name few commonly used friction materials.** BTL2 ➢ Wood ➢ Cork ➢ Leather ➢ Asbestos based friction materials and ➢ Powdered metal friction materials.
21	**In a hoisting machinery, what are the different energies absorbed by a brake system? (Nov/Dec 2014)**BTL2 In hoists and elevators, the potential energy released by the objects during the braking period is absorbed by the brake.
22	**In cone clutches semi-cone angle should be greater than 12 deg. Why? (May/June 2012)**BTL4 The semi cone angle is kept greater than a certain value to avoid self-engagement; otherwise disengagement of clutch would be difficult. This is kept around 12.5deg.if the angle is less than this value than the clutch is liable to jam in engagement
23	**Sketch the internal shoe brake and name the various parts.(May/June 2012)**BTL3 

24 **Name the profile of cam that gives no jerk. (Nov/Dec 2015)**BTL2

Cycloidal curve profile of cam that gives no jerk.

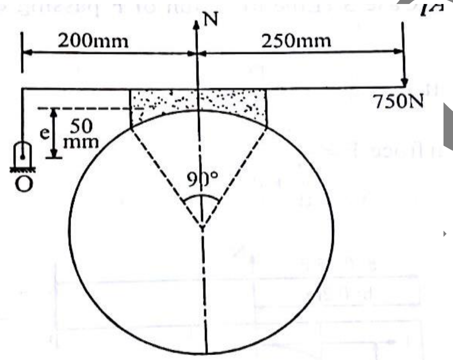
25 **What is meant by positive clutch? (Nov/Dec 2015)**BTL1

Positive-contact clutches have interlocking engaging surfaces to form a rigid mechanical junction.

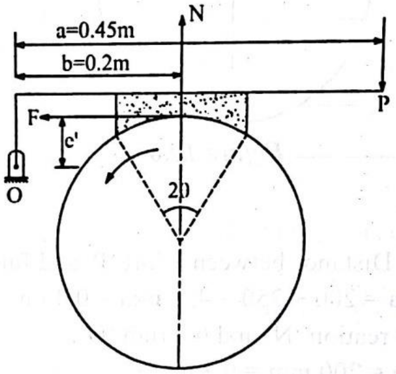
PART * B

1 **A single shoe brake is shown. The diameter of drum is 250 mm and angle of contact is 90º. If the operating force of 750 N is applied at the end of the lever and μ = 0.35, determine the torque that may be transmitted by the brake.(13M)(Nov/Dec 2016)**BTL5

Answer: Page: 5.149 – Dr.A.Baskar



i) Drum rotates in anticlockwise direction:

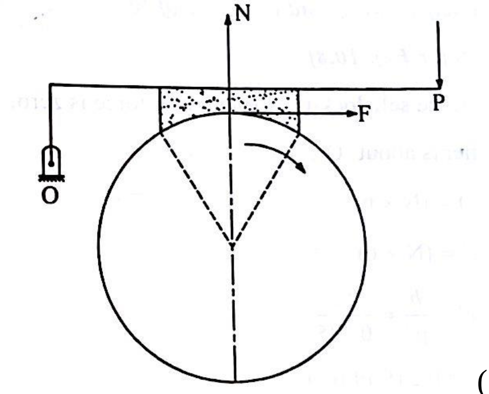
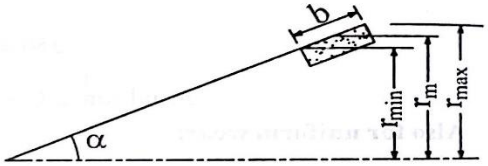
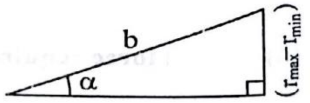


(2M)

$Friction\ force, F = \frac{Pa}{\frac{b}{\mu}+e} = 592.65\ N$(2M)

$Torque\ transmitted, M_t = F \times \frac{D}{2} = 74.08\ N-m$ (2M)

ii) Drum rotates in clockwise direction:

	 (3M) $Friction\ force, F = \frac{Pa}{\frac{b}{\mu}+e} = 718.88\ N$(2M) $Torque\ transmitted, M_t = F \times \frac{D}{2} = 89.86\ N - m$(2M)
2	**A power of 20 kW is to be transmitted through a cone clutch at 500 rpm. For uniform wear condition, find the main dimensions of clutch and shaft. Also determine the axial force required to engage the clutch. Assume coefficient of friction as 0.25, the maximum normal pressure on the friction surface is not be exceeds 0.08 MPa and take the design stress for the shaft materials as 40 MPa.(13M)(April/May 2015)**BTL5 **Answer: Page: 5.115 – Dr.A.Baskar**  ***Figure (a)***  ***Figure (b)*** (2M) $Torque\ transmitted, M_t = \frac{60\times Power\ in\ watts}{2\pi n} = 382\ N - m$(2M) **Clutch shaft diameter, d:**(2M) $[M_t] = \frac{\pi}{16}[\tau]d^3; d = 37\ mm$ **Dimensions of clutch:** Assume semi cone clutch, α = 12º. **Face width, b:**(2M) $b = \frac{r_m}{2}$ $[M_t] = 2\pi\mu p r_m^2 b;\ r_m = 0.183\ m$ **For uniform wear,**(2M) $Mean\ radius, r_m = \frac{r_{min} + r_{max}}{2}$ $r_{min} + r_{max} = 0.366\ m$ From geometry;

$$\sin\alpha = \frac{r_{max} - r_{min}}{b}$$

Already assumed,

$b = \frac{r_m}{2} = 0.0915\, m$

$r_{max} - r_{min} = 0.019\, m$

Solving:(1M)

Inner radius of friction surface, r_{min} = 0.1735 m.

Outer radius of friction surface, r_{max} = 0.1925 m.

Axial force required to engage the clutch, Q_E:(2M)

$Q = p \times 2\pi r_m (b.\sin\alpha)$

$Q_n = \frac{Q}{\sin\alpha} = 8417\, N$

$Q_E = Q_n(\mu\cos\alpha + \sin\alpha) = 3808\, N$

3 **A 50 kg wheel, 0.5 m in diameter turning at 150 rpm in stationary bearings is brought to rest by pressing a brake shoe radially against the rim with a force of 100 N. If the radius of gyration of wheel is 0.2 m, how many revolution will the wheel make before coming to rest? Assume that the coefficient of friction between shoe and rim has the steady value 0.25.(13M)(May/June 2016)]**BTL5

Answer: Page: 5.152 – Dr.A.Baskar

Mass moment of inertia, I:(2M)

$I = mk^2 = 2.0\, kg - m^2$

Angular velocity, ω:(2M)

$\omega = \frac{2\pi n}{60} = 15.708\frac{rad}{s}$

$Energy\ stored\ in\ the\ rotating\ wheel, E = \frac{1}{2}I\omega^2 = 246.74\, N - m$ (2M)

Braking torque, M_t:(4M)

$$Workdone\ during\ braking = Braking\ torque \times Angular\ displacement\ during\ braking$$

$$Friction\ force, F = \mu \times N = 25N$$

$$Braking\ torque, M_t = F \times \frac{D}{2} = 6.25N - m$$

$Angular\ displacement\ during\ braking, \theta = Angle\ turned\ in\ one\ revolution \times$
$No.of\ revolutions\ made\ during\ braking\ before\ coming\ to\ rest$(2M)

$\theta = 2\pi n_b$

$E = M_t \times \theta_b$

No. of revolutions, n_b = 6.293. (1M)

4 **A radial cam rotates at 1200 rpm with translating flat face follower rising 20 mm with simple harmonic motion in 150° of cam rotation. The base circle radius is 38 mm. Check whether undercutting will occur. (13M)(Nov/Dec 2016)**BTL5

Answer: Page: 5.40 – Dr.A.Baskar

$Angular\ velocity\ of\ cam, \omega = \frac{2\pi N}{60} = 125.664\, rad/s$(2M)

For flat follower;

$\rho_{c\,min} = R_b + \left(y + \frac{1}{\omega^2}.\frac{d^2y}{dt^2}\right) > 0$(3M)

For SHM;

$Acceleration, a = \frac{d^2y}{dt^2} = \frac{h}{2}\left(\frac{\pi\omega}{\beta}\right)^2 .\cos\frac{\pi\theta}{\beta}$(3M)

The min acceleration occurs at θ = β and y = h.

$a = \frac{-h}{2}\left(\frac{\pi\omega}{\beta}\right)^2 \ldots\ldots \cos\pi = \cos 180 = -1$(2M)

$\rho_{c\,min} = R_b + \left[h + \frac{1}{\omega^2}.\left(\frac{-h}{2}\left(\frac{\pi\omega}{\beta}\right)^2\right)\right] > 0$(2M)

$$= 38 + \left[20 - \frac{20 \times \pi^2}{2 \times (2.618)^2}\right]$$

$\rho_{c\,min} = 43.6\ which\ is\ > 0; (positive)$(1M)

Thus undercutting will not occur.

5 **An automobile single plate clutch consists of two pairs of contacting surfaces. The inner and outer radii of friction are 120 mm and 250 mm respectively. The coefficient of friction is 0.25 and the total axial force is 15 kN. Calculate the power transmitting capacity of the clutch plate at 500 rpm using: (i) Uniform wear theory and, (ii) Uniform pressure theory.(13M)(May/June 2013)**BTL5

Answer: Page: 5.87 – Dr.A.Baskar

i) Uniform wear theory:

$Mean\ radius, r_m = \frac{r_{min}+r_{max}}{2} = 0.185\ m$(2M)

$Torque\ transmitted, M_t = 2\mu Q r_m = 1387.5\ N - m$(2M)

$Power\ transmitted, P = \frac{2\pi n M_t}{60} = 72649\ Watts$(2M)

ii) Uniform pressure theory:

$Mean\ radius, r_m = \frac{2}{3}\left[\frac{r_{max}^3 - r_{min}^3}{r_{max}^2 - r_{min}^2}\right] = 0.1926\ m$(3M)

$Torque\ transmitted, M_t = 2\mu Q r_m = 1444.59\ N - m$(2M)

$Power\ transmitted, P = \frac{2\pi n M_t}{60} = 75639\ Watts$(2M)

PART * C

1 **A multi plate clutch with both sides effective transmits 30 kW at 360 rpm. Inner and outer radii of the clutch discs are 100 mm and 200 mm respectively. The effective coefficient of friction is 0.25. An axial load of 600 N is applied. Assuming uniform wear conditions, find the number of discs required and the maximum intensity of pressure developed. (15M)(May/June 2016)**BTL5

Answer: Page: 5.98 – Dr.A.Baskar

Torque, M_t: (4M)

$$Mean\ radius, r_m = \frac{r_{min} + r_{max}}{2} = 0.15\ m$$

$$Torque\ transmitted, M_t = \frac{60 \times Power\ in\ watts}{2\pi n} = 795.77\ N - m$$

Design torque, [M$_t$]:

[M$_t$] = M$_t$ = 795.77 N-m (assumed) (2M)

Clutch shaft diameter, d – not asked for.

Allowable pressure, P$_a$:(3M)

$$P_a = \frac{Q}{2\pi n \times r_{min} \times (r_{max} - r_{min})} = 9549.3\ N/m^2$$

Torque transmitted per pair of friction surface, [M$_t$]$_1$:(2M)

$$[M_t]_1 = 2\mu Q r_m = 22.5\ N - m$$

Number of pairs of friction surfaces, i:(2M)

$$i = \frac{[M_t]}{[M_t]_1} = 36\ pairs\ of\ surfaces$$

Number of plates = Number of friction surfaces + 1 = 37. (2M)

2 **The displacement function of a cam follower mechanism is given by y(θ) = 100(1-cosθ) mm; 0≤θ≤2π, where y is the follower displacement and θ is the cam rotation. The cam speed is 1000 rpm. The spring constant is 20 N/mm and the spring has an initial compression of 10 mm, when the roller follower is int its lowest position. The weight of the mass to be moved including the follower is 10 N, length of the follower outside the guide A = 40 mm, length of the guide B = 100 mm, R$_b$ = 50 mm, R$_r$ = 10 mm and the coefficient of friction between the guide and the follower = 0.05. Compute normal force and the cam shaft torque when the cam has rotated 60°. (15M) (Nov/Dec 2011)**BTL4

Answer: Page: 5.50 – Dr.A.Baskar

$$Angular\ velocity\ of\ cam, \omega = \frac{2\pi N}{60} = 104.72\ rad/s \text{(2M)}$$

$$Velocity, v = \frac{dy}{dt} = \frac{dy}{d\theta}.\frac{d\theta}{dt} = \frac{dy}{d\theta}\omega \text{(4M)}$$

$$v = 100\omega.sin\theta$$

$$\tan\alpha = \frac{\frac{dy}{d\theta}}{R_p + y\theta} \text{(3M)}$$

$$\alpha = 38.212°$$

Normal force, P$_n$;(4M)

$$P = Spring\ stiffness \times total\ compression = 1200\ N$$

$$P_n = \frac{P}{\cos\alpha - \mu\left(\frac{2A+B}{B}\right).\sin\alpha} = 1644\ N$$

Cam shaft torque, M$_t$:(2M)

$$M_t = \frac{P.v}{\omega} = 103.93\ N - m$$

3 **A multi plate clutch steel on bronze is to transmit 6 kW power at 750 rpm. The inner radius of contact surface is 4 cm and outer radius is 7 cm. The clutch plates operate in oil, so the coefficient of friction is 0.1. The average pressure is 0.5 N/mm2. Determine (i) the total number of steel and bronze friction discs, (ii) actual axial force required, (iii) actual average**

pressure, (iv) actual maximum pressure.(15M)(Nov/Dec 2016)BTL5

Answer: Page: 5.104 – Dr.A.Baskar

Torque transmitted: (2M)

$$Mean\ radius, r_m = \frac{r_{min} + r_{max}}{2} = 0.055$$

$$Torque\ transmitted, M_t = \frac{60 \times Power\ in\ watts}{2\pi n} = 76.39\ N - m$$

Design torque, [M$_t$]:(2M)

[M$_t$] = M$_t$ = 76.39 N-m (assumed)

Clutch shaft diameter, d – not asked for.

Average pressure, P_{av} = 0.35 N/mm^2

Torque transmitted per pair of friction surface, [M$_t$]$_1$:(2M)

$$[M_t]_1 = 2\mu\pi \left[P_{av}\left(\frac{r_{min} + r_{max}}{2}\right)\right](r_{max} + r_{min})r_m = 19.96\ N - m$$

Number of pairs of friction surfaces, i:(3M)

$$i = \frac{[M_t]}{[M_t]_1} = 4\ pairs\ of\ surfaces$$

Number of plates = Number of friction surfaces + 1 = 5.

Actual average pressure, σ:(2M)

$$\sigma = \frac{[M_t]}{2\pi \times 4i \times b \times \mu(r_m)^2} = 334927\ N/m^2$$

Axial force required:(2M)

$$Q = 2\pi \left[P_{av}\left(\frac{r_{min} + r_{max}}{2}\right)\right](r_{max} + r_{min}) = 3472\ N$$

Actual maximum pressure, P$_a$:(2M)

$$P_a . r_{min} = P_{min} . r_{max} = P_{av}\left(\frac{r_{min} + r_{max}}{2}\right)$$

$$P_a = 453750\ N/m^2$$

ME8691 COMPUTER AIDED DESIGN AND MANUFACTURING

L T P C
3 0 0 3

OBJECTIVES:

- To provide an overview of how computers are being used in mechanical componentdesign
- To understand the application of computers in various aspects of Manufacturing viz., Design, Proper planning, Manufacturing cost, Layout & Material Handling system.

UNITI INTRODUCTION 9

Product cycle- Design process- sequential and concurrent engineering- Computer aided design – CAD system architecture- Computer graphics – co-ordinate systems- 2D and 3D transformations- homogeneous coordinates - Line drawing -Clipping- viewing transformation-Brief introduction to CAD and CAM – Manufacturing Planning, Manufacturing control- Introduction to CAD/CAM – CAD/CAM concepts —Types of production - Manufacturing models and Metrics – Mathematical models of Production Performance

UNITII GEOMETRIC MODELING 9

Representation of curves- Hermite curve- Bezier curve- B-spline curves-rational curves-Techniques for surface modeling – surface patch- Coons and bicubic patches- Bezier and B-spline surfaces. Solid modeling techniques- CSG andB-rep

UNITIII CAD STANDARDS 9

Standards for computer graphics- Graphical Kernel System (GKS) - standards for exchange images- Open Graphics Library (OpenGL) - Data exchange standards - IGES, STEP, CALS etc. - communication standards.

UNITIV FUNDAMENTAL OF CNC ANDPART PROGRAMING 9

Introduction to NC systems and CNC - Machine axis and Co-ordinate system- CNC machine tools- Principle of operation CNC- Construction features including structure- Drives and CNC controllers- 2D and 3D machining on CNC- Introduction of Part Programming, types - Detailed Manual part programming on Lathe & Milling machines using G codes and M codes- Cutting Cycles, Loops, Sub program and Macros- Introduction of CAM package.

UNITV CELLULAR MANUFACTURING ANDFLEXIBLEMANUFACTURINGSYSTEM(FMS) 9

Group Technology(GT),Part Families–Parts Classification and coding–Simple Problems in Opitz Part Coding system–Production flow Analysis–Cellular Manufacturing–Composite part concept–Types of Flexibility - FMS – FMS Components – FMS Application & Benefits – FMS Planning and Control– Quantitative analysis in FMS

Upon the completion of this course the students will be able to

CO1	Explain the 2D and 3D transformations, clipping algorithm, Manufacturing models and Metrics
CO2	Explain the fundamentals of parametric curves, surfaces and Solids
CO3	Summarize the different types of Standard systems used in CAD
CO4	Apply NC & CNC programming concepts to develop part programme for Lathe & Milling Machines
CO5	Summarize the different types of techniques used in Cellular Manufacturing and FMS

TEXT BOOKS:

1. Ibrahim Zeid “Mastering CAD CAM” Tata McGraw-HillPublishingCo.2007
2. Mikell.P.Groover “Automation, Production Systems and Computer Integrated Manufacturing”, Prentice Hall of India,2008.
3. Radhakrishnan P, SubramanyanS.andRaju V., “CAD/CAM/CIM”, 2nd Edition, New Age International (P) Ltd, NewDelhi,2000.

REFERENCES:

1. Chris McMahon and Jimmie Browne “CAD/CAM Principles", "Practice and Manufacturing management “ Second Edition, Pearson Education,1999.
2. Donald Hearn and M. Pauline Baker “Computer Graphics”’. Prentice Hall,Inc,1992.
3. Foley, Wan Dam, Feiner and Hughes - "Computer graphics principles & practice" Pearson Education-2003
4. William M Neumann and Robert F.Sproul “Principles of Computer Graphics”, McGraw Hill Book Co. Singapore,1989.

REGULATION :2017 **ACADEMIC YEAR : 2019-2020**

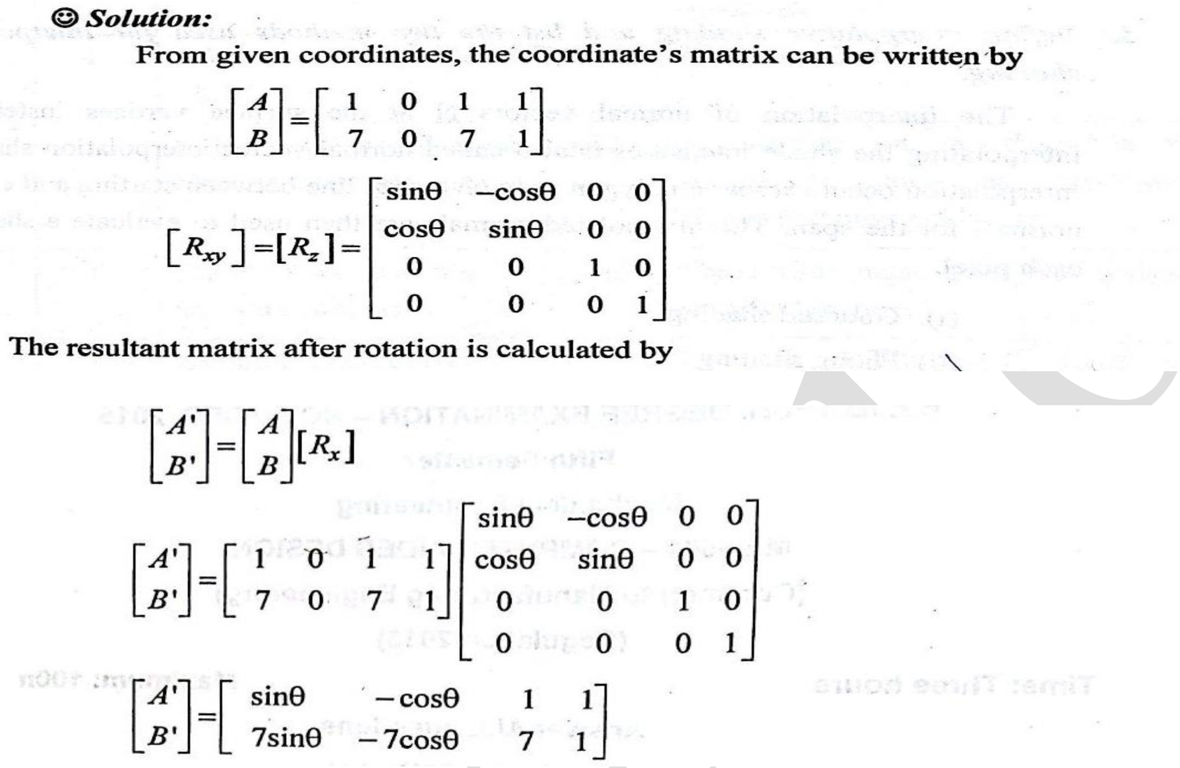
Subject Code:ME8691 **Year/Semester: III /06**
Subject Name: Computer Aided DesignAnd Manufacturing
Subject Handler: Mr.M.Kalaimani &Mr. S.Vignesh

UNIT I – INTRODUCTION

Product cycle- Design process- sequential and concurrent engineering- Computer aided design – CAD system architecture- Computer graphics – co-ordinate systems- 2D and 3D transformations- homogeneous coordinates - Line drawing -Clipping- viewing transformation-Brief introduction to CAD and CAM – Manufacturing Planning, Manufacturing control- Introduction to CAD/CAM –CAD/CAM concepts —Types of production - Manufacturing models and Metrics – Mathematical models of Production Performance

PART * A

Q.No.	Questions
1	**Mention any four applications of computer aided design in mechanical engineering. (or) What is CAD? (or) What are the steps involved in CAD? BTL1- Nov/Dec 15** Computer Aided Design (CAD) is the technology concerned with the use if computer systems to assign the creation, modification, analysis and optimization of a design. CAD process is the subset of the design process. The application of computer aided design in mechanical engineering cover all type of manufacturing operation such as milling, turning, Wire cut EDM, punching, etc. (a) Design engineering. (b) Computer graphics. (c) Geometric modelling.
2	**List the type of 2D geometric transformation (or) Define transformation?BTL1Nov/Dec 15** a) Windowing and viewing transformation b) Clipping transformation c) Reflection transformation d) Zooming transformation. e) Panning transformation. f) Transmitting information on a network. g) Graphics libraries. Transformation converts the geometry from one coordinate system to another coordinate system. By means of transformation, the images can be enlarged in size or reduced, rotate or moved on the screen.
3	**Generate the conical surface obtained by rotation of the line segment AB around the Z-axis with A=(1,0,1) and B=(7,0,7). BTL3 - Nov/Dec 15**

	 ☺ ***Solution:*** **From given coordinates, the coordinate's matrix can be written by** $\begin{bmatrix}A\\B\end{bmatrix}=\begin{bmatrix}1&0&1&1\\7&0&7&1\end{bmatrix}$ $[R_{xy}]=[R_z]=\begin{bmatrix}\sin\theta&-\cos\theta&0&0\\\cos\theta&\sin\theta&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}$ **The resultant matrix after rotation is calculated by** $\begin{bmatrix}A'\\B'\end{bmatrix}=\begin{bmatrix}A\\B\end{bmatrix}[R_x]$ $\begin{bmatrix}A'\\B'\end{bmatrix}=\begin{bmatrix}1&0&1&1\\7&0&7&1\end{bmatrix}\begin{bmatrix}\sin\theta&-\cos\theta&0&0\\\cos\theta&\sin\theta&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}$ $\begin{bmatrix}A'\\B'\end{bmatrix}=\begin{bmatrix}\sin\theta&-\cos\theta&1&1\\7\sin\theta&-7\cos\theta&7&1\end{bmatrix}$
4	**List the various stages in life cycle of a product. May/June'16 (or) What are the types of product process? BTL1** Product cycle is the process of managing the entire life cycle of a product from starting, through design and manufacture, to repair and removal of manufactured products. This product undergoes the following two process. (a) Design process. (b) Manufacturing process.
5	**What is the design process? Mention the steps involved in shigelys model for the design process. (or) Mention some design models included in design process? BTL1, May/June'16** Product design is the process of creating a new product to be sold by a business to its customers. It is essentially the efficient and effective generation and development of ideas through a process that leads to new products. (a) Shighely model. (b) Ohsuga model. (c) Earle model. (d) Paul bietz model.
6	**What is homogeneous coordinate? Nov/Dec'16, BTL1**

Homogeneous coordinates are ubiquitous in computer graphics because they allow common vector operations such as translation, rotation, scaling and perspective projection to be represented as a matrix by which the vector is multiplied. P'=P×M_1+M_2

(a) For translation:

$$P' = P \times \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} + \begin{bmatrix} Tx \\ Ty \end{bmatrix}$$

Where M_1 = identity matrix or unit matrix which is denoted by T

M_2 = Translation matrix.

(b) For rotation:

$$P' = P \times \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

Where M_1 = rotational matrix which is denoted by R.

M_2 = 0

7 **What do you mean by synthesis of design? BTL1, Nov/Dec'16**

Design Synthesis is the process of taken the functional architecture developed in the Functional Analysis and Allocation step and decomposing those functions into a Physical Architecture (a set of product, system, and/or software elements) that satisfy system required functions.

The following process are involved in synthesis of design:

(a) Design need.
(b) Design specification.
(c) Feasibility study with collecting design information.

8 **State any two benefits of CAD. BTL1 May/June'17**

a) Easy editing: Drawing editing and modifications can be easily and quickly done.
b) Copies of the same drawing can be duplicated without sacrificing image quality.
c) High quality: Created drawings are more neat, precise and sharp.
d) Drawings can be plotted quickly in different scales.
e) Information about length, area, perimeter, volume, mass are calculated easily.
f) Compact storage: Drawings can be stored in CDs, DVDs. Or hard disks.
g) Three dimensional can be seen from any view point for better visualization.

9 **Mention some advantages of computer graphics?BTL2**

a) Concurrent Engineering is a methodology of reconstructing the product development activity in a manufacturing organization using a cross functional team approach.
b) Product responsibility lie on the team of multi-disciplinary group.
c) Integration of design, process planning and production will be achieved.
d) Most of the modification changes are carried out in the planning stage itself.
e) Rapid prototyping and frequently review of design and development process.

10 **Mention some advantages of computer graphics? BTL1**

	a) Various views of the object such as orthographic, isometric, axonometric or perspective projections can be easily created. b) Accurate drawing can be made. c) Sectional drawings can be easily created. d) Modification of geometric model of objects is easy. e) The object drawings can be denoted by its geometric model in three dimensions. Ie.,X, Y and Z coordinates.
11	**List out the types of computer graphics? And write its applications? BTL2** **Types:** a) Passive computer graphics. b) Interactive computer graphics. **Application:** a) Paint programs: it allows rough free hand sketching. It is stored as bitmaps and easily can be edited. b) Design program: it supports more than the paint program particularly for drawing curved lines. The images are usually stored vector based formats. And it is called as draw program. c) Presentation graphics software: bar chart, pie chart, graphics and other types of images for slide show and reports are created. The charts based data imported from spread sheet application. d) Cad software: it enables architects and engineer to draft design.
12	**Define modelling and viewing? BTL1** a) Modelling is the process of creating an object in the computer by using the basic primitives such as points, lines, arc, circle, edges, area, surface, and volumes. b) Viewing refers to looking of the model in various angles, zooming, orthographic and isometric.
13	**Define clipping and write its applications? BLT1** **Clipping** is the process of determining the visible portion of a drawing lying within a window and discarding the rest. a) Identify the visible surface in three dimensional views. b) Displaying multi window environment. c) Antialiasing line segments or object boundaries. d) Creating objects using solid modeling procedures. e) Drawing and painting operation.
14	**State some advantages and disadvantages of DDA algorithm. BLT1** **Advantages:** a) It is the simplest algorithm and it does not need special skill for implementation. b) It is far method to calculate pixel position than the direst use of straight line equation which is given by y= mx + c. it eliminates the multiplication of necessary increments

	applied in x or y directions to find the pixel positions along the line path. **Disadvantage:** a) Floating point arithmetic in DDA algorithms still time consuming. b) The algorithm is oriented dependent. Therefore, end point accuracy is poor.
15	**Define zooming and scaling? BLT1** **Zooming** transformation is a combination of scaling, translation and clipping transformation processes. Zooming = scaling + Translation + clipping. **Scaling** is the transformation applied to change the scale of an entity. It is done by increasing the distance between points of the drawing.
16	**What is concentration transformation and what is meant by working station transformation? BLT1** a) It is a single transformation by combining many transformations linked one after the other to perform the final task. b) The transformation which maps the normalized device coordinates to physical devices coordinates is called workstation transformation.
17	**What is concurrent Engineering? May/June'17 write some characteristics of concurrent engineering?BLT1** Concurrent engineering is a methodology of restricting the product development activity in a manufacturing organization using a cross functional team approach. a) Product responsibilities lies on the team of multi-disciplinary group. b) Integration of design, process planning and production will be achieved. c) Product lead time will be less because cross functional activities are started simultaneously. d) Most of the modification charges are carried out in the planning stages itself.
	PART * B
1	**Rotate the rectangle (0,0), (2,0), (2,2), (0,2) shown in fig.1, 30º counter clockwise about its centroid andthe new coordinate of the rectangle. BTL5 - N/D'15 (13 marks)**

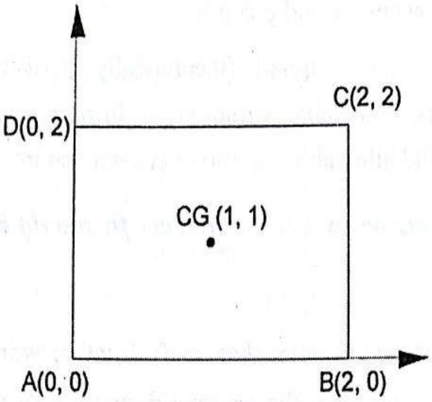


Figure Q 1

☺ ***Solution:***

From given coordinates, the coordinate's matrix can be written by

$$\begin{bmatrix} A \\ B \\ C \\ D \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 \\ 2 & 0 & 1 \\ 2 & 2 & 1 \\ 0 & 2 & 1 \end{bmatrix}$$

The centroid of the given rectangle lies at (1, 1)

The rotation of the rectangle about centroid can be performed in three steps as follows.

(a) First, the rectangle is translated about centroid to the origin for (−1, −1).

(b) Second, the rectangle is rotated to 30^o counterclockwise ($\theta = 30^o$).

(c) Last, the rotated rectangle is again translated about centroid to the initial position (1, 1).

Step 1: Translation to point (1, 1)

. $T_x = -1$ and $T_y = -1$

So, the translation matrix becomes,

$$T_{(-1,-1)} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -1 & -1 & 1 \end{bmatrix}$$

Step 2: Rotation by 30° in counterclockwise direction

$$\text{Rotation matrix, } R = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R_{30^o} = \begin{bmatrix} \cos 30^o & \sin 30^o & 0 \\ -\sin 30^o & \cos 30^o & 0 \\ 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0.866 & 0.5 & 0 \\ -0.5 & 0.866 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Step 3: Translation to point (1, 1)(Back-translation)

$T_x = 1$ and $T_y = 1$

So, the back-translation matrix becomes,

$$T_{(1,1)} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

The concatenated transformation matrix is calculated by

$$T_{(-1,-1)}.R_{30^o}.T_{(1,1)} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -1 & -1 & 1 \end{bmatrix} . \begin{bmatrix} 0.866 & 0.5 & 0 \\ -0.5 & 0.866 & 0 \\ 0 & 0 & 1 \end{bmatrix} . \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 1\times 0.866 + 0\times(-0.5) + 0\times 0 & 1\times 0.5 + 0\times 0.866 + 0\times 0 & 1\times 0 + 0\times 0 + 0\times 1 \\ 0\times 0.866 + 1\times(-0.5) + 0\times 0 & 0\times 0.5 + 1\times 0.866 + 0\times 0 & 0\times 0 + 1\times 0 + 0\times 1 \\ (-1)\times 0.866 + (-1)\times(-0.5) + 1\times 0 & (-1)\times 0.5 + (-1)\times 0.866 + 1\times 0 & (-1)\times 0 + (-1)\times 0 + 1\times 1 \end{bmatrix}$$

$$. \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} 0.866 & 0.5 & 0 \\ -0.5 & 0.866 & 0 \\ -0.366 & -1.366 & 1 \end{bmatrix} . \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 1 & 1 & 1 \end{bmatrix}$$

$$=\begin{bmatrix} 0.866\times1+0.5\times0+0\times1 & 0.866\times0+0.5\times1+0\times1 & 0.866\times0+0.5\times0+0\times1 \\ (-0.5)\times1+0.866\times0+0\times1 & (-0.5)\times0+0.866\times1+0\times1 & (-0.5)\times0+0.866\times0+0\times1 \\ (-0.366)\times1+(-1.366)\times0+1\times1 & (-0.366)\times0+(-1.366)\times1+1\times1 & (-0.366)\times0+(-1.366)\times0+1\times1 \end{bmatrix}$$

$$=\begin{bmatrix} 0.866 & 0.5 & 0 \\ -0.5 & 0.866 & 0 \\ 0.634 & -0.366 & 1 \end{bmatrix}$$

Now, the transformed matrix is calculated by

$$\begin{bmatrix} A' \\ B' \\ C' \end{bmatrix} = \begin{bmatrix} A \\ B \\ C \end{bmatrix} [\text{Overall matrix}]$$

$$\begin{bmatrix} A' \\ B' \\ C' \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 \\ 2 & 0 & 1 \\ 2 & 2 & 1 \\ 0 & 2 & 1 \end{bmatrix} . \begin{bmatrix} 0.866 & 0.5 & 0 \\ -0.5 & 0.866 & 0 \\ 0.634 & -0.366 & 1 \end{bmatrix}$$

$$=\begin{bmatrix} 0\times0.866+0\times(-0.5)+1\times0.634 & 0\times0.5+0\times0.866+1\times(-0.366) & 0\times0+0\times0+1\times1 \\ 2\times0.866+0\times(-0.5)+1\times0.634 & 2\times0.5+0\times0.866+1\times(-0.366) & 2\times0+0\times0+1\times1 \\ 2\times0.866+2\times(-0.5)+1\times0.634 & 2\times0.5+2\times0.866+1\times(-0.366) & 2\times0+2\times0+1\times1 \\ 0\times0.866+2\times(-0.5)+1\times0.634 & 0\times0.5+2\times0.866+1\times(-0.366) & 0\times0+2\times0+1\times1 \end{bmatrix}$$

$$=\begin{bmatrix} 0.634 & -0.366 & 1 \\ 2.366 & 0.634 & 1 \\ 1.366 & 2.366 & 1 \\ -0.366 & 1.366 & 1 \end{bmatrix}$$

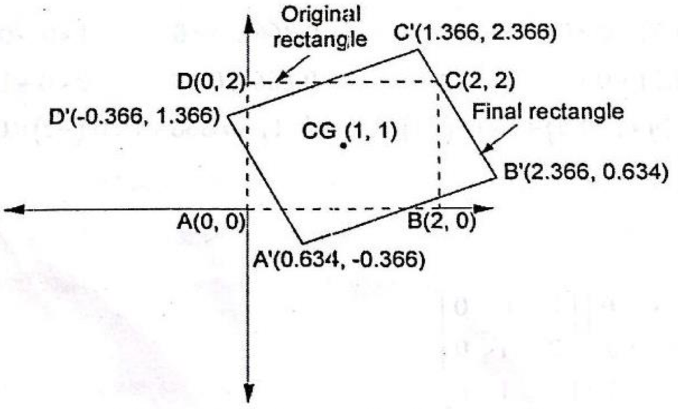


Figure Q2 Rectangle after rotation

A' (0.634, -0.366), B' (2.366, 0.634), C' (1.366, 2.366) and D' (-0.366, 1.366) - Ans

2 **Given the triangle, described by the homogeneous points matrix below, scale it by a factor**

3/4, keeping the centroid in the same location. Use (1) separate matrix method and (2) condensed matrix for transformation. BTL5 - N/D’15, (13 marks)

$$[P]=\begin{bmatrix}2 & 2 & 0 & 1\\ 2 & 5 & 0 & 1\\ 5 & 5 & 0 & 1\end{bmatrix}$$

☺ ***Solution:***

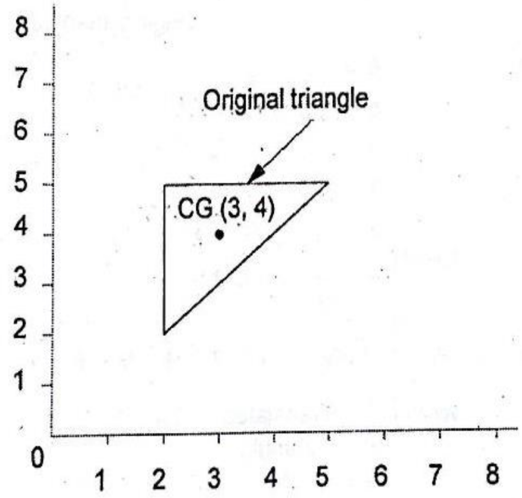


Figure Q3

The centroid of the triangle is at,

$x = (2+2+5)/3 = 3$, $y = (2+5+5)/3 = 4$ and $z = (0+0+0)/3 = 0$ or the centroid is C (3, 4, 0).

(i) Separate matrix method:

The scaling of the triangle about centroid can be performed in three steps as follows.

(a) First, the triangle is translated about centroid to the origin for (–3, –4).

$$\text{Translation matrix, } T_{(-3,-4,0)}=\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 1 & 0\\ -3 & -4 & 0 & 1\end{bmatrix}$$

After translation, the given homogeneous points matrix becomes

$$[P_1]=[P]\left[T_{(-3,-4,0)}\right]$$

$$[P_1]=\begin{bmatrix}2 & 2 & 0 & 1\\ 2 & 5 & 0 & 1\\ 5 & 5 & 0 & 1\end{bmatrix}.\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 1 & 0\\ -3 & -4 & 0 & 1\end{bmatrix}$$

$$=\begin{bmatrix}-1 & -2 & 0 & 1\\ -1 & 1 & 0 & 1\\ 2 & 1 & 0 & 1\end{bmatrix}$$

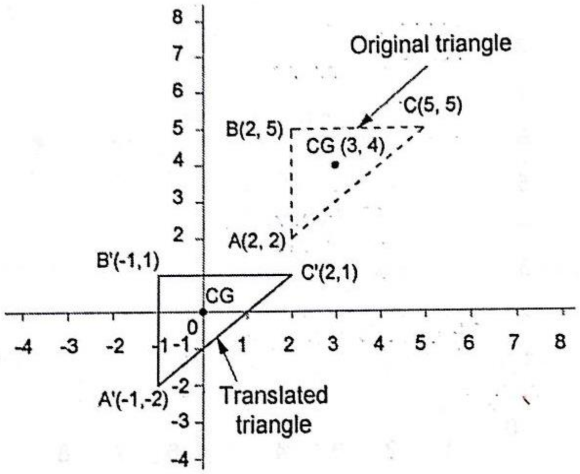


Figure Q4 Triangle after translation

(b) Second, the translated triangle is scaled to 3/4.

$$\text{Scaling matrix, } S_{(0.75,0.75,0.75)}=\begin{bmatrix}0.75 & 0 & 0 & 0\\ 0 & 0.75 & 0 & 0\\ 0 & 0 & 0.75 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}$$

After scaling, the translated triangle matrix becomes

$$[P_2]=[P_1]\left[S_{(0.75,0.75,0.75)}\right]$$

$$[P_2]=\begin{bmatrix}-1 & -2 & 0 & 1\\ -1 & 1 & 0 & 1\\ 2 & 1 & 0 & 1\end{bmatrix}.\begin{bmatrix}0.75 & 0 & 0 & 0\\ 0 & 0.75 & 0 & 0\\ 0 & 0 & 0.75 & 0\\ 0 & 0 & 0 & 1\end{bmatrix}$$

$$=\begin{bmatrix}-0.75 & -1.5 & 0 & 1\\ -0.75 & 0.75 & 0 & 1\\ 1.5 & 0.75 & 0 & 1\end{bmatrix}$$

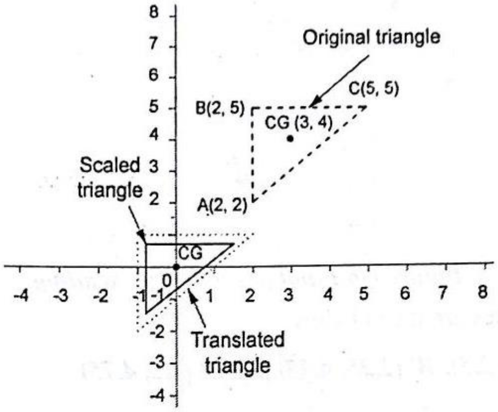


Figure Q5 Triangle after scalling

(c) Last, the scaled triangle is back-translated about centroid to the initial position (3, 4).

$$\text{Translation matrix, } T_{(3,4,0)}=\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 1 & 0\\ 3 & 4 & 0 & 1\end{bmatrix}$$

After translation, the scaled triangle matrix becomes

$$[P_3]=[P_2]\left[T_{(3,4,0)}\right]$$

$$=\begin{bmatrix}-0.75 & -1.5 & 0 & 1\\ -0.75 & 0.75 & 0 & 1\\ 1.5 & 0.75 & 0 & 1\end{bmatrix}.\begin{bmatrix}1 & 0 & 0 & 0\\ 0 & 1 & 0 & 0\\ 0 & 0 & 1 & 0\\ 3 & 4 & 0 & 1\end{bmatrix}$$

$$=\begin{bmatrix}2.25 & 2.5 & 0 & 1\\ 2.25 & 4.75 & 0 & 1\\ 4.5 & 4.75 & 0 & 1\end{bmatrix}$$

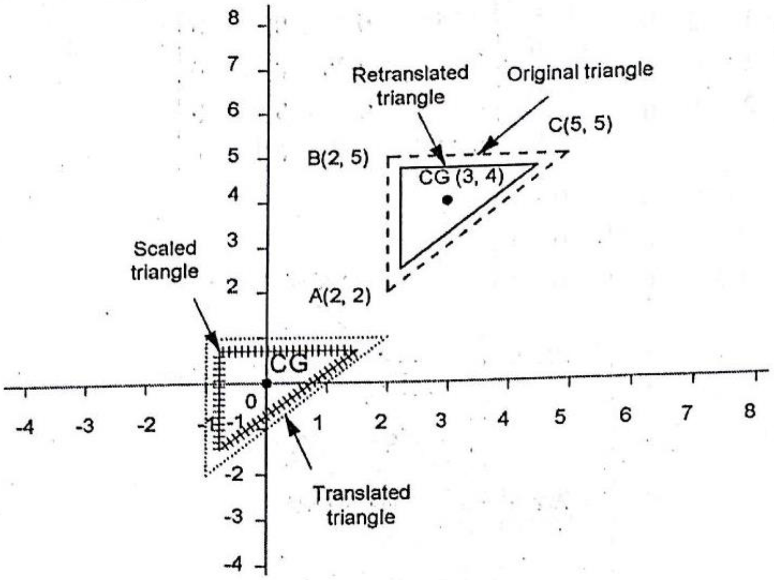


Figure Q6 Final position after scalling

New coordinates are given below.

A'' (2.25, 2.5), B' (2.25, 4.75) and ***C' (4.5, 4.75)*** **Ans.** ☜

(ii) Condensed matrix method:

The concatenated transformation matrix or condensed matrix is calculated by

$$T_{(-3,-4,0)}.S_{(0.75,0.75,0.75)}.T_{(3,4,0)} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -3 & -4 & 0 & 1 \end{bmatrix} . \begin{bmatrix} 0.75 & 0 & 0 & 0 \\ 0 & 0.75 & 0 & 0 \\ 0 & 0 & 0.75 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} . \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 3 & 4 & 0 & 1 \end{bmatrix}$$

Multiplying first two matrices, the above matrix becomes,

$$= \begin{bmatrix} 0.75 & 0 & 0 & 0 \\ 0 & 0.75 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ -2.25 & -3 & 0 & 1 \end{bmatrix} . \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 3 & 4 & 0 & 1 \end{bmatrix}$$

$$=\begin{bmatrix}0.75 & 0 & 0 & 0\\ 0 & 0.75 & 0 & 0\\ 0 & 0 & 0 & 0\\ 0.75 & 1 & 0 & 1\end{bmatrix}$$

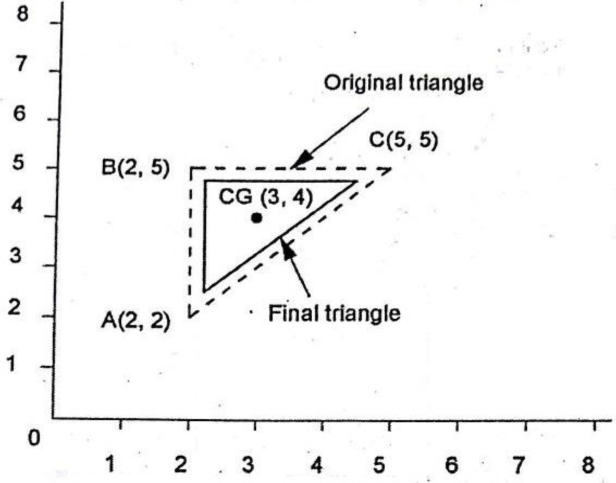


Figure Q7

Now, the transformed matrix is calculated by

$$\left[P^{'}\right]=[P][\text{Concatenated matrix}]$$

$$=\begin{bmatrix}2 & 2 & 0 & 1\\ 2 & 5 & 0 & 1\\ 5 & 5 & 0 & 1\end{bmatrix}.\begin{bmatrix}0.75 & 0 & 0 & 0\\ 0 & 0.75 & 0 & 0\\ 0 & 0 & 0 & 0\\ 0.75 & 1 & 0 & 1\end{bmatrix}$$

$$=\begin{bmatrix}2.25 & 2.5 & 0 & 1\\ 2.25 & 4.75 & 0 & 1\\ 4.5 & 4.75 & 0 & 1\end{bmatrix}$$

New coordinates are given below.

A'' (2.25, 2.5), B' (2.25, 4.75) and ***C' (4.5, 4.75)*** **Ans.**

3 **Write short notes on concurrent engineering. BTL5 - N/D’15 (8 marks)**

In the conventional manufacturing method both design and manufacturing are separated. Because of this quality may be lost and design modifications cannot be possible at the last stage of production.

To achieve this in the product planning stage itself a cooperation work between design and manufacturing and other specialists has to be made. It is known as concurrent engineering or simultaneous engineering or parallel engineering.

For example, planning activity is made as concurrent shown in fig.Therefore an intensive team work between product development, production planning and manufacturing team is essential for effective implementation of concurrent engineering in an organisation figure shows:

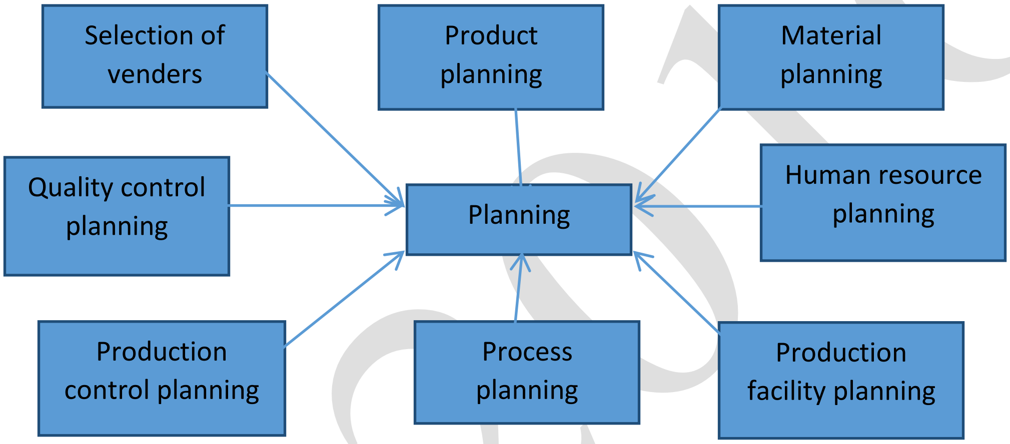


Figure 1.11 Concurrent workflow in the planning stage

4

Rotate the rectangle shown in Fig 2, 30º counter clockwise about the line EF and find the new coordinates of the rectangle. BTL5 - N/D'15. (13 marks)

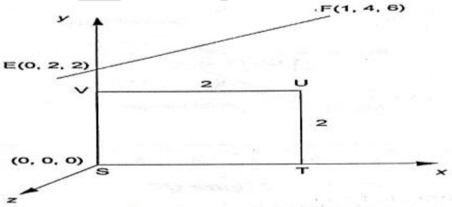


Figure Q8

☺ *Solution:*

From given coordinates, the coordinate's matrix can be written by

$$[P]=\begin{bmatrix} S \\ T \\ U \\ V \end{bmatrix}=\begin{bmatrix} 0 & 0 & 0 & 1 \\ 2 & 0 & 0 & 1 \\ 2 & 2 & 0 & 1 \\ 0 & 2 & 0 & 1 \end{bmatrix}$$

The given rectangle can be rotated about the line EF for 30° counter in seven steps as follows.

(i) First, the line is translated about origin for (0, —2, —2).

(ii) Rotate the axis so that it will lie in yz-plane.

(iii) Rotate the line so that it will coincide with z-axis

(iv) Rotate the rectangle to 30° counterclockwise ($\theta = 30°$).

(v) Back-rotate the line about z-axis so that it will come to original position.

(vi) Back-rotate the axis about yz-plane so that it will come to original position.

(vii) First, the line is back-translated about the origin for (0, 2, 2).

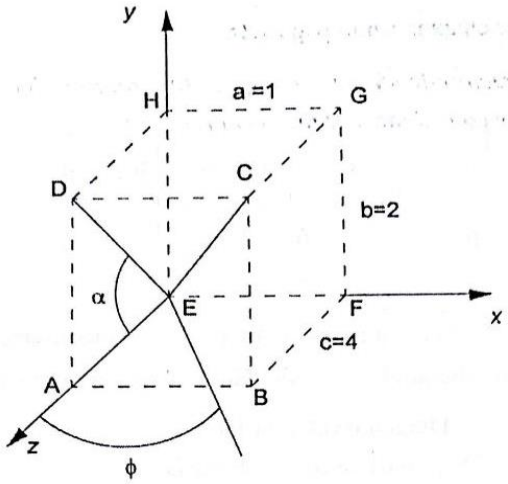


Figure Q9

Step 1:

First, the line is translated about the origin for (0, –2, –2). So, the translation matrix of line EF can be written as

$$T_{(0,-2,-2)} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -2 & -2 & 1 \end{bmatrix}$$

Step 2:

Next, the axis is rotated at an angle of α counter clockwise to lie in yz-plane. The angle α is calculated using trigonometric relations of cuboid. So, only rectangular face of ADFE is considered.

$$\cos\alpha = \frac{\text{Adjacent side}}{\text{Diagonal value}}$$

$$\cos\alpha = \frac{AE}{DE}$$

In cuboid, AE = c = 4, AD = 2 and DE = $\sqrt{b^2 + c^2} = \sqrt{2^2 + 4^2} = 4.472$

$$\therefore \quad \cos\alpha = \frac{4}{4.472} = 0.894$$

and $\alpha = 26.57^o$

similarly, $\sin\alpha = \frac{AD}{DE} = \frac{2}{4.472} = 0.447$

$$R_{26.57^o} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\alpha & \sin\alpha & 0 \\ 0 & -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0.894 & 0.447 & 0 \\ 0 & -0.447 & 0.894 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Step 3:

Then, the line is rotated at an angle of ϕ counter clockwise about y-axis to coincide with z-axis. Similarly, the angle ϕ is calculated using trigonometric relations of cuboid.

$$\cos\phi = \frac{\text{Diagonal value of DE}}{\text{Diagonal length of cuboid}, L}$$

In cuboid, AB = a = 1, DE = $\sqrt{b^2 + c^2} = \sqrt{2^2 + 4^2} = 4.472$ and

$$L = \sqrt{a^2 + b^2 + c^2} = \sqrt{1^2 + 2^2 + 4^2} = 4.583$$

$$\therefore \quad \cos\phi = \frac{4.472}{4.583} = 0.976$$

and $\phi = 12.58^o$

similarly, $\sin\phi = \frac{AB}{\text{Diagonal length of cuboid}, L} = \frac{1}{4.583} = 0.218$

By considering xz plane, the matrix can be written as

$$R_{12.58^o} = \begin{bmatrix} \cos\phi & 0 & -\sin\phi & 0 \\ 0 & 1 & 0 & 0 \\ \sin\phi & 0 & \cos\phi & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0.976 & 0 & -0.218 & 0 \\ 0 & 1 & 0 & 0 \\ 0.218 & 0 & 0.976 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Step 4:

Next, the rectangle is rotated 30° counter clockwise about z axis.

$$R_{30^o} = \begin{bmatrix} \cos\theta & \sin\theta & 0 & 0 \\ -\sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0.866 & 0.5 & 0 & 0 \\ -0.5 & 0.866 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Step 5:

Next, the line is back-rotated at an angle of 12.58° clockwise ($\phi = -12.58^o$) about z-axis so that it will come to original position. Since, cos ($-\phi$) = cosϕ and sin($-\phi$) = $-$sin(ϕ),

$$R_{(-12.58^o)} = \begin{bmatrix} \cos(-\phi) & 0 & -\sin(-\phi) & 0 \\ 0 & 1 & 0 & 0 \\ \sin(-\phi) & 0 & \cos(-\phi) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0.976 & 0 & 0.218 & 0 \\ 0 & 1 & 0 & 0 \\ -0.218 & 0 & 0.976 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Step 6:

Next, the axis is back-rotated at an angle of 26.57° clockwise ($\phi = -26.57^o$) about yz-plane so that it will come to original position.

$$R_{-26.57^o} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(-\alpha) & \sin(-\alpha) & 0 \\ 0 & -\sin(-\alpha) & \cos(-\alpha) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0.894 & -0.447 & 0 \\ 0 & 0.447 & 0.894 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Step 7:

Last, the line is back-translated to initial position. So, the back-translation matrix of line EF can be written as

$$T_{(0,2,2)} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 2 & 2 & 1 \end{bmatrix}$$

Concatenated transformation matrix is calculated by

$$T_c = T_{(0,-2,-2)} . R_{26.57^o} . R_{12.58^o} . R_{30^o} . R_{(-12.58)^o} . R_{(-26.57^o)} . T_{(0,2,2)}$$

$$T_c = \begin{bmatrix} 0.9312 & 0.1634 & -0.3256 & 0 \\ -0.1743 & 0.9846 & -0.0044 & 0 \\ 0.3199 & 0.0609 & 0.9454 & 0 \\ -0.2919 & -0.0909 & 0.1179 & 1 \end{bmatrix}$$

The transformed matrix is calculated by

$$[P'] = [P][T_c] = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 2 & 0 & 0 & 1 \\ 2 & 2 & 0 & 1 \\ 0 & 2 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0.9312 & 0.1634 & -0.3256 & 0 \\ -0.1743 & 0.9846 & -0.0044 & 0 \\ 0.3199 & 0.0609 & 0.9454 & 0 \\ -0.2919 & -0.0909 & 0.1179 & 1 \end{bmatrix}$$

$$[P'] = \begin{bmatrix} -0.2913 & -0.0909 & 0.1179 & 1 \\ 1.5712 & 0.2359 & -0.5334 & 1 \\ 1.2226 & 2.2051 & -0.5421 & 1 \\ -0.6399 & 1.8783 & 0.1092 & 1 \end{bmatrix}$$

New coordinates are given below.

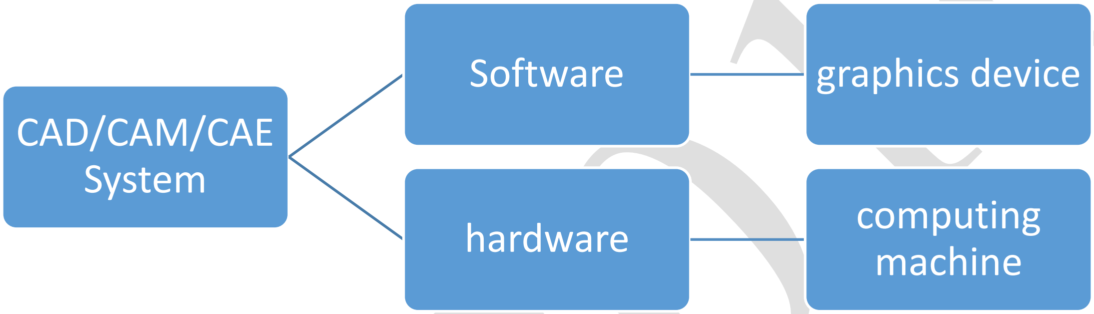
S′ (– 0.2913, – 0.0909, 0.1179), T′ (1.5712, 0.2359, – 0.5334), U′ (1.2226, 2.2051, – 0.5421) and ***V′ (–0.6399, 1.8783, 0.1092)*** **Ans.** ☜

5 **Compare and contrast sequential and concurrent Engineering with suitable examples? BTL4 M/J'17 (8 marks)**

S.No	Sequential Engineering	Concurrent Engineering
1	Sequential engineering is the term used to explain the method of production in a linear system. The various steps are done one after another, with all attention and resources focused on that single task.	Concurrent Engineering is the term used to explain the method of production in non-linear system. It is also called as parallel engineering.
2	Sequential engineering is a system by which a group within an organization works sequentially to create new products and services.	Concurrent engineering is a method by which several groups within an organization work simultaneously to create new products and services.
3	The sequential engineering is a linear product design process during which all stages of manufacturing operate in serial.	The concurrent engineering is a non-linear product design process during which all stages of manufacturing operate at the same time.
4	Both process and product design run in a serial and take place in the different time.	Both product and process design run in parallel and take place in the same time.
5	Process and product are not matched to attain optimal matching.	Process and product are coordinated to attain optimal matching of requirements for effective quality and delivery.
6	Decision making done by only group of experts.	Decision making involves full team involvement.

6 **Explain with block diagram, the cad process with suitable examples? BTL4 - M/J'17 (13 marks)**

- ➢ Two types of activities: Synthesis and analysis.
- ➢ Synthesis is largely qualitative and hard to capture on computers.
- ➢ Analysis can be greatly enhanced with computers.
- ➢ Once analysis is complete, design evaluation-rapid prototyping's are done.



CAD Hardware:

These are basically two types of devices that constitutes CAD hardware: (a) Input devices, (b). Output devices.

(a). Input Devices:

- ❖ These are the devices that we use for communicating with computer, and providing our input in the form of text and graphics.
- ❖ The text input is mainly provided through keyboard. For graphic input, there are several devices available and used according to the work environment.
- ❖ A briefly description of these devices are given.

(b). Mouse:

- ❖ This potentiometric device, which contains several variable resistors that send signals to the computer.
- ❖ The functions of a mouse include locating a point on the screen, sketching, dragging an object, entering values, accepting a software command, etc.
- ❖ Joystick and trackballs are analogous to a mouse device, and operate on the same principle.

(c). Digitizer:

- ❖ Digitizers are used to trace a sketch or other 2-D entities by moving cursor over a flat surface (which contains the sketch).
- ❖ The position of the cursor provides a feedback to the computer connected with the device.
- ❖ There are electrical wires embedded in orthogonal directions that receive a pass signals

between the device and the computer.

- The device is basically a free moving pen shaped stylus, connected to a tablet.

(d). Light pens:

- Lockheed's CAD/CAM software utilized this device to carry out the graphic input.
- A light pen looks like a pen and contains a photocell, which emits an electronics signal.
- When the pen is pointed at the monitor screen, it senses light, which is converted to signal.
- The signal is sent to another computer for determination of the exact location of the pen on the monitor screen.

(e). Touch sensitive screens:

- This device is embedded in the monitor screens, usually, in the form of an overlay.
- The screen senses the physical contact of the user.
- The new generation of the laptop computer is a good example of this device

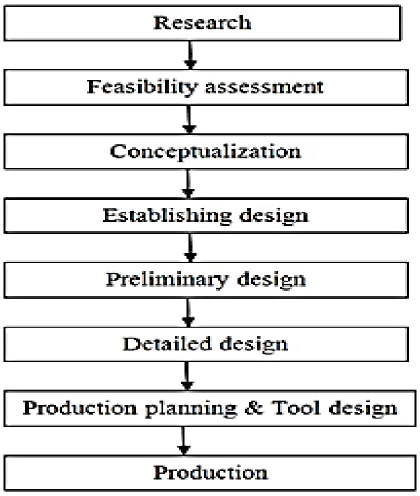
(f). Other graphic input devices:

- In additional to the devices described above, some CAD software will accept input via image scanners, which can copy a drawing or schematic with a camera and light beam assembly and convert it into a pictorial database.
- Resolution.
- Accuracy.
- Repeatability.
- Linearity.

(g). Output devices:

- After creating CAD modelling we often need a hard copy, using an output device plotters and printers are used for this purpose.
- A plotter is often used to produce large drawings and assemblies, whereas laser jet printer is adequate to provide a 3D view of a model.
- Most CAD software require a plotter for producing a shaded or a rendered view.

7 **Describe various stages of design process with an example. BTL4 - N/D'16 (8 marks)**



i.Recongination of Need: Identification of need of the product by market survey, research or consumer feedback form.

ii.Definition: The above needs the idea involves a through specification of the product to be designed.

iii. Synthesis and Analysis: Functionality and uniqueness of the product are all determined during synthesis.

iv. Analysis and Optimization: The components and sub systems are synthesized during optimization to offer optimized performance with in constraints imposed by designer.

v.Evaluation: The product qualities are measured agaist the standard and specifications set during definition phase.

vi. Presentation: Phase of this process is to present the design by name of drawings, Material specifications, assembly lists etc.

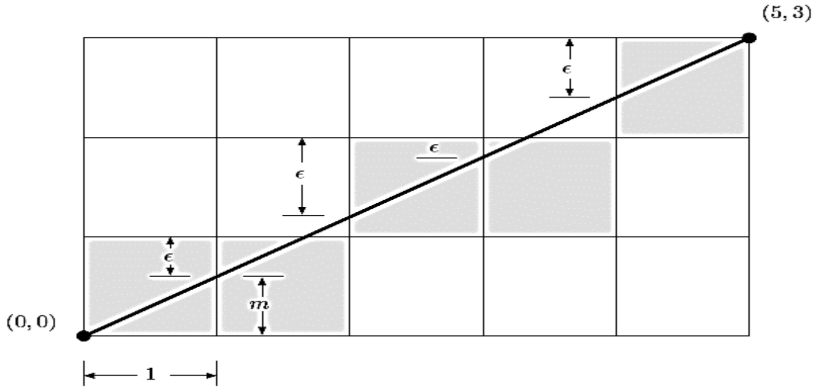
8 **Explain a line drawing algorithm.BTL5 N/D'16. (8 marks)**

Bresenham's Algorithm

Consider a line with initial point (x1, y1) and terminal point (x2, y2) in device space. If $\Delta x = x2-x1$and $\Delta y = y2 - y1$, we define the *driving axis* (*DA*) to be the x-axis if $|\Delta x|$ ε | $\Delta y|$, and the y-axis if $|\Delta y| > |\Delta x|$.Δ The *DA* is used as the "axis of control" for the algorithm and is the axis of maximum movement.

Within the main loop of the algorithm, the coordinate corresponding to the *DA* is incremented by one unit. The coordinate corresponding to the other axis (usually denoted the *passive axis* or *PA*) is only incremented as needed.

The best way to describe Bresenham's algorithm is to work through an example. Consider the following example, in which we wish to draw a line from (0, 0) to (5, 3) in device space.

	 Bresenham's algorithm begins with the point (0, 0) and "illuminates" that pixel. Since x is the *DA* in this example, it then increments the x coordinate by one. Rather than keeping track of the y coordinate (which increases by $m = \Delta y/\Delta x$, each time the x increases by one), the algorithm keeps an error bound ε at each stage, which represents the negative of the distance from the point where the line exits the pixel to the top edge of the pixel (see the figure). This value is first set to $m - 1$, and is incremented by m each time the x coordinate is incremented by one. If ε becomes greater than zero, we know that the line has moved upwards one pixel, and that we must increment our y coordinate and readjust the error to represent the distance from the top of the new pixel – which is done by subtracting one from ε.
9	**Define clipping. Also explain the working of a simple line clipping algorithm. BTL5 N/D'16 (8 marks)** Clipping, in the context of computer graphics, is a method to selectively enable or disable rendering operations within a defined region of interest. **Cohen-Sutherland Algorithm** You may assume that this case takes place when you have projected the three dimensional object into the projection plane, and therefore we have a rectangular window in the projection plane, given by (WL, WR, WB, WT). The algorithm tries to replace unnecessary calculations, which should be done in floating point arithmetic, with bits operations. Input: Two endpoints of a line segment Output: Two points, or none. It extends the sides of the window to infinity, to divide the plane into 9 regions. To the points of each region, we assign a four bits code $b_tb_bb_rb_l$. See figure.

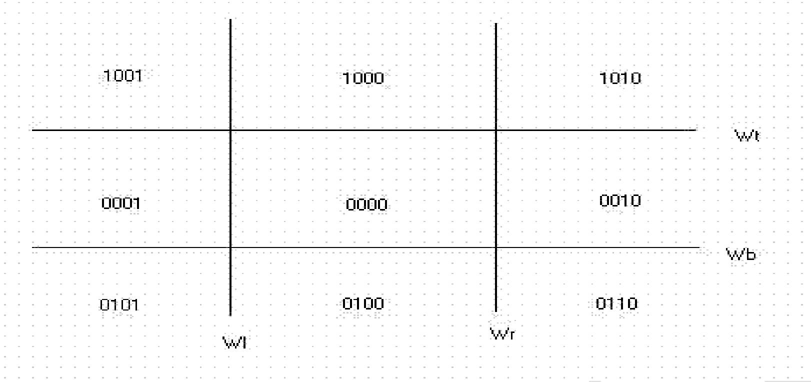


Figure 1

b_t will be assigned the value of 1 if y > WT , 0 otherwise.
b_b will be assigned the value of 1 if y < WB , 0 otherwise.
b_r will be assigned the value of 1 if x > WR , 0 otherwise.
b_l will be assigned the value of 1 if x < WL , 0 otherwise.

Consider the endpoints P1 and P2, of a line segment, with coordinates (x1 , y1) and (x2 , y2)and compute code(P1) and code(P2).

I - If code(P1) & code(P2) (bitwise and) gives a code with anything but zeros, discard the line.
II - If code(P1) | code(P2) (bitwise or) gives a code with only zeros, keep the segment line.
III – Assume that P1 is such that code(P1) is not identically zero (otherwise switch points).

UNIT II – GEOMETRIC MODELING

Representation of curves- Hermite curve- Bezier curve- B-spline curves-rational curves-Techniques for surface modeling – surface patch- Coons and bicubic patches- Bezier and B-spline surfaces. Solid modeling techniques- CSG and B-rep

PART * A

Q.No.	Questions
1	**What do you mean by zero order, first order and second order continuity? BTL1** a) Zero order continuity (C^0) means simply that the curves meet. b) First order continuity (C^1) means that the first parametric derivatives of the coordinate function for two successive curve sections are equal at their joining points. c) Second order (C^2) refers that both first and second parametric derivatives of two curves sections are the same at the intersection.
2	**State limitations of B-spline curve? BTL1** a) The number of specified polygon vertices fixes the order of the resulting polynomial which defines the curve. The only way to reduce the degree of the curve is to reduce the number of vertices and vice versa. b) Bezier curve is considered as a single curve controlled by all control points. Because of this, with an increase in the number of control points, the order of the polynomial representing the curve increases. It increases the complexity of the curve and its calculation. c) A change in one vertex is felt throughout the entire curve because of the global nature of the Bernstein basis. It means that the value of blending function is non-zero for all parametric values over the entire curve.
3	**Write down hermite matrix and What are limitations of hermite curves? BTL2 N/D'15** Hermite curve = $\begin{bmatrix} 2 & -2 & 1 & 1 \\ -3 & 3 & -1 & -1 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$ The curve is defined by two data points that lie at the beginning at the end of the curve, along with the slopes at these points. When two end points and their slope define a curve, the curve is called a hermite cubic curve.
4	**State the advantages of rotational splines? BTL1** a) Rotational splines have the following two important advantages compared to non-rotational splines. b) Rational splines provide an exact representation for quadratic curves (conics) such as circles and ellipses. Non-rotational splines which are polynomial can only approximate conics. It allows graphics packages to model all curve shapes with one representation rotational splines

without needing a library of curve functions to handle different design shapes.

c) Rational splines are invariant with respect to a perspective viewing transformation. It means, we can apply a perspective viewing transformation to control points of the rotational curve and we will obtain the correct view of the curve. Non-rational splines, on the other hand, are not invariant with respect to a perspective viewing transformation.

5 **Differentiate between analytical curves, interpolated curves and approximated curves. BTL1 N/D'15**

S.No	Analytical curves	Interpolated curves	Approximated curves
1	These curves are represented by a simple mathematical equation.	An interpolated curve is drawn by interpolating the given data points.	These curves provide the most flexibility in drawing curves of very complex shapes.
2	They have a fixed form and cannot be modified to achieve a shape that violates the mathematical equations.	These curves have some limited flexibility in shape creation.	The model of a curved automobile fender can be easily created with the help of approximate curves and surfaces.

6 **What are the advantages and disadvantages of wire frame modelling? BTL2- M/J'16**

a) Advantages of this type of model include ease of creation and low level hardware and software requirements. Additionally, the data storage requirements are slow.

b) The main disadvantage of a wire frame model is that it can be very confusing to visualize. For example, a blind hole in a box may look like a solid cylinder.

7 **What is called plane surface? How is ruled surface produced? How is tabulated surface generated? How are coons surface generated? BLT1**

a) The most elementary and simplest form of the surface types is the plane surface which may be defined between two parallel straight lines through three points or through a line and a point.

b) A ruled surface is produced by linear interpolation between two different boundary curves that define the surface.

It is surface generated by translating a planar curve for a given distance along a specified direction.

A coon's patch or surface is generated by the interpolation of four edges curves.

8 **Define curve and State advantages of Bezier Curves. BTL 1 M/J'16**

Curve is a continuous map from one dimensional space to n dimensional space.The curve is a straight line if and only if all the control points are collinear. The start and end of the curve is

	tangent to the first and last section of the Bezier polygon, respectively. A curve can be split at any point into two sub curves, or into arbitrarily many sub curves, each of which is also a Bezier curve.
9	**Mention the advantages of CGS? BTL2** a) It creates fully valid geometrical solid model. b) Complex shapes may be development relatively quicker with the available set of primitives. c) Less skill is enough. d) The data file of CSG is concise. e) CSG guarantees automatically in which objects drawn by CSG are valid. f) CSG is more user friendly. g) Algorithms for converting CSG into B-rep have been developed.
10	**Why B-rep modelling approach are widely followed than CSG approach? BTL2 N/D'16** Boundary Representation (B – Rep) approach allows the designer to draw a boundary or an outline of an object in the CRT screen for displaying various views like left side view, top view, and front view. The boundaries of the views are interlinked with edges, faces and vertices.
11	**What are the disadvantages of CSG? BTL1** a) More computational effort and time are required whenever the model is to be displayed in the screen. b) Getting fillet, chamfer and taperness in the model are very difficult. c) CSG database contains information about a solid in an unevaluated form. d) The validity of a feature of an object cannot be assessed without evaluating the entire tree. e) The tree is not unique for the same part design.
12	**Why B-rep scheme is more widely used? BTL1** a) In CSG, the number of basis primitives available is limited but it is not so in B-rep. b) The performance of B-rep scheme is very much superior to that of CSG scheme for complex engineering models. c) Conversion of CGS to B-rep is possible but the conversion from B-rep to CSG is not possible. d) Combining the wire frame and surface model is possible only through B-rep solid representation.
13	**State any four advantages and disadvantages of B-rep? BTL2** a) **Advantages:** computational effort and time required to display the model are less compared with CSG. b) Combining wireframe and surface model are possible. c) Complex engineering objects can be easily modelled compared with CSG, Examples are aircraft fuselage and automobile body styling. d) The information is complete especially for adjacent topology relation.

e) **Disadvantage:** The data to be stored is more and hence, it requires more memory. So, it is not suitable for tool path generation.
f) Sometimes, geometrically valid solids are not possible.
g) There is no guarantee for the created objet to check whether it is valid or not.
h) It is generally less robust than the half space method.

14 **What are the rules to be followed in topological consistency? BTL1**

a) Face should be bound by a simple loop of edges and they should be not intersected by itself.
b) Each edge should exactly adjoin two faces and each edge should have a vertex at each end.
c) At least three edges, it should meet at each vertex.

15 **What is the significance of CGS? BTL1 - M/J'17**

a) Constructive solid geometry (CGS) is one of the most popular methods of representing and building complex solids.
b) In this scheme, simple primitives are combined in certain order by means of regularized Boolean set operators which are directly included in the representation.

16 **Define quadratic Bezier curve. BTL1 M/J'17**

a) The shape of Bezier curve is controlled by its defining points only.
b) The curves do not pass through the given data points. Instead, these points are used to control the shape of the resulting curves.
c) Flexibility of Bezier curve is more.

17 **Write down the difference between Bezier curve and cubic spline curves? BTL1**

S.No	**Bezier curve**	**Cubic spline curve**
1	The shape of Bezier curve is controlled by its defining points.	First order derivatives are used in the curve development.
2	The curve does not pass through the given data points. Instead, these points are used to control the shape of the resulting curves.	The curves pass through the given data points exactly.
3	Bezier curve permits higher order continuity as the degree or order of Bezier curve is variable and it is depending on the number of defining data points. For example, n + 1 points define nth degree curve.	The order or the degree of cubic spline is fixed one. It is always cubic for a spline segment.

4	The shape of the Bezier curve is smoother than the cubic spline curve because of its higher order continuity.	It is not much smoother as Bezier curve.

PART – B

1 **Briefly explain the different schemes used to generate a solid model. N/D'15 (or) Explain in detail B-rep solid modelling approach. BTL5 - N/D'16, (13 marks)**

A representation scheme is defining as a relation which maps a valid point set into a valid model. For example, a constructive solid geometry (CSG) scheme maps the valid primitive into the valid solid via Boolean operations. It possesses the following properties,

- It is closed regular set. There should not be any dangling portions.
- It is a semi - analytic set. It does not oscillate infinitely fast anywhere in the set.

Out of which, the following two basic approaches are important from our subject point of view.

(1) Constructive solid geometry (CSG)
(2) Boundary representation (B - rep)

1. Constructive solid geometry (CSG):

Constructive solid geometry (CSG) is one of the most popular methods of representing and building complex solids. The type of Boolean operations is used in CSG are Union (U), difference (-), and intersection (∩).

Simple Boolean operations have been already described in earlier topics of this chapter. The data representation of CSG objects is represented by a binary tree. Directed graph scheme is used to store the model in the data structure.

The general form of the tree – type data structure used in CSG approach is shown in figure 2.41. Any node may have one parent node and two child node.

A balanced tree can be defined as a tree whose left and right subtrees have almost an equal number of nodes. The creation of balanced or an unbalances tree is entirely dependent on the user and it is related to how the primitives are combined.

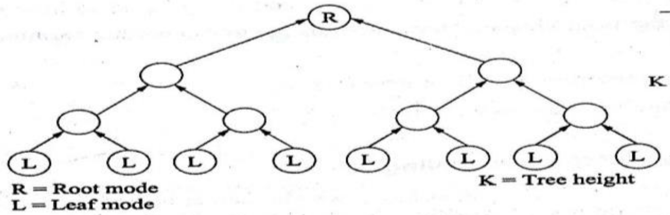


Figure 2.41

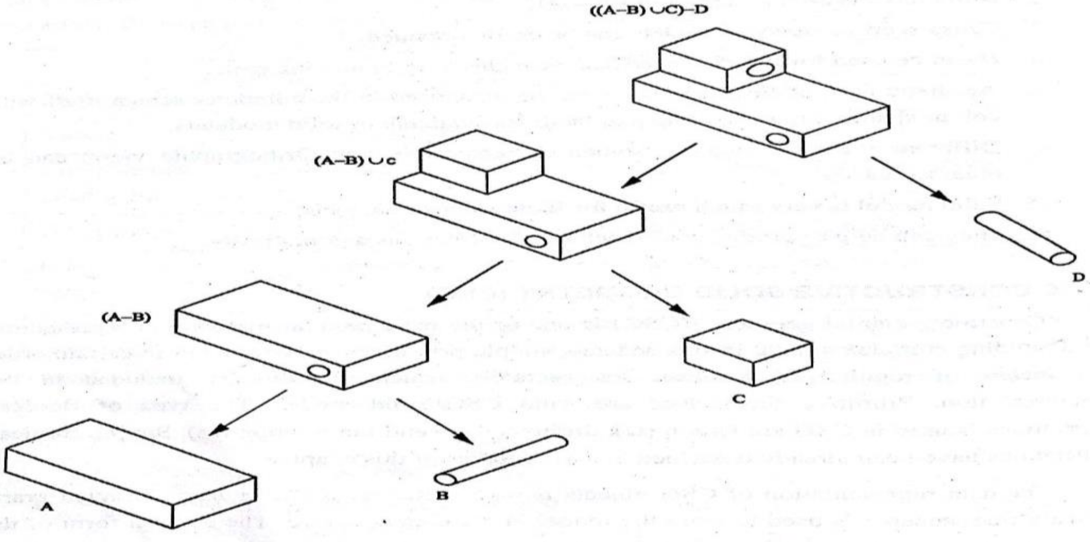


Figure 2.42 Unbalanced tree

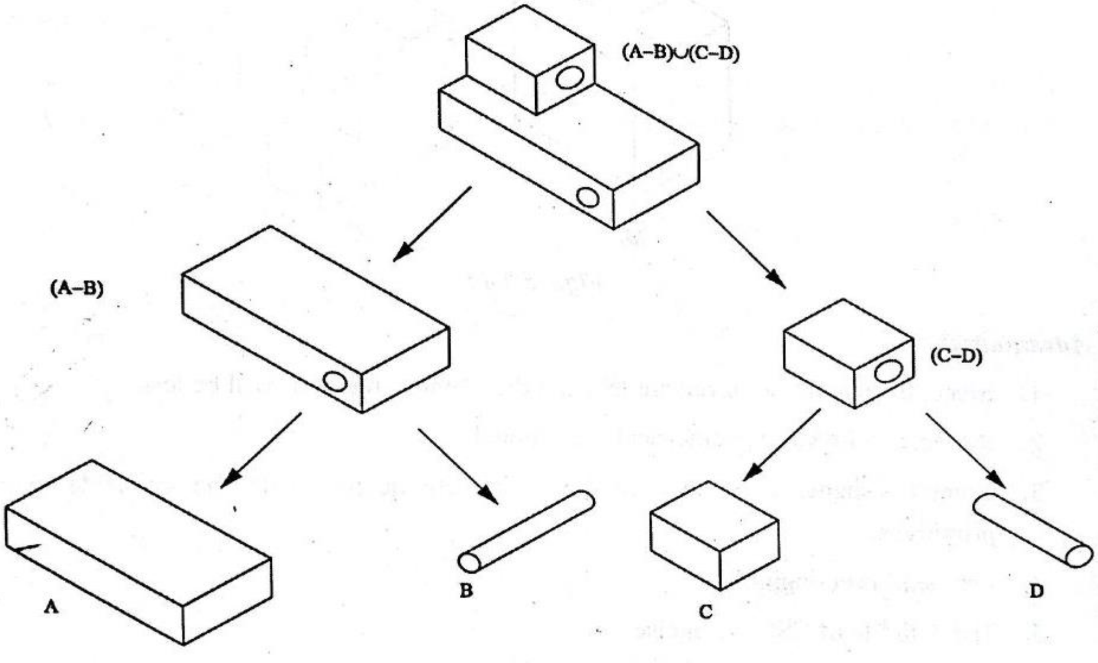


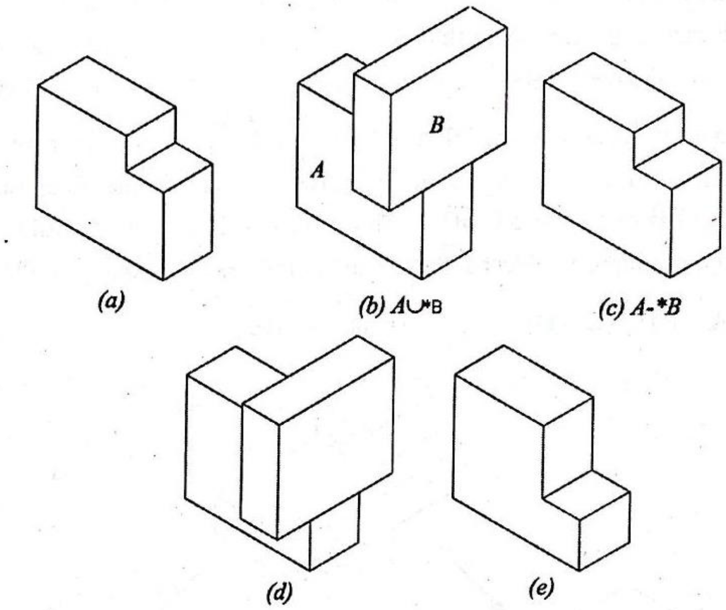
Figure 2.43 Balanced tree

A balanced and unbalanced method of building the same subject is shown in figure 2.42.

For example, to create a model as shown in figure 2.43, four primitives – two rectangular blocks and two cylinders are required.

To create the final object following Boolean operation has to be carried out. Applying the same operation to two objects which are initially the same can yield two different results as shown in figure 2.44.

The object shown in may be defined by different CSG operations shown in (b) and (c). The modification of the top face of (b) and (c) upward yields different objects shown in (d) and (e).



(a) (b) A∪*B (c) A-*B

(d) (e)

Figure 2.44

Advantages:

- Since the data to be stored are less and the memory required will be less.
- It creates fully valid geometrical solid model.
- CSG is more user friendly.
- Algorithms for converting CSG into B-Rep have been developed.

2 **Boundary representation (B - rep)? BTL5 (13 marks may ask in individual)**

Boundary representation (also known as B-rep) is based on the concept. A physical object is bounded by a set of faces.

This approaches widely used in most of the solid modellers. This scheme describes an object in terms of its surface boundaries: vertices, edges and faces.

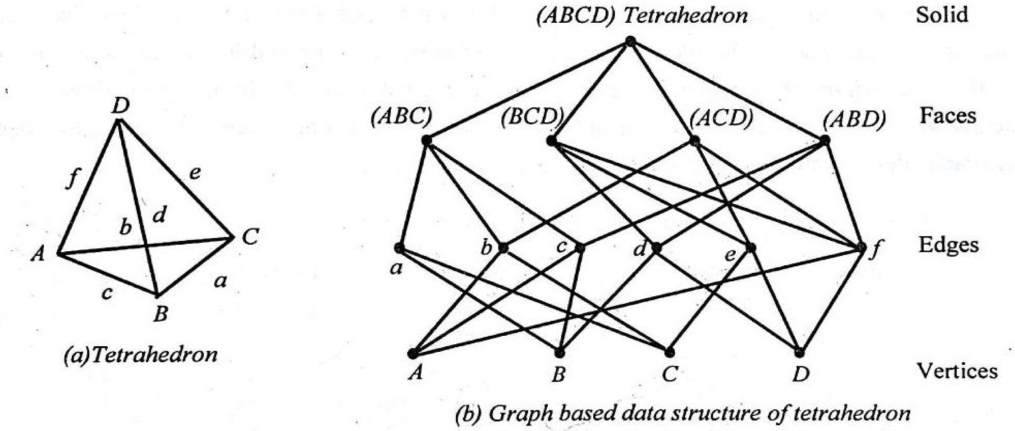
Some B-reps are restricted to planer, polygonal boundaries and it may even require faces to be convex polygons or triangles.

Only the boundary surfaces of the model are stored and the volumetric properties are calculated by the Gauss Divergence theorem which relates the volume integral to surface integrals.

It is illustrated with a simple example of tetrahedron shown in figure 2.45 (a). The tetrahedron is composed of four vertices namely A, B, C and D. the coordinate of these vertices is stored in the database.

Figure 2.45 (b) shows how the vertices are connected to form edges (a, b, c, d, e, and f) and how these edges are connected together to form the face (ABC, BCD, ACD, ABD) which makes the complete solid of tetrahedron.

This connectivity to form the solid is popularly known as topology.



(a)Tetrahedron

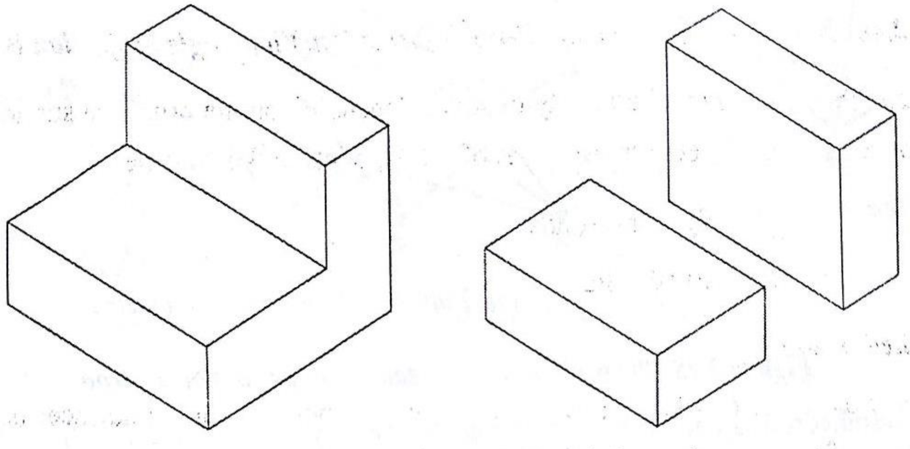
(b) Graph based data structure of tetrahedron

Figure 2.45 Illustration of B-rep data structure of tetrahedron

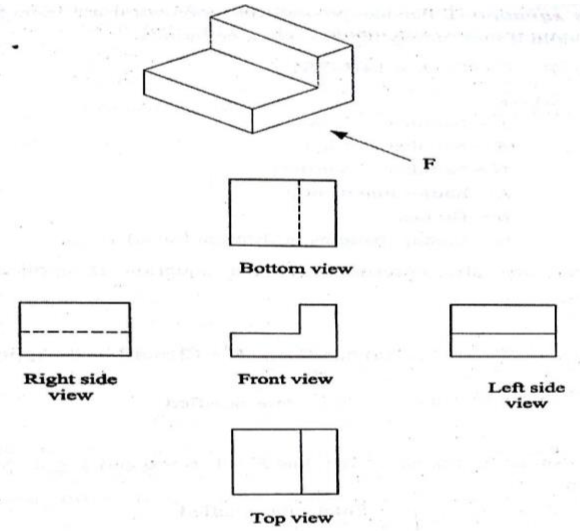
For better understanding of the difference between CSG and B-ref schemes the information contained in a same solid both in the schemes are given in figure 2.46.

As stated earlier, in B-ref scheme, the solid is made of a set of faces. These faces are subsets of closed and orientable surfaces.

A closed surface is one and it is continuing without break. In an orientable surface, it is possible to distinguish two sides by using the direction of the surface normal to point inside or outside the solid model. Each face is bounded by edges and each edge is bounded by vertices.



(a) Desired object (b) CSG information



(c) B-rep information

Figure 2.46 Comparison of CSG and B-rep information(First angle projection is followed)

Advantages:

- Computational effort and time required to display the model are less compared with CSG.
- Combining wire frame and surface model are possible.

2. Complex engineering objects can be easily modelled compared with CSG. Example are aircraft fuse lase and automobile body styling.

- The information is complete especially for adjacent topology relations.

3 **Explain different types of geometric modelling with suitable examples? BTL5 M/J'17 (13 marks)**

Geometric modelling is the starting point of the product design and manufacture process.Functions of Geometric Modelling are:

Design Analysis

- ❖ Evaluation of area, volume, mass and inertia properties
- ❖ Interference checking in assemblies
- ❖ Analysis of tolerance build-up in assemblies
- ❖ Kinematic analysis of mechanisms and robots
- ❖ Automatic mesh generation for finite element analysis

Drafting

- ❖ Automatic planar cross-sectioning
- ❖ Automatic hidden lines and surface removal
- ❖ Automatic production of shaded images
- ❖ Automatic dimensioning
- ❖ Automatic creation of exploded views of assemblies

Manufacturing

- Parts classification
- Process planning
- NC data generation and verification
- Robot program generation

Production Engineering

- Bill of materials
- Material requirement
- Manufacturing resource requirement
- Scheduling

Inspection and quality control

- Program generation for inspection machines
- Comparison of produced parts with design

WIRE FRAME MODELING

It uses networks of interconnected lines (wires) to represent the edges of the physical objects being modeled

Also called ‘Edge-vertex’ or ‘stick-figure’ models

Two types of wire frame modeling:

1. 2 ½ - D modeling

2. 3 – D modeling

3-D Wire frame models: These are

Simple and easy to create, and they require relatively little computer time andmemory; however, they do not give a complete description of the part.

They contain little information about the surface and volume of the part and cannot distinguish the inside from the outside of part surfaces.

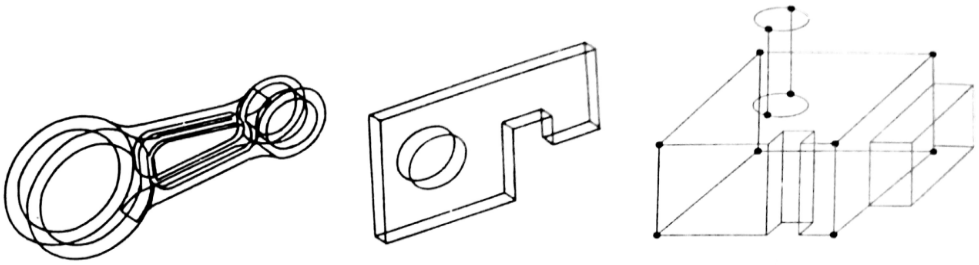
They are visually ambiguous as the model can be interpreted in many different ways because in many wire frame models hidden lines cannot be removed.

Section property and mass calculations are impossible, since the object has no faces attached to it. It has limited values a basis for manufacture and analysis

2 ½ - D Wire frame models:

Two classes of shape for which a simple wire-frame representation is often adequate are those shapes defined by projecting a plane profile along its normal or by rotating a planar profile about an axis.

Such shapes are not two-dimensional, but neither do they require sophisticated three-dimensional schemes for their representation. Such representation is called 2 ½ - D.



2½ D wire frame model

TECHNIQUES IN SURFACE MODELLING

The various methods for representing the solids are:

1. Half-space method
2. Boundary representation method (B-rep)
3. Constructive solid geometry (CSG and C-rep)
4. Sweep representation
5. Analytical solid modelling (ASM)
6. Primitive instancing
7. Spatial partitioning representation
    a. Cell decomposition.
    b. Spatial occupancy enumeration.
    c. Octree encoding.

Boundary representation method (B-rep)

- In solid modelling and computer-aided design, boundary representation often abbreviated as
- B-rep or BREP—is a method for representing shapes using the limits.
- A solid is represented as a collection of connected surface elements, the boundary between solid and non-solid.
- Boundary representation models are composed of two parts:
- Topology, and
- Geometry (surfaces, curves and points).

The main ***topological*** items / primitives of b-rep are:

- Vertex (V): It is a unique point (an ordered triplet) in space
- Edge (E): It is finite, non-self-intersecting, directed space curve bounded by two vertices that are not necessarily distinct.
- Face (F): It is defined as a finite connected, non-self-intersecting, region of

a closed oriented surface bounded by one or more loops

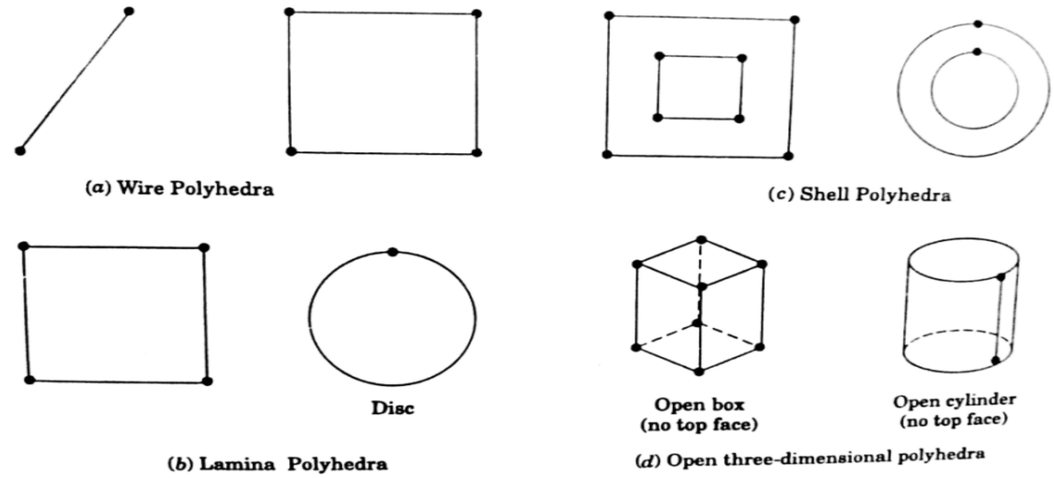
- Loop (L): It is an ordered alternating sequence of vertices and edges
- Genus(G): It is the topological name for the number of handles or through holes in an

object

- ❖ Body/Shell(B): It is a set of faces that bound a single connected closed volume. A minimum body is a point.
- ❖ A minimum body is a point; topologically this body has one face, one vertex, and no edges. It is called a seminal or singular body.

Geometry

- ❖ **Open polyhedral objects**



Open polyhedral objects.

4 **Explain various curve generation techniques with suitable examples? Or** Write **short notes on approximated synthetic curves. BTL5 N/D'15 (13 marks)**

Bezier curves

- ✓ Hermite curves
- ✓ B-spline curves
- ✓ NURBS curves

BEZEIR CURVES

- ❖ Splines draw their name from the traditional drafting tool called "French curves" or "splines".
- ❖ Cubic splines use cubic polynomials. A cubic polynomial has four co-efficient and thus required four condition to evaluate.
- ❖ These condition could be combination of points and tangent vectors.
- ❖ A cubic splines uses four data points.
- ❖ The herniate cubic spline uses two data points at its ends and two tangent vectors at these points.
- ❖ The parametric equation of a cubic spline segment is given below
- ❖ $P(u) = \sum_{i=0}^{3}$ $Ciu^i 0 \leq u \leq 1$---(1)
- ❖ Where u is the parameter and Ci are the polynomial co efficient.

- In scalar form the equation is written as
- $X(u)=C_{3X}\ U3 + C_{2X}\ U2 + C_{1X}\ U + C_{0X}$
  $X(u)=C_{3Y}\ U3 + C_{2Y}\ U2 + C_{1Y}\ U + C_{0Y}$ ---(2)
  $X(u)=C_{3Z}\ U3 + C_{2Z}\ U2 + C_{1Z}\ U + C_{0Z}$
- In expand vector from equation (1) can be written as
  $P(u) = C_3\ U^3 + C_2\ U^2 + C_{1X}\ U + C_0$ ---(3)
- Equation 3 can also write in matrix form
  $P(u) = U^TC$ ---(4)
  Where $U = [U^3\ U^2\ U^1]^T$
  And $C = [C^3\ C^2\ C^1]^T$
  C is called co-efficient vector
- The tangent vector to the curve at any point is given by differentiating eqn(1) with respect to u to give
  $P'(u) = \sum_{i=o}^{3}\ Ci\ iu^{i-1}\ 0 \leq u \leq 1$ -- ---------------------(5)
- In order to find the co-efficient $C_{1,}$ consider the cubic spline segment with the two end points P_0 and = P_1 shown in figure.
- Applying the boundary condition P_0 and P_1at u = 0 and $P_{1,}$ P_1 at u = equation (1) and (5)
  $P_0 = C_0$
  $P'_0 = C_1$
  $P_1 = C_3 + C_2 + C_1 + C_0$
  $P_1 = 3C_3 + 2C_2 + C_1$ --(6)
  Solve these four equation simultaneously for the co-efficient gives
  $C_0 = P_0$
  $C_1 = P'_0$
  $C_2 = 3(P_1 – P_0) – 2P'_0 - P'_1$
  $C_3 = 3(P_0 – P_1) + P'_0 + P'_1$ ---(7)

$$[M_H]^A = \begin{bmatrix} 2 & -2 & 1 & 1 \\ -3 & 3 & -2 & -2 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

5 **Explain different features of a Bezier curve with construction details. BTL5 N/D'16 (13 marks)**

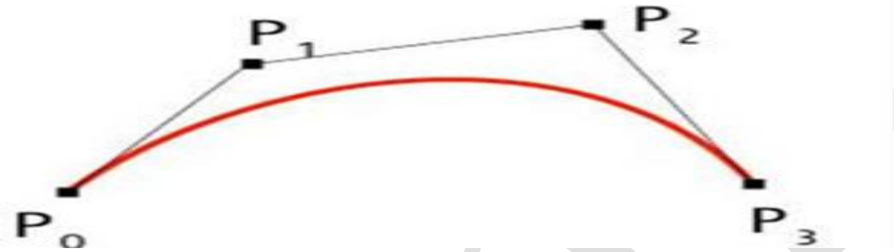
Bezier curves are extensively applied in CAD to model smooth curves. As the curve is totally limited in the convex hull of its control points P0, P1, P2& P3, the points can be graphically represented and applied to manipulate the curve logically.

The control points P0 and P3 of the polygon lie on the curve. The other two vertices described the order, derivatives and curve shape. The Bezier curve is commonly tangent to first and last vertices.

Cubic Bezier curves and Quadratic Bezier curves are very common. Higher degree Bezier curves are highly computational to evaluate.

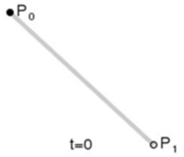
When more complex shapes are required, Bezier curves in low order are patched together to produce a composite Bezier curve. A composite Bezier curve is usually described to as a 'path' in vector graphics standards and programs.

For smoothness assurance, the control point at which two curves meet should be on the line between the two control points on both sides.



Linear Bezier curves

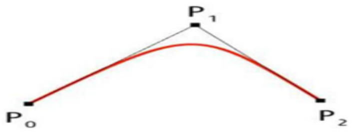
The given points P0 and P1, a linear Bezier curve is merely a straight line between those two points. The Bezier curve is represented by



$$B(t) = (1-t)^3P_0 + 3(1-t)^2tP_1 + 3(1-t)t^2P_2 + t^3P_3 \text{ , } t \in [0,1].$$

Quadratic Bezier curves

As shown in the figure, a quadratic Bezier curve is the path defined by the function B(t), given points P0, P1, and P2,



$$B(t) = (1-t)[(1-t)P_0 + tP_1] + t[(1-t)P_1 + tP_2] \text{ , } t \in [0,1]$$

This can be interpreted as the linear interpolate of respective points on the linear Bezier curves from P0 to P1 and from P1 to P2 respectively. Reshuffle the preceding equation gives:

$$\mathbf{B}(t) = (1-t)^2\mathbf{P}_0 + 2(1-t)t\mathbf{P}_1 + t^2\mathbf{P}_2 \text{ , } t \in [0,1].$$

The derivative of the Bezier curve with respect to the value 't' is

$$\mathbf{B}'(t) = 2(1-t)(\mathbf{P}_1 - \mathbf{P}_0) + 2t(\mathbf{P}_2 - \mathbf{P}_1).$$

From which it can be finished that the tangents to the curve at P0 and P2 intersect at P1. While 't' increases from zero to one, the curve departs from P0 in the direction of P1, then turns to land at P2 from the direction of P1.

The following equation is a second derivative of the Bezier curve with respect to 't':

$$\mathbf{B}''(t) = 2(\mathbf{P}_2 - 2\mathbf{P}_1 + \mathbf{P}_0).$$

A quadratic Bezier curve is representing a parabolic segment. Since a parabola curve is a conic

	section, a few sources refer to quadratic Beziers as ‘conic arcs’.
6	**Derive the transformation matrix for a Hermite Curve. BTL5 - N/D’16 (8 marks)** AHermitecurveisasplinewhereeverypieceisathirddegreepolynomialdefinedinHermite form: that is, by its values and initial derivatives at the end points of the equivalent domain interval. Cubic Hermite splines are normally used for interpolation of numeric values defined at certain dispute valuesx1, x2, x3,…...,xn,toachieveasmoothcontinuousfunction.Thedatashouldhavethepreferred function value and derivative at each X_k. The Hermite formula is used to every interval (X_k, X_{k+1}) individually. The resulting spline become continuous and will have first derivative. Cubic polynomial splines are specially used in computer geometric modeling to attain curves that pass via defined points of the plane in3Dspace. In these purposes, each coordinate of the plane is individually interpolated by a cubic spline function of a divided parameter ‘t’. Cubic splines can be completed to functions of different parameters, in several ways. Bicubic splines are frequently used to interpolate data on a common rectangular grid, such as pixel values in a digital picture. The following vectors needs to compute a Hermite curve: • P1: the start point of the Hermite curve • T1: the tangent to the start point. • P2: the endpoint of the Hermite curve • T2: the tangent to the endpoint ThesefourvectorsarebasicallymultipliedwithfourHermitebasisfunctionsh1(s),h2(s),h3(s) and,h4(s)and added together. h1(s) = $2s^3-3s^2+1$ h2(s) = $-2s^3+3s^2$ h3(s) = $s^{3\,-}2s^{2\,+}s$ h4(s) = $s^{3\,-}s^2$

UNIT III CAD STANDARDS

Standards for computer graphics- Graphical Kernel System (GKS) - standards for exchange images- Open Graphics Library (OpenGL) - Data exchange standards - IGES, STEP, CALS etc. - communication standards.

PART * A

Q.No.	Questions
1	**What is meant by CAD data exchange? Mention its importance. BTL1 N/D'15** CAD data exchange involves a number of a software technologies and methods to translate data from one computer-aided design system to another CAD file format. The exchange process targets primarily the geometric information of the CAD data but it can also target other aspects such as metadata, knowledge, manufacturing information, tolerances and assembly structure. There are three options available for CAD data exchange: direct model translation, neutral file exchange and third-party translators.
2	**What are the importance's of standards in CAD? BTL1 M/J'16** • Openness, accessibility: availability and willingness to respond. • Truthfulness: unconditional honesty is the only policy. • No secrets: our behaviour, our attitudes, our plans and positive. • In the engineering world, CAD is extremely important and widely used to design and develop products to be used by consumers. • This knowledge is a hot commodity for those employing engineers, because of its benefits in the engineering workplace.
3	**Write any three CAD Standards for exchange of modelling data. BTL1 - M/J'16** • Graphics Kernel System (GKS) • Initial Graphics Exchange Specification • DXF (Drawing/Data Exchange Format) • STEP (Standard for the Exchange of Product model data)
4	**State the needs for data exchange standards. BTL1 N/D'16** CAD data exchange is a modality of data exchange used to translate data between different Computer-aided design (CAD) authoring systems or between CAD and other downstream CAx systems. Data exchange allows data to be shared between different computer programs. It is similar to the related concept of data integration except that data is actually restructured (with possible loss of content) in data exchange. There may be no way to transform an instance given all of the constraints.
5	**What is GKS cell array? BTL1 N/D'16** The GKS cell array function displays raster like images in a device-independent manner. The cell array function takes the two corner points of a rectangle that you specify, a number of

	divisions (M) in the X direction and a number of divisions (N) in the Y direction. It then partitions the rectangle into M x N sub-rectangles called cells. You assign each cell a color and create the final cell array by coloring each individual cell with its assigned color. At level 0A, cell array has no associated attributes.
6	**Define Graphical Kernel system? BTL1 M/J'17** GKS basically a set of procedures which can be called by user programs to carry out certain generalized functions such as arc, circle, ellipse etc. GKS is defined in terms of number of levels describing the level of support in terms of facilities. Graphical Kernel System provides a set of drawing features for two dimensional vector graphics suitable for charting and similar duties.
7	**What is open graphics library? BTL1 M/J'17** Open GL draws primitives into a structured buffer focus to a various selectable mode. Every point, line, polygon, or bitmap are called as a primitive. Each mode can be modified separately; the parameters of one do not affect the parameters of others. Open graphics Library (Open GL) is a cross language multi-platform Application Programming Interface (API) for rendering 2D and 3D vector graphics. It is extensively used in the field of CAD, virtual reality, scientific visualization, information visualization, flight simulation and video games.
8	**Mention the need for graphic standards. BTL2** ✓ There is need for portability of the geometric model among different hardware platforms. ✓ Where there is situation to exchange drawing database among software packages. ✓ There is need for exchanging graphic data between different computer systems. ✓ To understand the graphic kernel system and its extension for developing the graphic software systems.
9	**What are the features of GKS? BTL2** ✓ It is an independent device. So it can work with all types of input and output devices. ✓ All text and annotation can be prepared and stored in natural languages. ✓ Graphic functions are defined for both 2D and 3D. ✓ It includes all types of display elements. ✓ GKS supports picture data into two routines.
10	**Classify GKS. BTL1** ✓ Control function ✓ Output function ✓ Output primitives ✓ Segment function ✓ Transformation ✓ Input function ✓ Meta file function
11	**List down the output primitives in GKS. BTL2** ✓ Polyline ✓ Polymakers

	✓ Text ✓ Fill area
12	**State the segment used in GKS inquiry functions. BTL1** ✓ Segment storage ✓ Segment creation, deletion and renaming ✓ Segments name ✓ Segment association, copying and insertion ✓ Pick identifier ✓ Segment redrawing
13	**What are the reasons and requirements of exchanging data? BTL1** ✓ All use the same CAD packages. ✓ Special translator application is used to change the data from one format to another format ✓ A neutral format is used to data exchange. Requirements for the Exchange Shape data: both geometric and topological information, part and form features. Fonts, color, annotation are considered part of the geometric information. • Non-shape data: graphics data such as shaded images, and model global data as measuring units of the database and the resolution of storing the database numerical values. Design data: information that designers generate from geometric models for analysis purposes. Mass property and finite element mesh data belong to this type of data. Manufacturing data: information as tooling, NC tool paths, tolerancing, process planning, tool design, and bill of materials (BOM).
14	**Brief about DXF format. BTL2** DXF/DWG: DXF formats were developed by AutoDesk. • After creating drawings, designers can export data in DXF/DWG formatted files and import the 2D geometric data contained in a DXF/DWG file into other drawing tools. DXF File Structure: • Header Section • Tables Section • Block Section • Entities Section
15	**Explain the IGES file structure and format. BTL1** 1.Global section (G) – The Global Section includes properties and descriptions of the pre-processor and information that are needed by postprocessor to interpret the file. It is recognize by letter "G" in the IGES file.4. Directory section (D) – Index for the file and attribute information like colour, line type etc. 2.Data Entry Section (D) -Directory entry section defines the attributes or features of the entity like line , color, transformation matrix, etc. 3. For every geometric element within an IGES file there is one Directory Entry. This consists of

two 80-character lines i.e. 20 right-justified fields of 8 characters each

4. Parameter Entry section (P) Directory entry section defines the attributes or features of the entity like line , color, transformation matrix, etc. For every geometric element within an IGES file there is one Directory Entry. This consists of two 80-character lines i.e. 20 right-justified fields of 8 characters each

5. Terminate section – The terminal section contains only one record which shows the number of records in each section. This is used for checking purpose.

16 **Brief about STEP (Standard for the Transfer and Exchange of Product model data)file.BTL1**

The broad scope of STEP is as follows:

– The standard method of representing the information necessary to completely define a product throughout its entire life, i.e., from the product conception to the end of useful life.

– Standard methods for exchanging the data electronically between two different systems.

STEP AP203 / AP214 format (Standard for the Exchange of Product model data)

- It supports geometry and assembly structures and handles topology (shells, solids) on export and import.
- STEP files are human readable
- Other STEP APs are available, e.g. electronics data

17 **State the importance of PDES. BTL2**

PDES (PRODUCT DATA EXCHANGE STANDARD)

(Then Product Data Exchange Using STEP)

- To support any industrial application such as mechanical, electric, plant design, and architecture and engineering construction
- To include all four types of data which is relevant to the entire life-cycle of a product: design, analysis, manufacturing, quality assurance, testing, support, etc. PDES is a much more comprehensive and complex standard than IGES or any other predecessors

18 **Compare the shape based and product data based exchange standards. N/D'15**

S. No.	Shape based exchange standards	Product data based exchange standards
1	All data exchange files are neutral files.	It has specific file formats.
2	It has section of header, table, block, entities and end	It consists of a three layered architecture such as application, logical and physical layers.
3	These files do not have any software specific function.	These file must have any software specific function.
4	Example, DXF and IGES	Example, STEP, SDF, EDIF, and PDES.

PART-B

1 **Write a notes on (i) Open graphics Library (Open GL) BTL5 N/D’15 (16)**

- Open graphics Library (Open GL) is a cross language multi-platform Application Programming Interface (API) for rendering 2D and 3D vector graphics. API is typically used to interact with a Graphics Processing Unit (GPU) to obtain hardware accelerated rendering.
- It is extensively used in the field of CAD, virtual reality, scientific visualization, information visualization, flight simulation and video games.
- It describes an abstract of API for drawing 2D and 3D graphics. Although it is possible for the API to implement entirely in software, it is mainly designed to implement in hardware.
- API is defined as a number of functions which may be called by the client program alongside a number of named integer constants.
- Open GL ES 2.0, for 3D rendering from within a web browser, the C bindings WGL, GLX and CGL, the binding provided by IOS and the Java and C bindings provided by android.
- In addition to language independent, Open GL is also an independent platform. The specification explains obtaining and managing an OpenGL context. For the same reason, Open GL is purely concerned with rendering provide no APIs related to input, audio or windowing.

Features of Open GL

(i) Based on IRIS GL:

Open GL is supported on silicon graphics Integrated Raster Imaging System (IRIS), Graphics Library (IRIS GL).

(ii) Low-level:

A critical target of Open GL is to suggest device independence while still permitting the total contact to hardware.

(iii) Fine grained control:

Due to minimize the needs of application utilizing, the Application Programmers Interface (API) must save and present its information.

(iv) Modal:

A model API arises in executions in which process function in parallel on various primitives.

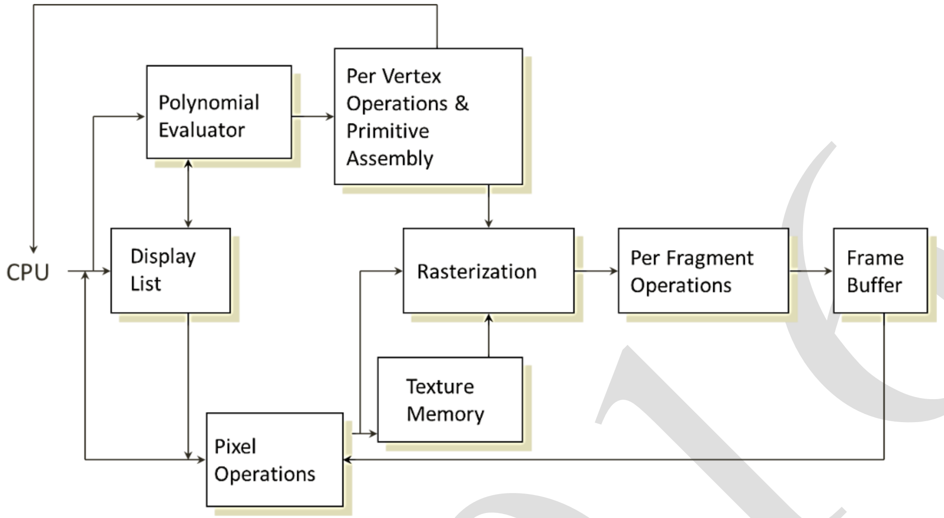
(v) Geometry and images:

Open GL supports to manage both 3D and 2D geometry. An API for utilizing with geometry should also provide guidance for reading, writing and copying images because geometry and images are regularly joint when a 3D view is laid over a background image.

Advantages:

- Industry standard
- Reliable and portable
- Easy to use
- Well documented

Simplified software development, speeds time to market



2 **Standards for computer graphics. BTL5 N/D’15 (8)**

Need for graphics standards:

- There is a need for portability of the geometric model among different hardware platforms.
- Where there is a situation to exchange drawing data base among software packages.
- There is a need for exchanging graphic between different computer systems.
- To understand the graphic kernel system and its extensions for developing the graphic software systems.
- There is a need for requirement of graphic data exchange formats and their details such as IGES, DXF and STEP.
- Dimensional measurement interface specification for communication between coordinate measuring machine and CAD data.

Standardising certain elements at each stage is to minimize the company investment on certain software and hardware without much modification on the newer and different systems. So, there should be some compatibility between various software elements as also between the hardware and software.

There are interface standards at various levels as follows:

- GKS (Graphical Kernel System)
- PHIGS (Programmers Hierarchical Interface for Graphics)
- CORE (ACM-SIGGRAPH)
- GKS-3D
- IGES (Initial Graphics Exchange Specification)
- DXF (Drawing Exchange Format)
- STEP (Standard for the Exchange of Product Model Data)

	• DMIS (Dimensional Measurement Interface Specification) • VDI (Virtual Device Interface) • VDM (Virtual Device Metafile) • GKSM (GKS Metaflie) • NAPLPS (North American Presentation Level Protocol Syntax)
3	**Explain the IGES structure and methodology with suitable examples?Explain IGES file format. BTL5 N/D’15, N/D’16, M/J’17 (16)** However, the IGES is the most comprehensive standard and is designed to transmit the entire product definition including that of manufacturing and any other associated information. A brief description of the IGES version 3.0 is given below highlighting the philosophy of the conversion methodology. In IGES the records are present with 80 column fields, with columns 1 to 72 providing the data and columns 73 to 80 providing a sequence number for the record with identification as to the location of the sub-section. This sequence number is utilized as a pointer for the data. The IGES file consists of the following 6 sub sections. **(a). Flag Section**: This is optional and used to indicate the form in which the data is specified, Originally, the initial versions contained the data in ASCII format with a very detailed structure. This has been criticized by a number of people in view of the very large sizes. From version 3.0 onwards the format has been standardized in the following three modes. • ASCII mode – default option. • Binary form. • Compressed ASCII form. IGES specification defines the format of the file, language format, and the product definition data in these formats. The product definition includes geometric, topological, and non-geometric data. The geometry part defines the geometric entities to be used to define the geometry. The topology part defines the entities to describe the relationships between the geometric entities. The geometric shape of a product is described using these two parts (i.e. geometry and topology). The non-geometric part can be divided into annotation, definition, and organization. The annotation category consists of dimensions, drafting notations, text, etc. The definition category allows users to define specific properties of individual or collections of entities. The organization category defines groupings of geometric, annotation, or property elements. An IGES file consists of six sections: Flag, Start, Global, Directory Entry, Parameter Data, and Terminate. Each entity instance consists of a directory entry and parameter data entry. The directory entry provides an index and includes attributes to describe the data. The parameter data defines the specific entity. Parameter data are defined by fixed length records, according to the corresponding entity. Each entity instance has bi-directional pointers between the directory entry

and the parameter data section. The size of IGES files and consequently the processing time are practical problems. IGES files are composed of fixed format records and each entity has to have records in both the directory entry section and the parameter data section with bi-directional pointers. This causes also errors in pre- and post-processor implementations.

The other two option provided will help in reducing the bulk of the drawing exchange file size. The sequence number has a starting character signifying the sub section, they are

1. S for Start section.
2. G for Global section.
3. D for Directory entry section.
4. P for Parameter entry section.
5. T for terminate section.

(b). Start section:

This section contains a man-readable prologue to the file. The information contained in this section is essentially for the person who would be post processing this for any other application.

Any number of lines can be contained in this section. A sample listening an IGES file for the drawing shown.

(c). Global Section:

This contains information about detail of the product, the person originating the product, name of the company originating it, date, the detail of the system which generated it, drafting standard used and some information required for its post processing on the host computer.

(d). Directory entry section:

For each entity present in the drawing is fixed in the size and contains 20 fields of 8 characters each. The purpose of this section is to provide an index for the file and to contain attribute information.

Some of the attribute information such as color, line type, transformation matrix, etc., may be present directly or through a pointer (to a record in the same file) where the necessary information is stored.

It also contains the pointer to the parameter data section entry which actually contains the requisite parameter data.

(e). Parameter data section.

This contains the data associated with entities. A free format is allowed for maximum convenience. It may contain any number of records. The total number of entities that are present in IGES version 5.1.

(f). Terminate section:

This contains the sub total of the records presented in each of the earlier sections. This would always contain a single record.

4 **Write a short note on STEP? BTL5 M/J’17 (16)**

New CAD data standard is developed through world wide effort known as STEP in year

1997. The ability to share data across application, across vendor, platforms and between contractors, suppliers and customers is the main objective of STEP standard.

STEP seeks to address a number of limitations of IGES. In IGES does not clearly between the logical specification of the standard (the meaning of the data fro CA system point of view), the applications requirements (how the data will be used in particular application) and the physical specification for the storage of data in exchange files.

Data loss:

Similar to any language translation, there is always information loss during the product data information translation.

Examples:

i. A design tolerance is captured as a text string placed on a drawing and its numerical values are lost.
ii. Circular cylinders (a hole) is represented by NURBS.
iii. The offset information is lost in offset surfaces.

The board scope of STEP is as follows:

i. The standard method of representing the information necessary to completely define a product throughout its entire life, ie., from the product conception to the end of useful life.
ii. Standard methods for exchanging the data electronically between two different systems.

STEP uses the formal model for the data exchange which is described using an information modelling language called EXPRESS. It is both human readable and computer processable. STEP has three layers architecture which enables the multiple application views and implements to be defined.

The STEP documentation has eight major areas which are described below.

1. **Introductory:**

It contains the details about general introduction and overview of the standard. It forms the part 1 of the ISO standard 10303. It comprises of part 1 which has overview and general principles.

2. **Description method:**

When compared to other standard, the application protocols are planned to reach vendors. So a new descriptive formal information modelling language called EXPRESS is developed and defined. It is given in part 11 to 13.

3. **Implementation method:**

It describes how express map physical files and storage mechanisms are represented for the data exchange. In refers the actual implementation level. These details are given in part 21 to 26.

4. **Conformance testing methodology and frame work:**

It provides the methods for testing implementation and test suits to be used during conformance tasting. It also gives the specification for conformance testing of the processors, guidance for creating abstract – test suites and the responsibilities of testing laboratories. These details are given in part 31to 35.

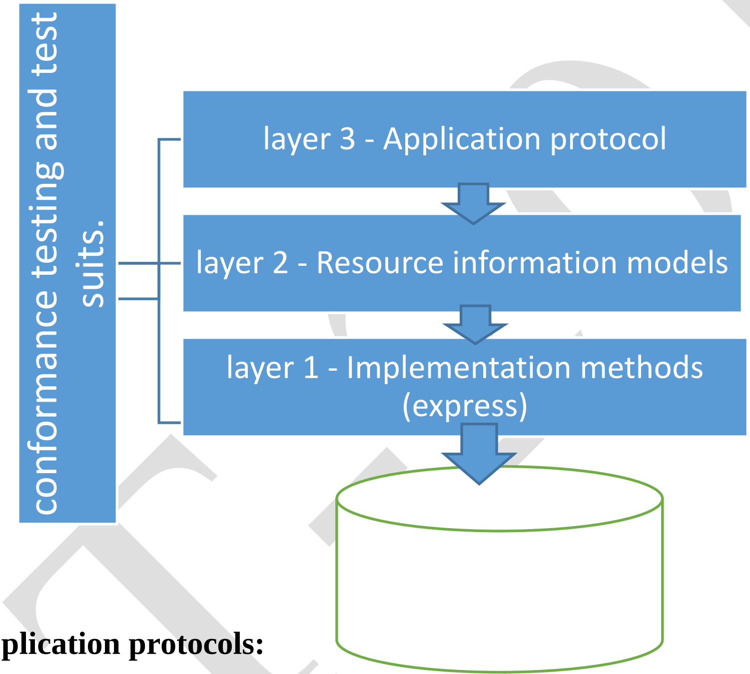
5. Integrated – generic resources:

It contains the specifications of the information models about generic resources such as geometry and structure representation. The specifications are geometric and topological representation, product structure organization, materials, visual presentation, tolerances, form features and process structures, and properties.

These details are given in part 41- 99

6. Application information models:

They specify the information models used for the particular application areas such as draughting, finite element analysis, kinematic, building core model and engineering analysis core. The details are given in part 101.



7. Application protocols:

In described implementations of STEP specific to a particular industrial application and they are associated with implementation methods to form the basis of a STEP implementation which provides test suits for each of the application protocol.

It is also defining the context for the use of product data for a specific industrial need. More complex models are used to illustrate the specific product data application.

It uses the integrated information resources in well-defined combination and configuration to represent a particular data model of some phase of product life. The information is given in 201.

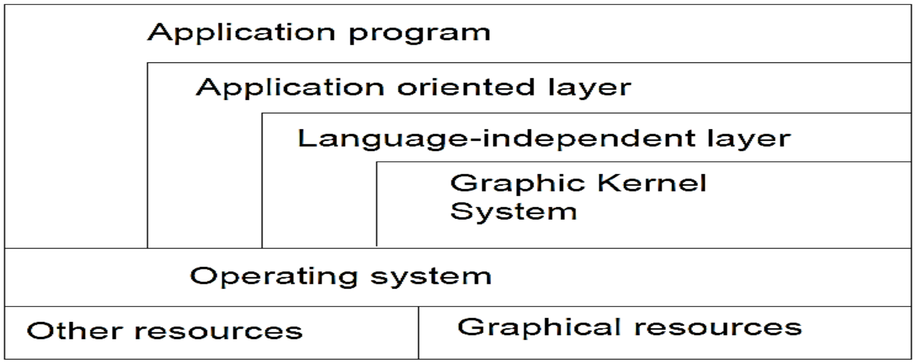
8. Application interpreted control:

It describes the various model entity construct and specific modelling approach. They relate to the specific resources useful for defining the geometric structures useful for applications.

In this case, the information can be reused. So it makes the process easier to express the identical semantics in more than one application protocol.

5 **Explain about various layers of GKS. BTL5 N/D'15, N/D'16 (16)**

Graphical Kernel System (GKS) provides a set of functions for the purpose of generating 2D pictures on vector graphics and/or raster devices. It also supports operator input and interaction by supplying basic functions for graphical input, picture segmentation and subsequent storage, retrieval and dynamic modification of graphical information.



Different Layers of GKS

GKS provides a functional interface between an application program and a configuration of graphical input and output devices. The functional interface contains all basic functions for interactive and non-interactive graphics on a wide variety of graphical equipment.

The geometric information (coordinates) contained in the output primitives, attributes and logical input values can be subjected to transformations. These transformations perform mapping between three coordinate systems, namely:

(a) World Coordinates (WCS) used by the application programmer to describe graphical information to GKS.

(b) Normalized Device Coordinates (NDC) used to define a uniform coordinate system for all workstations.

(c) Device Coordinates (DC), one coordinate system per workstation, representing its display surface coordinates. Input containing coordinates are expressed to GKS by the device using DC values.

Output primitives and attributes are mapped from WC to NDC by normalization transformation, from NDC to NDC by segment transformation (as indicated by a transformation matrix defining rotation, scaling and shift factors) and from NDC to DC by workstation transformation. Input from the display surface (expressed in DC) is mapped by an inverse workstation transformation from DC to NDC and by one of the inverse normalization transformation from NDC to WC.

Output primitives and primitive attributes may be grouped together in a segment. Segments

	are units for manipulation and change. Manipulation includes creation, deletion, and renaming while change includes transforming a segment, changing its visibility and also highlighting segments, i.e., causing segments to "flash". Segments also form the basis for workstation independent storage of pictures at run time. GKS primitives ❖ GKS output primitive is a collection of functions to display 2D images. ❖ It consists of Line, polygon, Spline, Dimension, Text etc., ❖ Attributes refer the Parameters Such as Colour , line Style etc., ❖ Circle is a primitive, its attributes may be Colour, line width and line type. ❖ **POLYLINE** to draw a set of connected straight-line vectors ❖ **POLYMARKER** to draw a set of markers or shapes ❖ **FILL AREA** to draw a closed polygon with interior fill ❖ **TEXT** to create characters ❖ GDP (Generalized Drawing Primitive) to specify the standard drawing entities like circle, ellipse etc. ❖ The attribute functions define the appearance of the image e.g. color, line-type etc. ❖ Current level of GKS is GKS-3D, which provides several other functions. GKS-3D is an extension to GKS, which allows the production of 3-D objects.
6	**Write short note on : Drawing Exchange Format (DXF) Standard. BTL5 M/J'16 (8)** DXF (Data eXchange Format) was originally developed by Autodesk, Inc., the vendor of AutoCAD. It has become a "de-facto" standard among most CAD vendors and is in wide use to exchange 2D/3D wireframe data. All implementations of AutoCAD accept this format and are able to convert it to and from their internal representation. A DXF file is a complete representation of the AutoCAD drawing database thus some features or concepts can't be used by other CAD systems. The DXF version R13 supports wireframe, surface, and solid representations. A DXF file consists of four sections: Header, Table, Block, and Entity section. The header section contains general information about the drawing. Each parameter has a variable name and an associated value. The table section contains definitions of line types, layers, text styles, views, etc. The block section contains entities for block definitions. These entities define the blocks used in the drawing. The format of the entities in the block section is identical to entities in the entity section. The entity section contains the drawing entities, including any block references. Items in the entity section exist also in the block section and the appearance of entities in the two sections is identical. Variables, table entries, and entities are described by a group that introduces the item, giving its type and/or name, followed by multiple groups that supply the values associated with the

	item. In addition, special groups are used for separators such as markers for the beginning and end of sections, tables, and the file itself. Group codes are used to describe the type of the value, and the general use of the group.

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UNIT IV FUNDAMENTAL OF CNC ANDPART PROGRAMING

Introduction to NC systems and CNC - Machine axis and Co-ordinate system- CNC machine tools- Principle of operation CNC- Construction features including structure- Drives and CNC controllers- 2D and 3D machining on CNC- Introduction of Part Programming, types - Detailed Manual part programming on Lathe & Milling machines using G codes and M codes- Cutting Cycles, Loops, Sub program and Macros- Introduction of CAM package.

PART * A

Q.No.	Questions
1.	**List the differences between NC and CNC.**BTL 1 NC stands for Numerical Control whereas CNC stands for Computer Numerical Control. In NC Machine the programs are fed into the punch cards. The cost of the NC machine is less as compared with the computer control machines.
2	**Define linear bearings.**BTL 1 A linear-motion bearing, or linear slide is a bearing designed to provide free motion in one direction. There are many different types of linear motion bearings. Motorized linear slides such as machine slides, XY tables, roller tables and some dovetail slides are bearings moved by drive mechanisms.
3	**Mention the type of ball screws.** BTL 3 A ball screw is a mechanical linear actuator that translates rotational motion to linear motion with little friction. A threaded shaft provides a helical raceway for **ball** bearings which act as a precision **screw**.
4	**Define feed drives.** BTL 1 Feed drive Computer. An optical drive that grabs the disc after it is partially inserted in the slot and pulls it onto the drive spindle.
5	**Discuss the types of motion control system used in NC machines.** BTL 1 Numerical control (NC) (also computer numerical control (CNC)) is the automated control of machining tools (drills, boring tools, lathes) by means of a computer. An NC machine alters a blank piece of material (metal, plastic, wood, ceramic, or composite) to meet precise specifications by following programmed instructions and without a manual operator.
6	**Express the meaning of APT language.** BTL 2 APT or Automatically Programmed Tool is a high-level computer programming language most commonly used to generate instructions for numerically controlled machine tools. ... APT is a language and system that makes numerically controlled manufacturing possible.
7	**Discuss closed loop NC system with open loop system.** BTL 1 In CNC systems, open and closed loop systems describes the two primary types of control systems: Open Loop: Refers to a system using a stepper motor, where the communication between the controller system and motor is one way This is considered a drawback to theopen loop system.
8	**Give the uses of preparatory function. How is it important in CNC programming?** BTL 3 Preparatory Functions. Preparatory functions are G codes. These codes are the most important functions in CNC programming because they direct the CNC system to process the coordinate data in a particular manner. Some examples are rapid traverse, circular interpolation, linear interpolation, and drilling.

9	**Illustrate the limitations of CNC machine tools.** BTL 2 The computer numerical control includes machine tool and also non-machine tools. The CNC system are mainly used in the milling machine, lathe machine, drill press, grinding, sheet metal process, laser machine working. There is an automatic changing of the cutting tool operation that is developed in the CNC machining process. In Non-machine tools it includes the welding machines, electronic assembly, coordinate measuring machine, and tape laying, filament winding machines for composites. a) Short production runs b) On conventional machining it requires expensive jigs and fixtures c) Parts with complicated outlines
10	**Examine - canned cycle.** BTL 3 A canned cycle is a way of conveniently performing repetitive CNC machine operations. Canned cycles automate certain machining functions such as drilling, boring, threading, pocketing, etc... Canned cycles are so called because they allow a concise way to program a machine to produce a feature of a part.
11	**Define NC.** BTL 1 Numerical control, popularly known as the **NC** is very commonly used in the machine tools. In other words, the numerical control machine is defined as the machined that is controlled by the set of instructions called as the program.
12	**Explain the major elements of NC machines.** BTL 1 The machine tool can be any machine like lathe, drilling machine, milling machine etc. The machine tool is the controlled part of the *NC* system. In case of the *CNC* machines, the microcomputer operates the machine as per the set of instructions or the program.
13	**Compare the different NC machines.** BTL 4 The machine tool can be any machine like lathe, drilling machine, milling machine etc. The machine tool is the controlled part of the *NC* system. In case of the *CNC* machines, the microcomputer operates the machine as per the set of instructions or the program.
14	**Compare incremental and absolute system.** BTL 1 Measurement solutions come in two flavors: Absolute and incremental. With an absolute measurement system, the system will generate an absolute signal, e.g. the position. An incremental system counts the number of steps between two positions. The clock isan absolute measurement system, it will tell you a point in time.
15	**Explain the role of computer for NC machine tool.**BTL 4 CNC is a computer assisted process to control general purpose machines from instructions generated by a processor and stored in a memory system. ... The controller uses a permanent resident program called an executive program to process the codes into the electrical pulses that control the machine.
	PART * B
1	**Describe the spindle drives used in CNC machine tools**. **(13M) (Nov.2017)** BTL 2 **Answer: Page 469Dr.R.PANNEERDHASS**

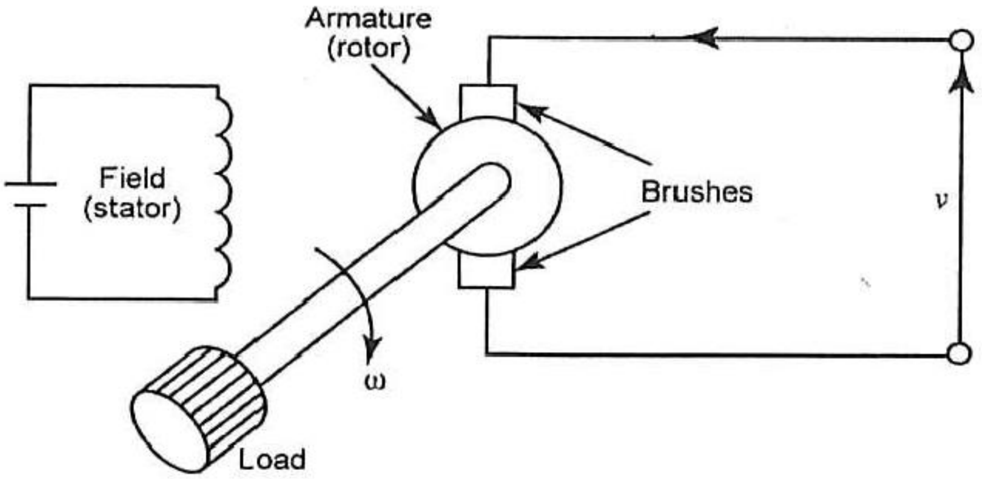
DRIVE SYSTEMS

Basically the NC and CNC components are divided into two groups. They are

1. Electromechanical devices
2. Digital Circuits

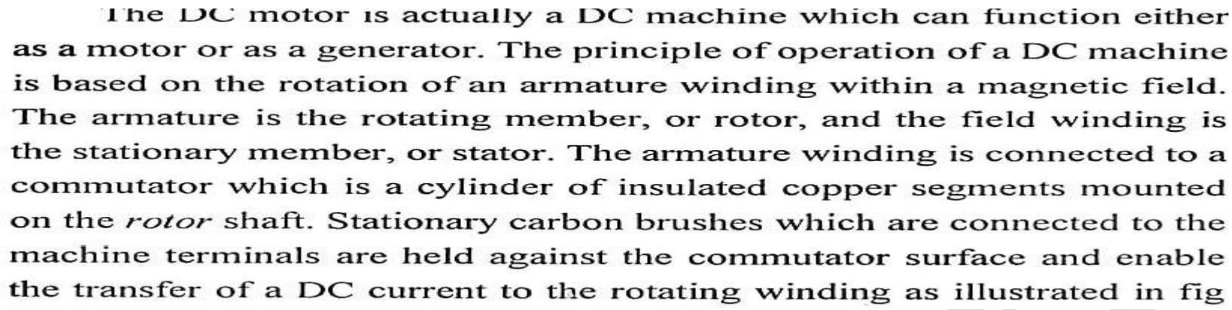
Every system includes a drive which converts the electrical command signals to mechanical motions. These are known as *electromechanical devices.* Drives for NC and robot systems are hydraulic actuators, DC motors or stepping motors. The selection depends upon the power requirements of the machine tool and the power sources available.

Principles of operation



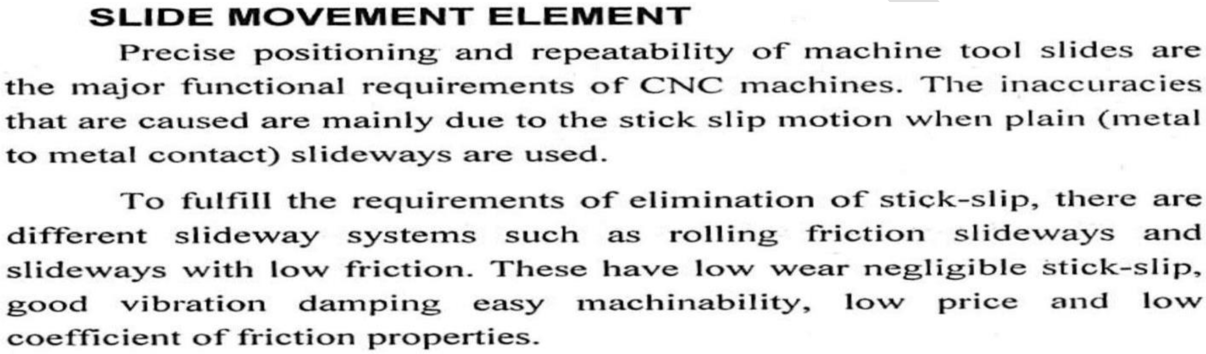
A separately excited dc motor

–



The DC motor is actually a DC machine which can function either as a motor or as a generator. The principle of operation of a DC machine is based on the rotation of an armature winding within a magnetic field. The armature is the rotating member, or rotor, and the field winding is the stationary member, or stator. The armature winding is connected to a commutator which is a cylinder of insulated copper segments mounted on the *rotor* shaft. Stationary carbon brushes which are connected to the machine terminals are held against the commutator surface and enable the transfer of a DC current to the rotating winding as illustrated in fig

Diagram(4M) Principle(4M)Construction(3M)Advantages and Disadvantages(2M



SLIDE MOVEMENT ELEMENT

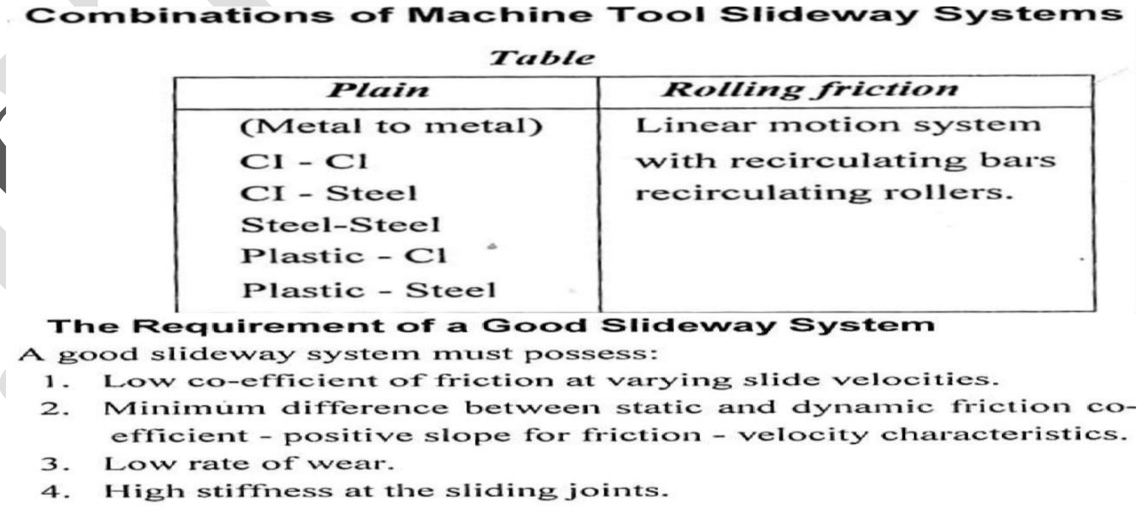
Precise positioning and repeatability of machine tool slides are the major functional requirements of CNC machines. The inaccuracies that are caused are mainly due to the stick slip motion when plain (metal to metal contact) slideways are used.

To fulfill the requirements of elimination of stick-slip, there are different slideway systems such as rolling friction slideways and slideways with low friction. These have low wear negligible stick-slip, good vibration damping easy machinability, low price and low coefficient of friction properties.

2 **Discuss about slide ways used in CNC machine tools. (13M) (Nov. 2017)** BTL 3

Answer: Page 477Dr.R.PANNEERDHASS

Diagram(4M) Principle(4M) Construction(3M) Advantages and Disadvantages(2M)



Combinations of Machine Tool Slideway Systems

Table

Plain	*Rolling friction*
(Metal to metal) CI - CI CI - Steel Steel-Steel Plastic - CI Plastic - Steel	Linear motion system with recirculating bars recirculating rollers.

The Requirement of a Good Slideway System

A good slideway system must possess:

1. Low co-efficient of friction at varying slide velocities.
2. Minimum difference between static and dynamic friction co-efficient - positive slope for friction - velocity characteristics.
3. Low rate of wear.
4. High stiffness at the sliding joints.

3 **Describe various type of CNC machine based on tool motion. (13M) (May 2017)** BTL 3

Answer: Page 440 Dr.R.PANNEERDHASS

Point to point system:

Tool is accurately located at some specified position. The spindle is first brought to the starting point, then moved to the next location (hole 1 along the marked path). On that location drilling operation is performed and then tool moves to next location.

Straight line system:

The cutting tool can be moved along a straight line only, which is parallel to the principal axes of motion. It is not possible to combine the motion of axes. Hence the tool motion is only along the X- axis, Y-axis and Z-axis. Due to this angular cuts cannot be produced.

Continuous system:

In this there is relative motion between the tool and workpiece during the whole operation. Due to this relative motion, different curves and profiles can be cut. Actually, it is a combination of point to point and straight cut system.

a) Diagram(4M)
b) Principle(4M)
c) Construction(3M)

Advantages and Disadvantages(2M)

4 **Explain the M code and G code with respect to manual part programming: (13M) (May 2017)** BTL 3

Answer: Page 469, 477Dr.R.PANNEERDHASS

M-codes are miscellaneous machine commands that do not command axis motion. The format for an M-code is the letter M followed by two to three digits; for example:

[M02 End of Program]
[M03 Start Spindle- Clockwise]
[M04 Start Spindle- Counter Clockwise]
[M05 Stop Spindle]
[M06 Tool Change]

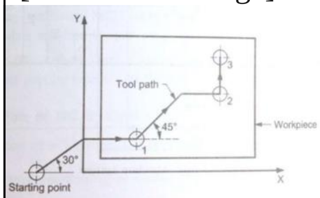


Fig. 7.4 (a) : Point to point system

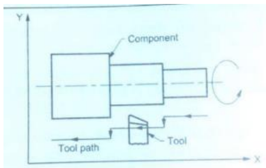


Fig. 7.4 (b) : Straight cut system

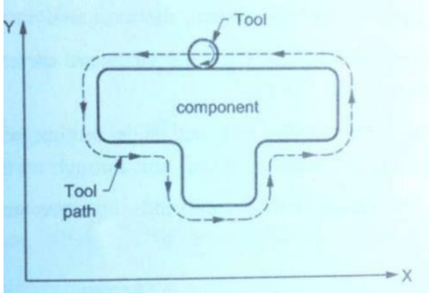


Fig. 7.4 (c) : Continuous path system

[M07 Coolant On]

[M53 Retract Spindle] (raises tool spindle above current position to allow operator to do whatever they would need to do)

M Codes are essential in **ALL** CNC programs to ensure a functioning line of code. All complete

CNC programs have an M code in both the first and last line of code.(7 M)

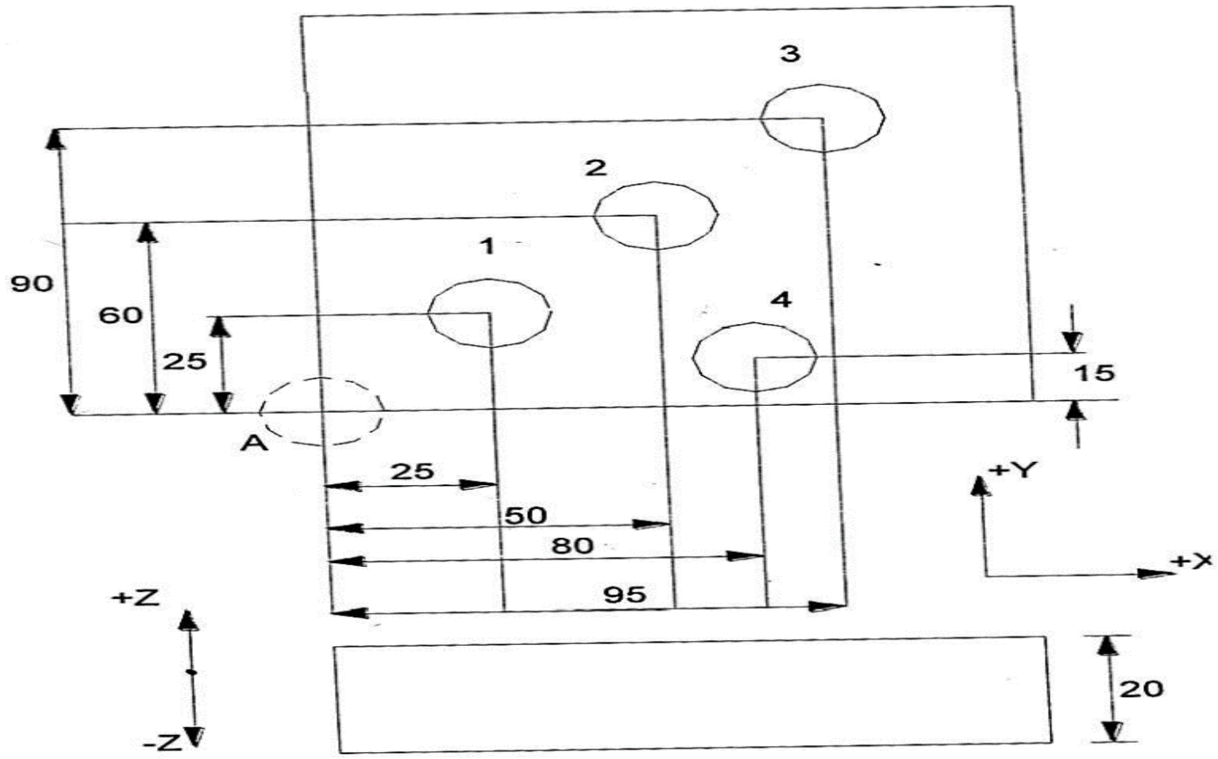
G-codes are used to command specific movements of the machine, such as machine moves or drilling functions. The format for a G-code is the letter G followed by two to three digits; for example G01. G-codes differ slightly between a mill and lathe application.

for example:

[G00 Rapid Motion Positioning]
[G01 Linear Interpolation Motion]
[G02 Interpolation Motion-Clockwise]
[G03 Circular Interpolation Motion-Counter Clockwise]
[G04 Dwell (Group 00) Mill]
[G10 Set offsets (Group 00) Mill]
[G12 Circular Pocketing-Clockwise]
[G13 Circular Pocketing-Counter Clockwise] (6 M)

5 **Write the part program for drilling holes in the part shown below. The plate thickness is 20mm. (13M) (Nov. 2016)** BTL4

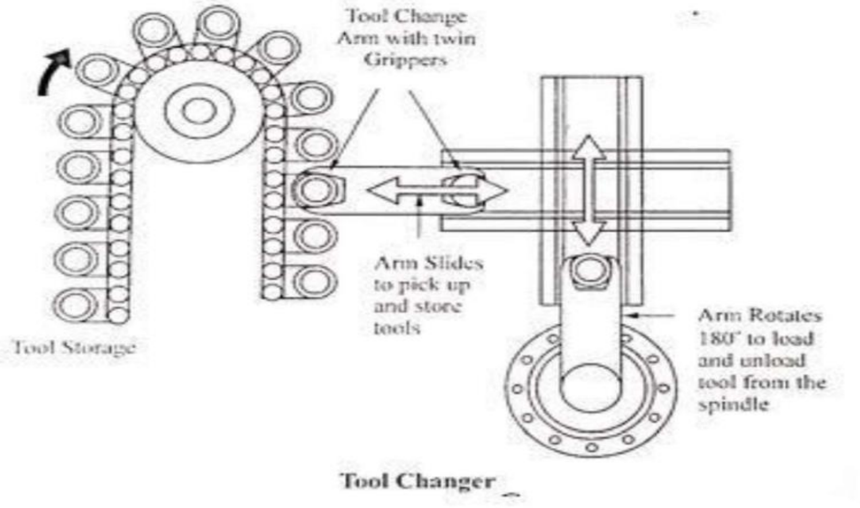
Answer: Page 530Dr.R.PANNEERDHASS

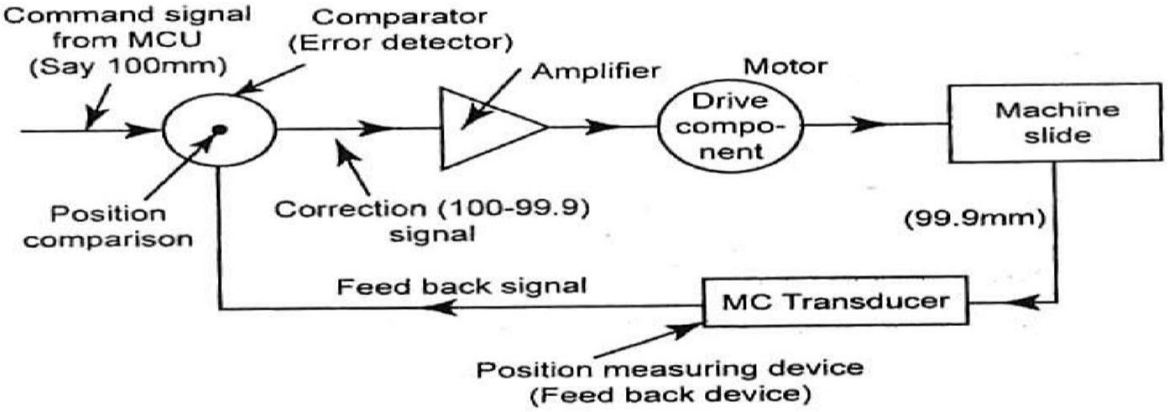


```
N100   G71    G91
N110   M06T1
N120   M03S1000
N130   G00    X00    Y00    Z10
N140   G01    Z–20   F0.5
N150   G00    X25    Y25    Z10
N160   G01    Z–20   F0.5
N170   G00    X50    Y60    Z10
N180   G01    Z–20   F0.5
N190   G00    X95    Y90    Z10
N200   G01    Z–20   F0.5
N210   G00    X80    Y15    Z10
N220   G01    Z–20   F0.5
N230   G00    X80    Y00    Z10
N240   G00    X00    Y00    Z10
N250   M05M02
```

6 **With a neat sketch explain the working of ATC. (13M) (Nov. 2016)** BTL 5
Answer: Page 443Dr.R.PANNEERDHASS

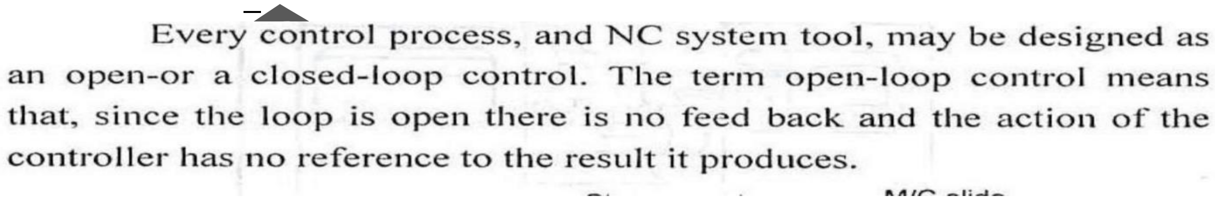
The CNC machines are designed to perform a number of operations in a single setting of the job. A number of tools may be required for making a complex part. In a manual machine, the tools are changed manually whenever required. In a CNC machine, tools are changed through program instructions. The tools are fitted in a tool magazine or drum. When a tool needs to be changed, the drum rotates to an empty position, approaches the old tool and pulls it. Then it again rotates to position the new tool, fits it and then retracts. This is a typical tool changing sequence of an automatic tool changer (ATC).





Closed loop positioning control

In closed loop, feed back system is used to close the loop. Position transducer acts as a feed back device. Figure 5.16 and 5.17 compare an open-loop and a closed-loop digital control for one axis of motion. The closed-loop control measures the axis actual position and compares it with the desired reference position. The difference between the actual and the desired valves is the error, and the control is designed in such a way as to eliminate or to reduce the error to a minimum. In this case, the system is a negative feed back one.



Every control process, and NC system tool, may be designed as an open-or a closed-loop control. The term open-loop control means that, since the loop is open there is no feed back and the action of the controller has no reference to the result it produces.

7 **List any five motions and control statements of computer assisted NC programming and explain. (13M) (May 2016)** BTL 2

Answer: Page 467Dr.R.PANNEERDHASS

Point to point system:

Tool is accurately located at some specified position. The spindle is first brought ot the starting p moved to the next location (hole 1 along the marked path). On that location drilling operation is p and then tool moves to next location.

Straight line system:

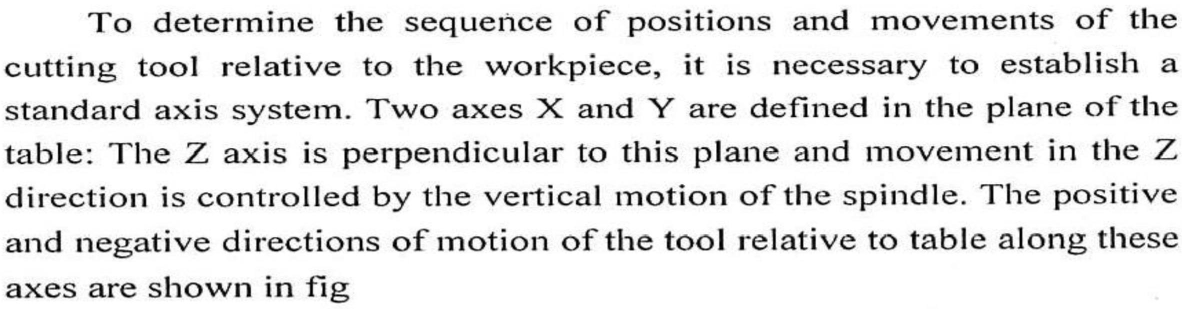
The cutting tool can be moved along a straight line only, which is parallel to the principal axes c It is not possible to combine the motion of axes. Hence the tool motion is only along the X-axi and Z-axis. Due to this angular cuts cannot beproduced.

Continuous system:

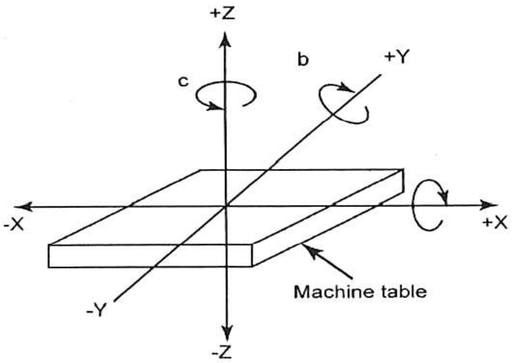
In this there is relative motion between the tool and workpiece during the whole operation. Due to this relative motion, different curves and profiles can be cut. Actually, it is a combination of point to point and straight cut system.

a) Diagram(4M)

Principle(4M)



To determine the sequence of positions and movements of the cutting tool relative to the workpiece, it is necessary to establish a standard axis system. Two axes X and Y are defined in the plane of the table: The Z axis is perpendicular to this plane and movement in the Z direction is controlled by the vertical motion of the spindle. The positive and negative directions of motion of the tool relative to table along these axes are shown in fig



8 **Describe in brief the basic components of a tape operated NC machine tool**. **(13M) (May 2015)** BTL 6

Answer: Page429 Dr.R.PANNEERDHASS

Load-N/C program controller- own memory - entire program - encoded paper or magnetic tape - execute commands-- one block at a time.

Controller - built-in memory (a CNC type of N/C machine)- three methods. The first method - keying program directly --multi thousand dollar controller and machine tool - keyed in one command at a time

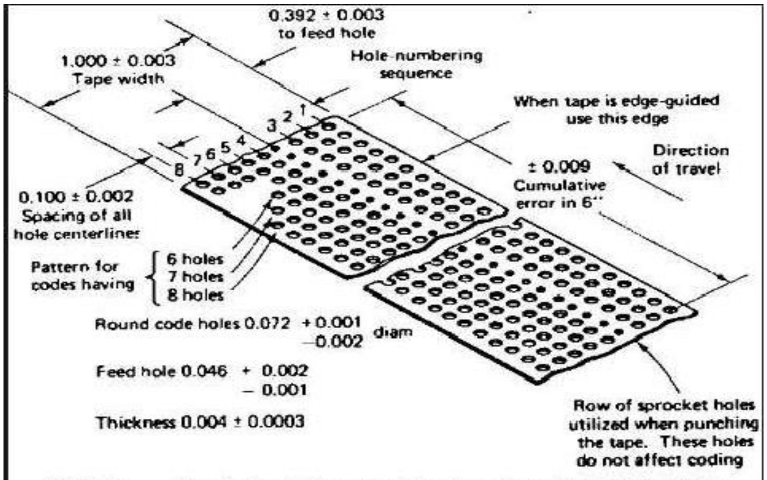


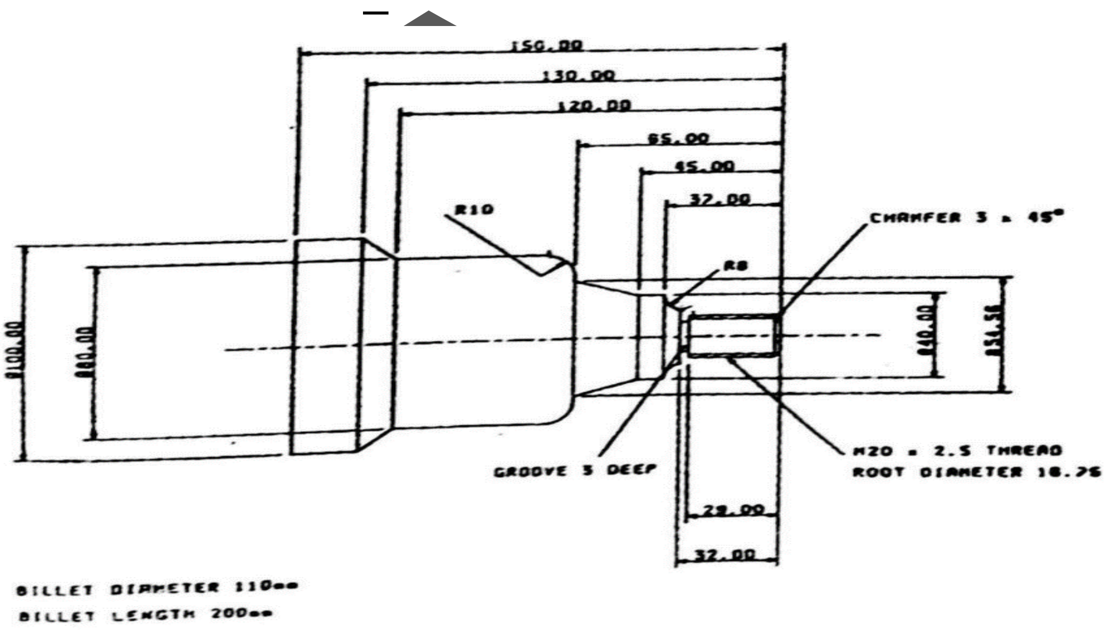
FIGURE Numerical control punched tape format as standardized by the Electronics Industries Association (EIA). (Reprinted from Childs [1].)

(8M)

PART * C

1 **Write CNC part program for the component shown in fig mention the assumptions made. (15M) (May 2017)** BTL 5

Answer: Page 433Dr.R.PANNEERDHASS

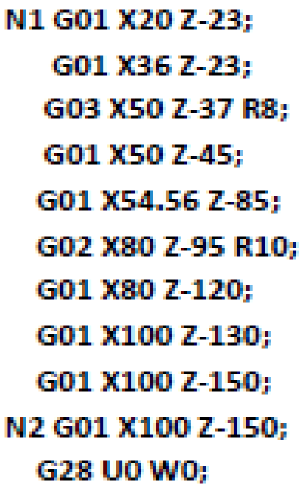


BILLET DIAMETER 110mm
BILLET LENGTH 200mm

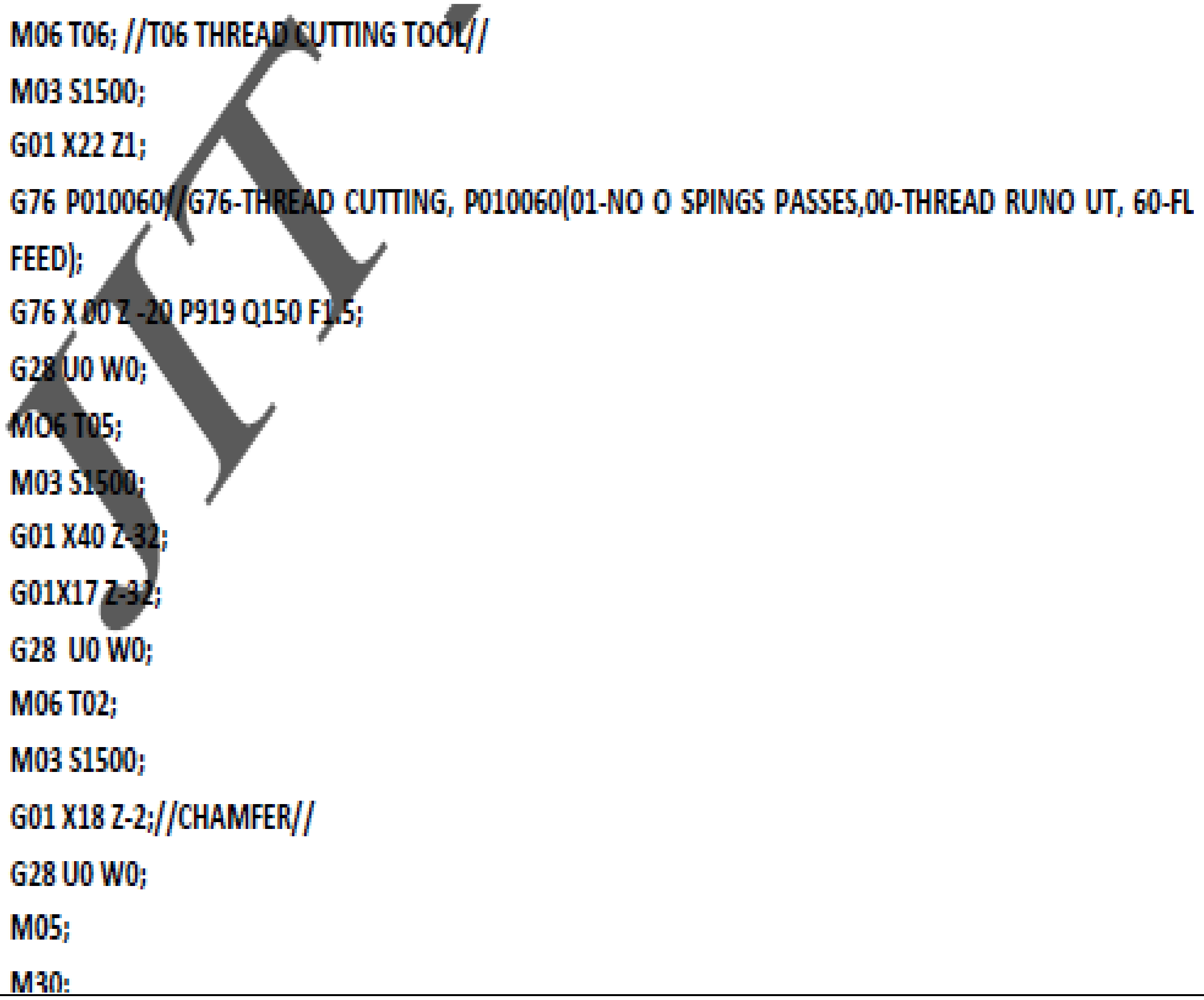
All dimensions in mm.

```
[BILLET X110 Z200;
G21 G98;
M06 T01; //T01 TURNING TOOL//
G28 U0 W0;
M03 S1500;
G00 X112 Z1;
G71 U0.5 R0.1; // G71 TURNING CYCLE FIRST BLOCK U-DEPTH OF CUT, R- RETURN VALUE OF EACH CUT//
G71 P1 Q2 U0.1 W0.1 F50; //G71 TURNING CYCLE SECOND BLOCK
 P, Contour start block number Q- Contour end block number, U- Finishing allowance in x- axis,
 W- finishing allowance in z-axis, F- feed rate during G71cycle, S-spindle speed during G71 cycle)//
```

(5 M)



```
 N1 G01 X20 Z-23;
      G01 X36 Z-23;
     G03 X50 Z-37 R8;
     G01 X50 Z-45;
    G01 X54.56 Z-85;
    G02 X80 Z-95 R10;
    G01 X80 Z-120;
    G01 X100 Z-130;
    G01 X100 Z-150;
 N2 G01 X100 Z-150;
    G28 U0 W0;
```



```
M06 T06; //T06 THREAD CUTTING TOOL//
M03 S1500;
G01 X22 Z1;
G76 P010060//G76-THREAD CUTTING, P010060(01-NO O SPINGS PASSES,00-THREAD RUNO UT, 60-FL
FEED);
G76 X 00 Z -20 P919 Q150 F1.5;
G28 U0 W0;
MO6 T05;
M03 S1500;
G01 X40 Z-32;
G01X17 Z-32;
G28  U0 W0;
M06 T02;
M03 S1500;
G01 X18 Z-2;//CHAMFER//
G28 U0 W0;
M05;
M30;
```

2

Write short notes on APT language. (15M) (May 2016) BTL 5

Answer: Page 493 – Dr.R.PANNEERDHASS

APT Program

```
    MACHIN/ MILL
P0 = POINT/ 0, 0, 3
P1 = POINT/ 1, 0
L1 = LINE/ P1 , SLOPE, 0
L2 = LINE/ P1 , SLOPE, 90
L3 = LINE/ PARLEL, L1, YLARGE, 2
L4 = LINE/ (POINT/ 4, 2), SLOPE, 1, L3
L5 = LINE/ (POINT/ 6, 4), ATANGL, 270, L4
L6 = LINE/ (POINT/ 10, 0), PEPTO, L3
P2 = POINT/ INTOF, L3, L4
P3 = POINT/ INTOF, L4, L5
P4 = POINT/ INTOF, L5, L3
PL = PLANE/ P1, P2, P3
    CUTTER/ 60
    TOLER/ 0.1
    SPINDL/ 200
    COOLNT/ ON
    FEDRAT/ 20
```

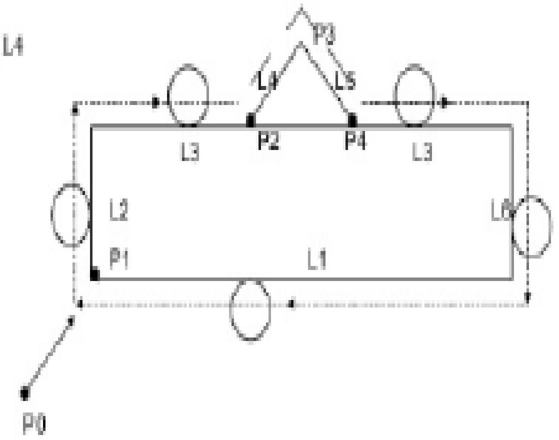
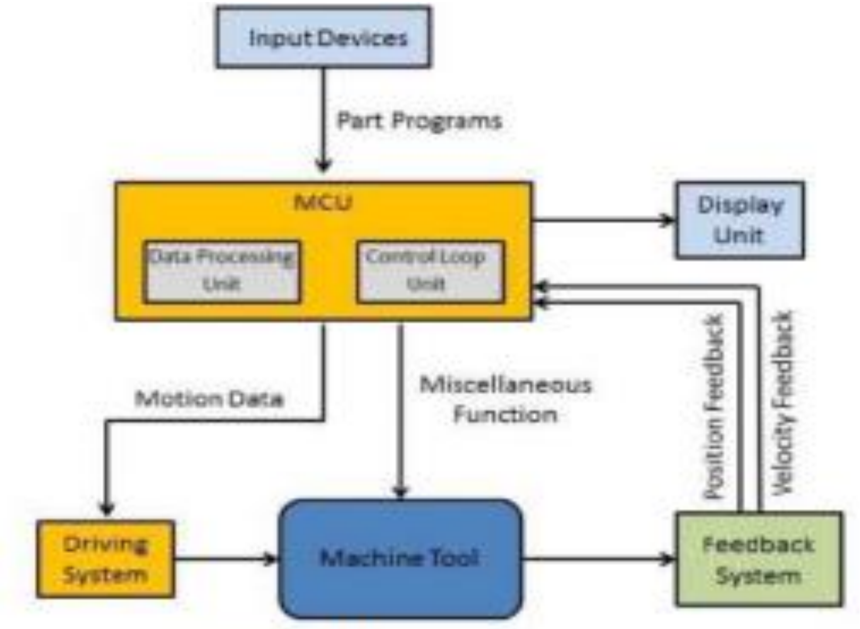


Diagram (7M)

APT or Automatically Programmed Tool is a high-level computer programming **language** most commonly used to generate instructions for numerically controlled machine tools.

Program (8M)

3	**Discuss the important design features of CNC machine tool. (15M) (May 2015) BTL 6** **Answer: Page 453 – Dr.R.PANNEERDHASS**  a) Diagram (4M) b) Principle (4M) c) Construction (4M) d) Advantages and Disadvantages (3M)

	UNIT V CELLULAR MANUFACTURING ANDFLEXIBLE MANUFACTURINGSYSTEM(FMS)
	Group Technology (GT),Part Families–Parts Classification and coding–Simple Problems in Opitz Part Coding system–Production flow Analysis–Cellular Manufacturing–Composite part concept–Types of Flexibility - FMS – FMS Components – FMS Application & Benefits – FMS Planning and Control– Quantitative analysis in FMS
Q.No.	**Questions**
	PART - A
1	**Define Group Technology (GT).**(BTL1) Identical or similar components grouped processed together during design, process planning and manufacturing so that a wide variety of components can be manufactured, at the least expense of time, inventory, man hours and material handling.
2	**List out the stages in Group Technology**.(BTL2) • Production planners to setup the GT database. • Grouping the parts or components into part-families with some similar characteristics. • Re-design the shop-floor arrangement according to common shape, function or manufacturing process and tooling.
3	**Define Part family.** (BTL1) collection of parts which are similar in terms of geometricshape, size, and similar processing steps required in manufacturing, so flow of materials through the plant improves"
4	**List the general methods used for grouping parts into families**.(BTL2) • Visual Inspection • Parts classification and coding system • Production flow analysis.
5	**What is Production Flow Analysis (PFA)?**(BTL1) Identifying part families and associated machine groupings that uses the information contained on production route sheets rather on part drawings.
6	**List the steps involved in PFA**.(BTL2) • Data Collection • Sortation of process routings • Preparation of PFA chart • Cluster analysis.
7	**List out the 3 basic code structures used in GT applications.**(BTL1) • Hierarchical codes • Attribute codes • Decision tree-codes.
8	**What is the main difference between hierarchical codes and attribute code structures?**(BTL1) Interpretation of each symbol in the sequence depends on the value of preceding symbols. Whereas in attribute/polycode structure, the interpretation of each symbol in the sequence does not depend on the value of preceding symbols.
9	**List any six coding systems that are widely recognized in industries.**(BTL2) • Optiz classification system • MICLASS system

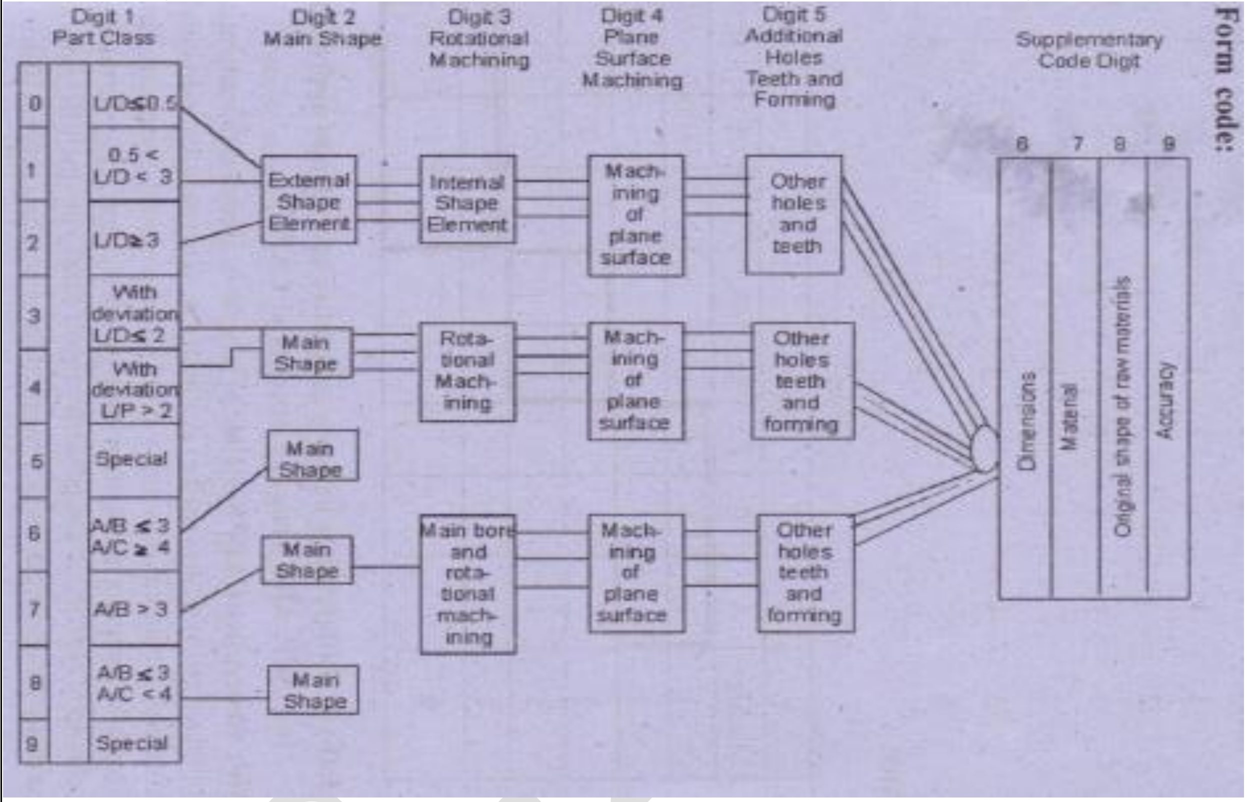
	• DCLASS system • KK-3 System • CODE system • CUTPLAN system
10	**What is cellular manufacturing?**(BTL1) Application of GT in which dissimilar machines have beenaggregated into cells, each of which is dedicated to the production of a part family.
11	**List any four design considerations guiding the cell formation.**(BTL2) • Parts/products to be fully completed in the cell. • Higher operator utilization • Fewer operations than equipment • Balanced equipment utilization in the cell.
12	**What is Process planning?**(BTL1) • Preparing a set of instructions that describe how to fabricate apart or build an assembly which will satisfy engineering design specifications. • Systematic determination of the methods by which product is to be manufactured, economically and competitively.
13	**List the activities associated with process planning.** (BTL2) • Analyzing finished part equipment's • Determining operating sequence • Selecting machines • Selecting material parameters • Calculating process times • Documenting process planning
14	**What is meant by CAPP?**(BTL1) CAPP refers to computer aided process planning. CAPP is used to overcome the drawbacks of manual process planning. With the use of computers in the process planning, one can reduce the routine clerical work of manufacturing engineers. Also it provides the opportunity to generate rational, consistent and optimal plans.
15	**What are the approaches the CAPP will recognize?**(BTL1) • Two approaches to CAPP are traditionally recognized: the variant approach and the generative approach. • Many CAPP systems combine both approaches.
16	**Why CAPP systems are called as variant system?**(BTL1) • The investment is less and the development time is shorter. Especially for medium sized companies which want to establish their own research groups. • The development costs and hardware costs are lower. Especially for some small companies where the products do not vary much and who still have process planners.
17	**Give the main component of generative CAPP systems.**(BTL1) CAPP system contains of two main components. • Manufacturing data base (part description, machine tool library etc.) • Decision logic (to represent the process planner)
18	**List out the basic approaches of CAPP.** (BTL1) • Retrieval (or variant) CAPP system • Generative CAPP system.
19	**List out the results of Process Planning?**(BTL1) • Routings which specify operations, operation sequences, work centers, standards, tooling and

	fixtures. - Process plans which typically provide more detailed, step-by-step work instructions including dimensions related to individual operations, machining parameters, set-up instructions, and quality assurance checkpoints. - Fabrication and assembly drawings to support
20	**List out the factors should be considered in selection of tooling.**(BTL1) - The type and amount of the material to be cut. - The surface finish required - The rigidity and shape of the part. - The capacity and condition of the available equipment
21	**List out the prerequisites for process planning.**(BTL1) - Part list - Annual demand/ batch size - Accuracy and surface finish requirement - Equipment details - Data on cutting fluids, tools, jigs and fixtures, gauges. - Standard available stock sizes. - Machining data, data on handling and setup.
22	**What is the weakness of PFA?**(BTL1) Data used are derived from production route-sheets. But the process-sequences have been prepared by different process lanners and the difference is reflected on to these route-sheets.
23	**List some commercially available CAPP**. (BTL2) - Some of the commercial variant CAPP systems include CUTPLAN. COMCAPP V, DCLASS and INTELLICAP. - Some of the commercial generative CAPP systems include AUTAP, CMPP, GENPLAN and LO CAM.
24	**What is CMPP?(BTL1)** CMPP stands for computer-managed process planning.It is a commercial generative process planning system capable of automatically making process decisions.
	PART – B
1	**Explain the various DCCLASS coding systems. (**BTL2) **Answer: Page.1.68 - Dr.V.Jayakumar** - The first segment (three digits) is used to denote the basic shape. (2M) - The second segment (4th digit) is used to specify the complexity of the parts. (2M) - The third segment (5th digit) is used to specify the overall size of the coded part.(2M) - The fourth segment (6th digit) represents precision.(2M) - The final segment (two digits) is used to denote the material type.(2M) Explanation of coding system (3M)

2 **Explain OPTIZ CODINGsystem?(13M)**BTL2
Answer:Page.1.68 - Dr.V.Jayakumar

Optiz(7 M)

Classification System:(4 M)
The optiz system was developed by H. Optic of Aachen University, Germany. In fact it was the most popular and one of the first published classification and coding systems schemes for mechanical parts.

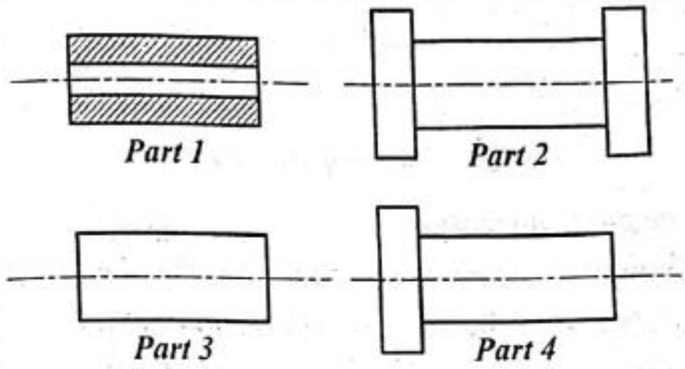
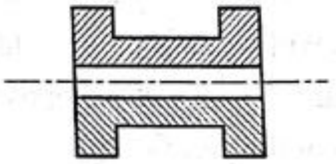


This system uses alpha numeric symbols to represent the, various attributes of the part.
The optiz coding system uses the following digit sequence:(4 M)
Example: 12345 6789 ABCD.
The first five (12345) digits code the major design of the part and are called the "Form Code".
The next for digits (6789) are for coding manufacturing related attributes and are called "Supplementary Code".

<table>
<tr><td>3</td><td>Give the form code for the part family using any one coding system. (BTL2)
Answer:Page.1.68 - Dr.V.Jayakumar

Coding is a systematic process of establishing an alphanumeric value for parts based on selected part features. Classification is the grouping of parts based on code values.(3M)
Design and manufacturing attributes (2M)
Systems based on part design attributes
Systems based on part manufacturing attributes
Systems based on both design and manufacturing attributes.
Coding system (2M)
Hierarchical codes
Attribute codes
Decision tree codes
Explanation of any one system : OPTIZ / MICLASS / DCLASS (6M)</td></tr>
<tr><td>4</td><td>Discuss how group technology is used in designing manufacturing cells. (BTL2)
Answer:Page.1.68 - Dr.V.Jayakumar
Once parts have been grouped into part families by parts classification and coding or production flow analysis, the next problem would be determining how to arrange the machines in the shop.(2 M)
<u>Facility layout</u>, also known as plant layout, refers to the physical arrangements of production facilities. It is the configuration of departments, work centers, and equipment in the conversion process.(2M)
The <u>objective</u> of facility layout is to design a physical arrangements that most economically meets the required output quantity and quality.(2M)
There are three basic ways to arrange machines in a shop. They are (2M)
Line (or product) layout,
Functional (or process) layout
Group (or combination) layout.
Explanation of any one layout (5M)</td></tr>
<tr><td></td><td>PART – C</td></tr>
<tr><td>1.</td><td>Discuss ERP with suitable modules. (BTL3)
Answer: Page 2.78 -Dr.V.Jayakumar
ERP : Enterprise Resource Planning (2 M)
List of different Modules: Finance module
Manufacturing module
Distribution module
Service module
Transportation module
Process module
Project module
Tools module(5M)
Explanation of any two modules
Accounting – oriented information system
Effective planning and control (8M)</td></tr>
</table>

2	**Briefly discuss various benefits of implementing a GT in a firm. Also bring out the adv and limitations of using group technology. (**BTL3)**Answer:Page.1.68 - Dr.V.Jayakumar** **Benefits of group technology** • Product design • Tooling and setups • Materials handling • Production and inventory control • Process planning • Management and employees(5 M) **Advantages of GT** • GT facilitates: efficient retrieval of similar parts • GT encourages standardization of designs, tooling, fixing and setups • GT facilities: Development of a computer-aided process planning (CAPP) • Times and costs for material handling and waiting between stages are reduced. • Production planning and control is simplified • Part and product quality are improved • Better employee involvement and increases workers satisfaction(10 M)
3	**Discuss arranging machines in a GT Cell in detail with holier method.** (BTL3) After part-machine groupings have been identified (by rank order clustering algorithm) a problem is to arrange the machines into the most logical sequence. Design the cellular manufacturing system are: • The determination of the most logical machine sequence in each cell • The development of a feasible layout plan for each cell Literature to determine the most logical machine in a GT Cell, the Holier method 2 (7M) **Procedure of Holier method** • Develop the From-TO chart from part routing data • Calculate the "'From/To ratio" for each machine • Arrange Machines in a GT Cell in order of decreasing "From/To ratio"(4M) Performance measures for Machine sequences in a GT Cell • Percentage of In sequences in a GT Cell • Percentages of Bypassing moves • Percentages of backtracking moves. (4M)
4	**Explain composite part concept in cellular manufacturing.** (May/June 2013).(BTL2) **Answer:Page.1.68 Dr.V.Jayakumar** A composite part is a hypothetical part which includes all of the design and manufacturing attributes of a family. The composite is a single hypothetical part that can be completely processed in manufacturing cell .(3M) Let us consider that there are four number of parts as shown in figure a, all of whom have similar machining operations to be done, Then it is possible to construct a new composite part as shown in figure b that has all the features identified in the four parts from figure b(4 M)

	 (a) Individual parts  (b) Composite part consisting of all attributes of the four parts (8M)

ME8692 FINITE ELEMENT ANALYSIS

L	T	P	C
3	0	0	3

OBJECTIVES:

- To introduce the concepts of Mathematical Modeling of Engineering Problems.
- To appreciate the use of FEM to a range of Engineering Problems.

UNIT I INTRODUCTION 9

Historical Background – Mathematical Modeling of field problems in Engineering – Governing Equations – Discrete and continuous models – Boundary, Initial and Eigen Value problems– Weighted Residual Methods – Variational Formulation of Boundary Value Problems – Ritz Technique – Basic concepts of the Finite Element Method.

UNIT II ONE-DIMENSIONALPROBLEMS 9

One Dimensional Second Order Equations – Discretization – Element types- Linear and Higher order elements – Derivation of Shape functions and Stiffness matrices and force vectors- Assembly of Matrices - Solution of problems from solid mechanics and heat transfer. Longitudinal vibration frequencies and mode shapes. Fourth Order Beam Equation –Transverse deflections and Natural frequencies of beams.

UNIT III TWO DIMENSIONAL SCALAR VARIABLE PROBLEMS 9

Second Order 2D Equations involving Scalar Variable Functions – Variational formulation – Finite Element formulation – Triangular elements – Shape functions and element matrices and vectors. Application to Field Problems - Thermal problems – Torsion of Non circular shafts – Quadrilateral elements – Higher Order Elements.

UNIT IV TWO DIMENSIONAL VECTOR VARIABLE PROBLEMS 9

Equations of elasticity – Plane stress, plane strain and axisymmetric problems – Body forces and temperature effects – Stress calculations - Plate and shell elements.

UNIT V ISOPARAMETRIC FORMULATION 9

Natural co-ordinate systems – Iso parametric elements – Shape functions for iso parametric elements – One and two dimensions – Serendipity elements – Numerical integration and application to plane stress problems - Matrix solution techniques – Solutions Techniques to Dynamic problems – Introduction to Analysis Software

TOTAL: 45 PERIODS

OUTCOMES:

Upon completion of this course, the students can able to understand different mathematical Techniques used in FEM analysis and use of them in Structural and thermal problem

TEXT BOOK:

1. Reddy. J.N., “An Introduction to the Finite Element Method”, 3rd Edition, Tata McGraw-Hill, 2005
2. Seshu, P, “Text Book of Finite Element Analysis”, Prentice-Hall of India Pvt. Ltd., New Delhi,2007.

REFERENCES:

1. Rao, S.S., “The Finite Element Method in Engineering”, 3rd Edition, Butterworth Heinemann,2004
2. Logan, D.L., “A first course in Finite Element Method”, Thomson Asia Pvt. Ltd., 2002
3. Robert D. Cook, David S. Malkus, Michael E. Plesha, Robert J. Witt, “Concepts and Applications of Finite Element Analysis”, 4th Edition, Wiley Student Edition, 2002.
4. Chandrupatla&Belagundu, “Introduction to Finite Elements in Engineering”, 3rd Edition,Prentice Hall College Div, 1990
5. Bhatti Asghar M, "Fundamental Finite Element Analysis and Applications", John Wiley & Sons,2005 (Indian Reprint 2013)

Subject Code: ME8692 Year/Semester: III /06
Subject Name: Finite Element Analysis Subject Handler: Mr.S.Arun & Mr.D. Arunkumar

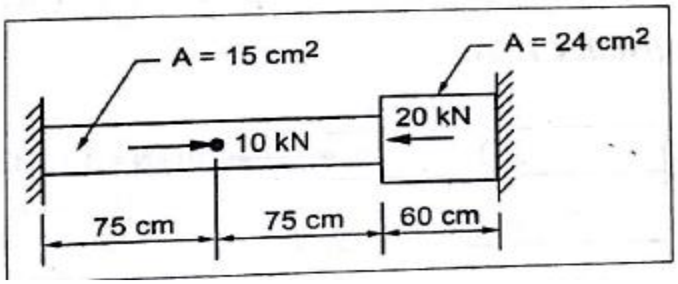
UNIT I INTRODUCTION

Historical Background – Mathematical Modeling of field problems in Engineering – Governing Equations – Discrete and continuous models – Boundary, Initial and Eigen Value problems– Weighted Residual Methods – Variational Formulation of Boundary Value Problems – Ritz Technique – Basic concepts of the Finite Element Method.

PART * A

Q.No.	Questions
1.	**What should be considered during piecewise trial functions?(APRIL 2011)**BTL1 Continuity of the field variable and its derivatives at the junctions are considered.
2	**Mention the basic steps of Rayleigh-Ritz method. (APRIL 2011)**BTL1 Basic steps of Rayleigh-Ritz method are, ' • Assume a displacement field • Evaluation of the total potential • Setup and solve the system of equations.
3	**What is meant by node or joint?(APRIL 2019)**BTL1 Each kind of finite element has a specific structural shape and is interconnected with the adjacent element by nodal point or nodes. At the nodes, degrees of freedom are located. The forces will act only at nodes at any others place in the element.
4	**What is the basic of finite element method?** BTL1 Discretization is the basis of finite element method. The art of subdividing a structure in to convenient number of smaller components is known as discretization.
5	**What are the types of boundary conditions?(APRIL 2019)**BTL1 • Primary boundary conditions • Secondary boundary conditions
6	**State the methods of engineering analysis. (APRIL 2010)** BTL1 • Experimental methods • Analytical methods • Numerical methods or approximate methods
7	**State the three phases of finite element method.(APRIL 2019)**BTL1 • Preprocessing • Analysis • Post Processing
8	**What is nonstructural problem? (APRIL 2014)** BTL1 Temperature or fluid pressure at each nodal point is obtained. By using these values properties such as heat flow fluid flow for each element can be calculated.
9	**What is structural problem? (APRIL 2013)** BTL1 Displacement at each nodal point is obtained. By these displacements solution stress and strain in each element can be calculated.
10	**What are the methods are generally associated with the finite element analysis?** BTL1 • Force method

	• Displacement or stiffness method.
11	**Explain stiffness method.** BTL1 Displacement or stiffness method, displacement of the nodes is considered as the unknown of the problem. Among them two approaches, displacement method is desirable.
12	**What is meant by post processing?** BTL1 Analysis and evaluation of the solution result is referred to as post processing. Postprocessor computer program help the user to interpret the result by displaying them in graphical form.
13	**Name the variation methods.** BTL1 • Ritz method • Ray-Leigh Ritz method
14	**What is meant by degrees of freedom?** BTL1 When the force or reaction act at nodal point node is subjected to deformation. The deformation includes displacement rotation, and or strains. These are collectively known as degrees of freedom.
15	**What is meant by discretization and assemblage?** BTL1 The art of subdividing a structure in to convenient number of smaller components is known as discretization. These smaller components are then put together. The process of uniting the various elements together is called assemblage.
17	**What is truss element?** BTL1 The truss elements are the part of a truss structure linked together by point joint which transmits only axial force to the element.
18	**What is Aspect ratio?** BTL1 • It is defined as the ratio of the largest dimension of the element to the smallest dimension. • In many cases, as the aspect ratio increases the in accuracy of the solution increases. • The conclusion of many researches is that the aspect ratio should be close to unity as possible
19	**What is Rayleigh-Ritz method?**BTL1 It is integral approach method which is useful for solving complex structural problem, encountered in finite element analysis. This method is possible only if a suitable function is available.
20	**What are the h and p versions of finite element method?** BTL1 • It is used to improve the accuracy of the finite element method. • In h version, the order of polynomial approximation for all elements is kept constant and the numbers of elements are increased. • In p version, the numbers of elements are maintained constant and the order of polynomial approximation of element isincreased.
	PART * B
1	**Find the nodal displacement and elemental stresses for the bar shown in fig.(13M) (APRIL 2015,APRIL 2019)** BTL3 **Answer: page – 1.07 Dr. S.Senthil**



Given

Area of element1= 15 cm^2
Area of element1= 15 cm^2
Area of element1= 24 cm^2
Length of element1= 75 cm
Length of element1= 75 cm
Length of element1= 60 cm

Find

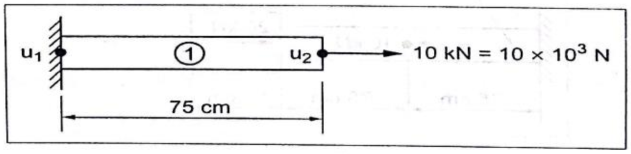
Nodal displacement
Elemental Stress

Solution

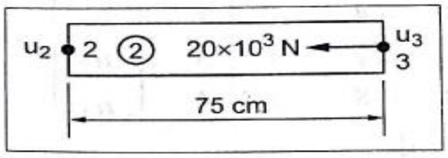
Finite element equation for one dimensional two noded bar element

$$\begin{Bmatrix} F_1 \\ F_2 \end{Bmatrix} = \frac{AE}{l} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix}$$

For element (1): (Nodes 1, 2):

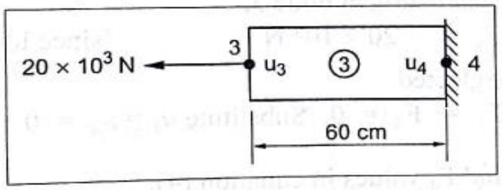


For element (2): (Nodes 2, 3)



(4 M)

For element (3), Nodes (3, 4):



(2 M)

Result

<table>
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(*i*) Nodal displacement, $u_1 = 0$ cm

$u_2 = 5 \times 10^{-4}$ cm

$u_3 = -1.5 \times 10^{-3}$ cm

$u_4 = 0$ cm

(*ii*) Elemental stresses, $\sigma_1 = 133.33$ N/cm² (Tensile)

$\sigma_2 = -533.33$ N/cm² (Compressive)

$\sigma_3 = 500$ N/cm² (Tensile)

(7 M)

</td>
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<tr>
<td>2</td>
<td>

Calculate nodal displacement and elemental stresses for the truss shown in fig. E= 70 Gpa. Cross sectional area A= 2 cm^2 for all truss members. (13 M) (APRIL 2011) BTL3

Answer: page – 1.09 Dr. S.Senthil

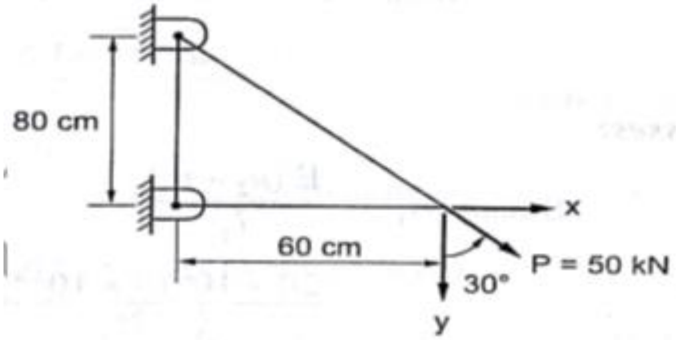
Given

Youngs modulus = 70 Gpa

Area = 2 cm^2

Point load = P sin30°

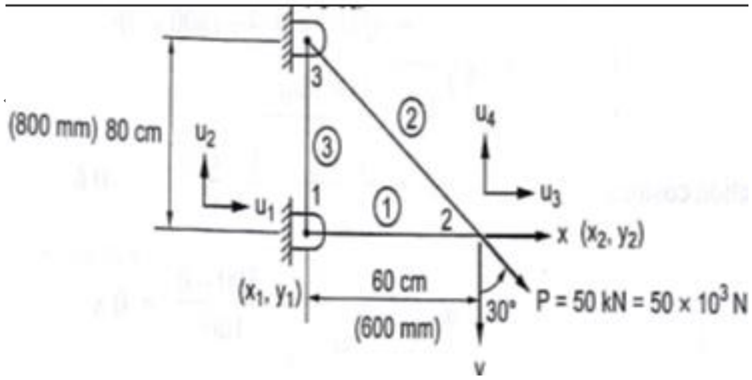
Point load = - P cos30°



Find

1. Nodal displacement
2. Stress in the member

Solution



(3 M)

</td>
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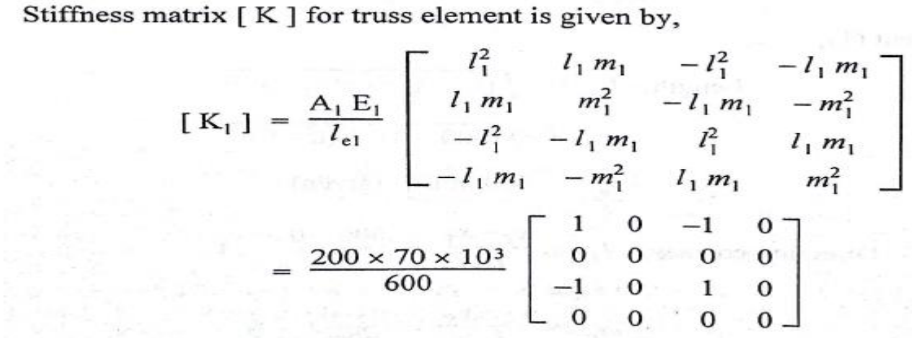


Stiffness matrix [K] for truss element is given by,

$$[K_1] = \frac{A_1 E_1}{l_{e1}} \begin{bmatrix} l_1^2 & l_1 m_1 & -l_1^2 & -l_1 m_1 \\ l_1 m_1 & m_1^2 & -l_1 m_1 & -m_1^2 \\ -l_1^2 & -l_1 m_1 & l_1^2 & l_1 m_1 \\ -l_1 m_1 & -m_1^2 & l_1 m_1 & m_1^2 \end{bmatrix}$$

$$= \frac{200 \times 70 \times 10^3}{600} \begin{bmatrix} 1 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 \\ -1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

(7 M)

Result

Nodal displacement at node3 = - 0.3256 mm

Nodal displacement at node4 = - 5.110 mm

Elemental stresses at 1= -37.98 N/mm^2

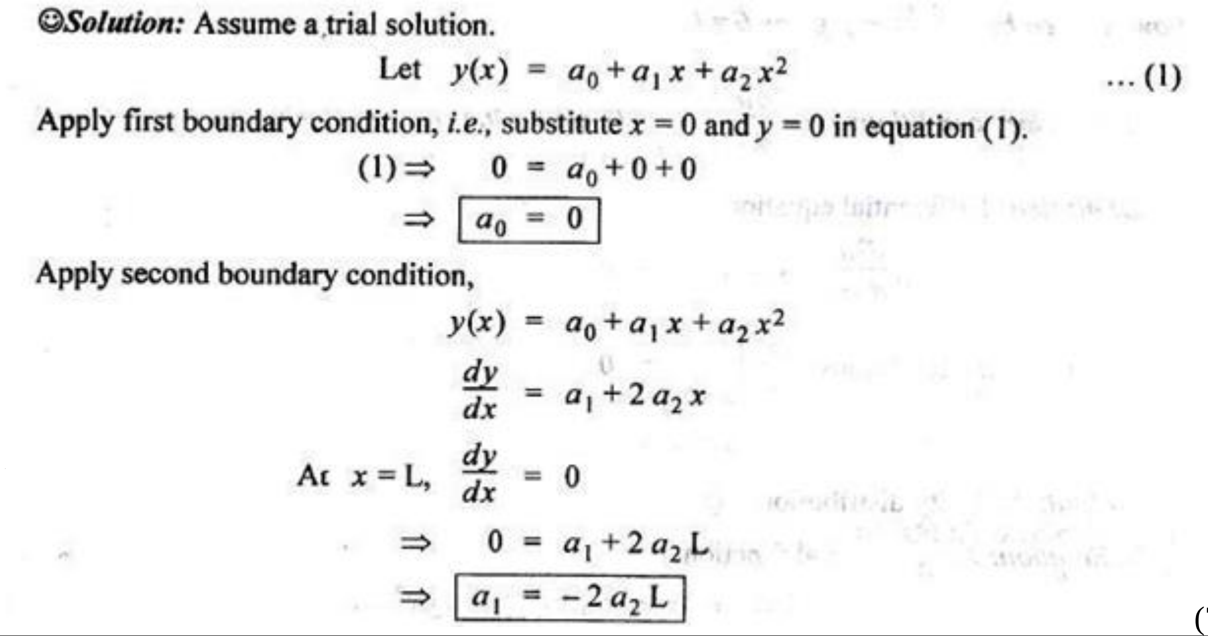
Elemental stresses at 2= 272.51 N/mm^2

Elemental stresses at 3= 0 N/mm^2(3M)

3

The following differential equation is available for a physical phenomenon AE d^{2}y/dx^2 +q$_0$ =0 with the boundary condition y(0)=0, x=L, dy/dx=0, find the value of f(x) using the weighted residual method. (13M) (APRIL 2014)BTL3

Answer: page – 1.16 Dr. S.Senthil



☺***Solution:*** Assume a trial solution.

$$\text{Let} \quad y(x) = a_0 + a_1 x + a_2 x^2 \qquad \ldots (1)$$

Apply first boundary condition, *i.e.*, substitute $x = 0$ and $y = 0$ in equation (1).

$$(1) \Rightarrow \quad 0 = a_0 + 0 + 0$$

$$\Rightarrow \boxed{a_0 = 0}$$

Apply second boundary condition,

$$y(x) = a_0 + a_1 x + a_2 x^2$$

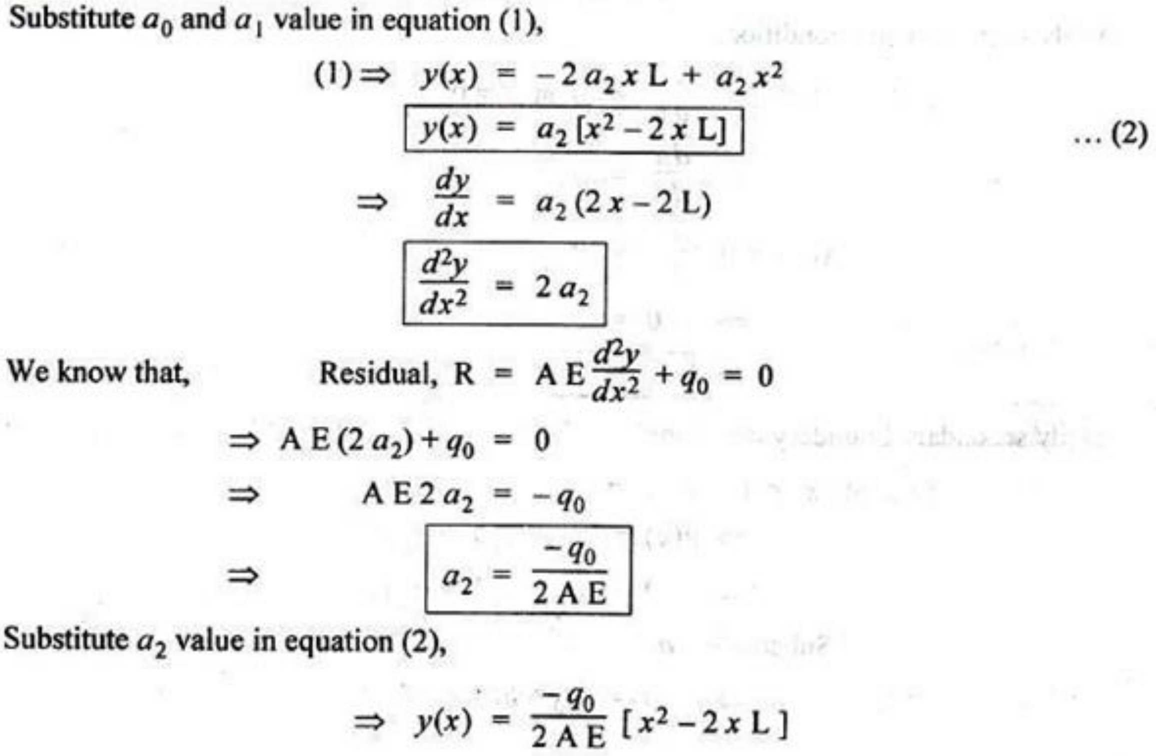
$$\frac{dy}{dx} = a_1 + 2 a_2 x$$

$$\text{At } x = L, \quad \frac{dy}{dx} = 0$$

$$\Rightarrow \quad 0 = a_1 + 2 a_2 L$$

$$\Rightarrow \boxed{a_1 = -2 a_2 L}$$

(7M)

	 Substitute a_0 and a_1 value in equation (1), $(1) \Rightarrow \; y(x) = -2\,a_2\,x\,L + a_2\,x^2$ $\boxed{y(x) = a_2\,[x^2 - 2\,x\,L]} \qquad \ldots(2)$ $\Rightarrow \; \frac{dy}{dx} = a_2\,(2\,x - 2\,L)$ $\boxed{\frac{d^2y}{dx^2} = 2\,a_2}$ We know that, Residual, $R = A\,E\,\frac{d^2y}{dx^2} + q_0 = 0$ $\Rightarrow A\,E\,(2\,a_2) + q_0 = 0$ $\Rightarrow A\,E\,2\,a_2 = -q_0$ $\Rightarrow \boxed{a_2 = \frac{-q_0}{2\,A\,E}}$ Substitute a_2 value in equation (2), $\Rightarrow \; y(x) = \frac{-q_0}{2\,A\,E}\,[x^2 - 2\,x\,L]$ (6M)
4	**We know that, linearly varying pressure acting on the side J, K,N =0 Determine the expression for the deflection and bending moment in a simply supported beam subjected to uniformly distributed load over the entire span. Find the deflection and moment at midspan and compare with exact solution using Rayleigh Ritz method Use $y = a_1 \sin(\pi x/l) + a_2 \sin(3\pi x/l)$. (13M) (NOVEMBER 2008)**BTL2 **Answer: page – 1.18 Dr. S.Senthil** **To find :** 1. Deflection and Bending moment at midspan. 2. Compare with exact solutions. **SOLUTION**

☺ ***Solution:*** We know that, for simply supported beam, the Fourier series,

$$y = \sum_{n=1,3}^{\infty} a \sin \frac{n\pi x}{l} \text{ is the approximating function.}$$

To make this series more simple let us consider only two terms.

$$\text{Deflection, } y = a_1 \sin \frac{\pi x}{l} + a_2 \sin \frac{3\pi x}{l}$$

where, a_1, a_2 are Ritz parameters.

We know that,

Total potential energy of the beam, $\pi = U - H$

where, U → Strain energy.

H → Work done by external force.

The strain energy, U, of the beam due to bending is given by,

$$U = \frac{EI}{2} \int^{l} \left(\frac{d^2y}{dx^2} \right)^2 dx$$

(7M)

$$\Rightarrow \quad y_{max} = \frac{4\omega l^4}{EI\,\pi^5} \sin \frac{\pi \times \frac{l}{2}}{l} + \frac{4\omega l^4}{243\,EI\,\pi^5} \sin \frac{3\pi \frac{l}{2}}{l}$$

$$\Rightarrow \quad y_{max} = \frac{4\omega l^4}{EI\,\pi^5} \sin \frac{\pi}{2} + \frac{4\omega l^4}{243\,EI\,\pi^5} \sin \frac{3\pi}{2}$$

$$y_{max} = \frac{4\omega l^4}{EI\,\pi^5} - \frac{4\omega l^4}{243\,EI\,\pi^5}$$

$$= \frac{4\omega l^4}{EI\,\pi^5}\left[1 - \frac{1}{243}\right] \qquad \left[\because \sin\frac{\pi}{2} = 1;\ \sin\frac{3\pi}{2} = -1\right]$$

$$= \frac{4\omega l^4}{EI\,\pi^5}\,(0.9958) = \frac{3.98\,\omega\,l^4}{EI\,\pi^5}$$

(6M)

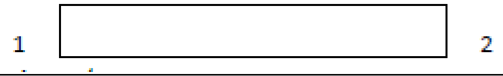
5

Explain briefly General steps of the finite element analysis. (13M) (NOVEMBER 2014)BTL2

Answer: page – 1.27 Dr. S.Senthil

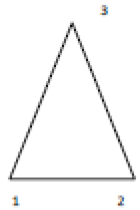
Step 1: Discretization of structure

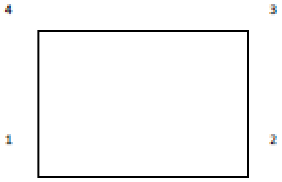
A bar and beam elements are considered as one dimensional element has two nodes, one at each end as shown.



(ii) Two Dimensional element: -

Triangular and Rectangular elements are considered as 2D element. These elements are located by their own place.

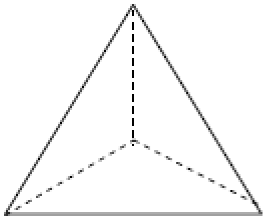




'(4M)

iii) Three dimensional element:-

The most common 3D elements are tetrahedral and lexahendral (Brick) elements. These elements are used for three dimensional stress analysis problems.



Step 2: Numbering of nodes and elements

Longer Side Numbering Process:

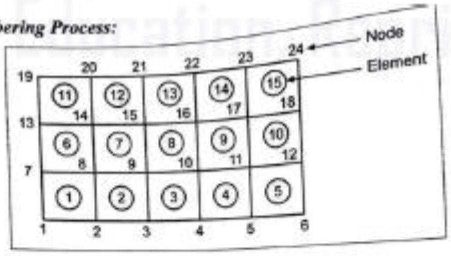
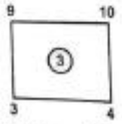


Fig. 1.6. (a)

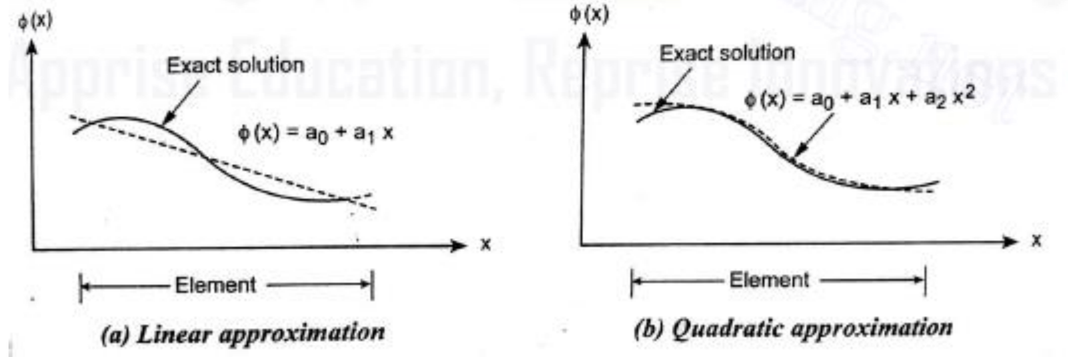
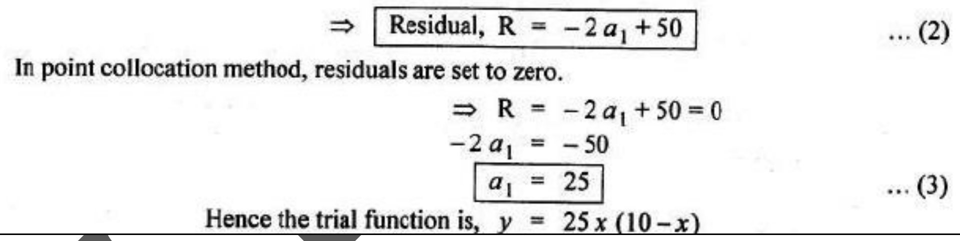
[*Note:* Number with circle denotes element.
Number without circle denotes node]

Considering element (3),



Maximum node number = 10
Minimum node number = 3
Difference = 7

Step 3: selection of a displacement function

	 *(a) Linear approximation* *(b) Quadratic approximation* (9M)
	PART * C
1	**Find the solution for the following differential equation.** **$d_2y/dx_2+50=0, 0<x<10$** **Trial function is $y=a_1x(10-x)$** **Boundary conditions are $y(0)=0$ $Y(10)=0$.** **Find the value of the parameter a_1 by the following methods** **(i)point collocations,** **(ii)subdomain collocation,** **(iii)least square method,** **(iv)galerkins (15m) (May 2014)** BTL4 **Answer: page – 1.101 Dr. S.Senthil**  $\Rightarrow \boxed{\text{Residual, R} = -2a_1+50}$ ... (2) In point collocation method, residuals are set to zero. $\Rightarrow R = -2a_1+50=0$ $-2a_1 = -50$ $\boxed{a_1 = 25}$ ... (3) Hence the trial function is, $y = 25x(10-x)$

(ii) Subdomain collocation method:

This method requires, $\int_0^{10} R \, dx = 0$

Substitute R value, $\Rightarrow \int_0^{10} [-2\,a_1 + 50]\,dx = 0$

$$\Rightarrow \int_0^{10} [-2\,a_1\,dx + 50\,dx] = 0$$

$$\Rightarrow \left[-2\,a_1 x + 50\,x\right]_0^{10} = 0$$

$$\Rightarrow -2\,a_1(10) + 50\,(10) - [0] = 0$$

$$\Rightarrow -20\,a_1 = -500$$

$$\boxed{a_1 = 25} \quad \ldots (4)$$

Hence the trial function is, $y = 25\,x\,(10 - x)$ (6M)

(iii) Least Squares Method:

This method requires $I = \int_0^{10} R^2\,dx$

It can also be written as, $\dfrac{\partial I}{\partial a_1} = \int_0^{10} R\,\dfrac{\partial R}{\partial a_1}\,dx \quad \ldots (5)$

We know that, $R = -2\,a_1 + 50$

$$\frac{\partial R}{\partial a_1} = -2$$

Substitute R and $\dfrac{\partial R}{\partial a_1}$ values in equation (5),

$$\Rightarrow \frac{\partial I}{\partial a_1} = \int_0^{10} (-2\,a_1 + 50)\,(-2)\,dx$$

$$\Rightarrow -2\,a_1\,(10) + 50\,(10) - [0] = 0$$

$$\Rightarrow -20\,a_1 + 500 = 0$$

$$\Rightarrow -20\,a_1 = -500$$

$$\Rightarrow \boxed{a_1 = 25} \quad \ldots (6)$$

Therefore, the trial function becomes, $y = 25\,x\,(10 - x)$.

(iv) Galerkin's method: In this method, the trial function itself is considered as the weighting function, w_i.

$$\Rightarrow \int_0^{10} w_i \, R \, dx = 0 \qquad \ldots (7)$$

Here, the trial function is, $y = w_i = a_1 x (10 - x)$

Substitute w_i and R values in equation (7),

$$\Rightarrow \int_0^{10} a_1 x (10 - x) \times (-2 a_1 + 50) \, dx = 0$$

$$\Rightarrow a_1 \int_0^{10} x (10 - x) \times (-2 a_1 + 50) \, dx = 0$$

$$\Rightarrow a_1 \int_0^{10} (10 x - x^2)(-2 a_1 + 50) \, dx = 0$$

$$\Rightarrow a_1 \int_0^{10} [-20 a_1 x + 500 x + 2 a_1 x^2 - 50 x^2] \, dx = 0$$

$$\Rightarrow a_1 \left[-20 a_1 \frac{x^2}{2} + 500 \frac{x^2}{2} + 2 a_1 \frac{x^3}{3} - 50 \frac{x^3}{3} \right]_0^{10} = 0$$

$$\Rightarrow \frac{-20 a_1}{2} [10^2 - 0] + \frac{500}{2} [10^2 - 0] + \frac{2 a_1}{3} [10^3 - 0] - \frac{50}{3} [10^3 - 0] = 0$$

$$\Rightarrow -10 a_1 [100] + 250 [100] + \frac{2 a_1}{3} [1000] - \frac{50}{3} [1000] = 0$$

$$\Rightarrow -1000 a_1 + 25{,}000 + 666.66 a_1 - 16{,}666.66 = 0$$

$$\Rightarrow -333.33 a_1 = -8333.33$$

$$\Rightarrow \boxed{a_1 = 25} \qquad \ldots (8)$$

The trial function is, $y = 25 x (10 - x)$

From equations (3), (4), (6) and (8), we know that the value of parameter a_1 is same for all the four methods.

(9M)

2 **Determine the expression for the deflection and bending moment in a simply supported beam subjected to uniformly distributed load over the entire span. Find the deflection and moment at midspan and compare with exact solution using Rayleigh Ritz method Use y = $a_1$sin (πx/l) + a_2 sin(3πx/l). (15M) (November 2008,APRIL 2019)**BTL2

Answer: page – 1.12 Dr. S.Senthil

To find : 1. Deflection and Bending moment at midspan.

2. Compare with exact solutions.

☺ ***Solution:*** We know that, for simply supported beam, the Fourier series,

$$y = \sum_{n=1,3}^{\infty} a \sin \frac{n\pi x}{l} \text{ is the approximating function.}$$

To make this series more simple let us consider only two terms.

$$\text{Deflection, } y = a_1 \sin \frac{\pi x}{l} + a_2 \sin \frac{3\pi x}{l} \quad \ldots (1)$$

where, a_1, a_2 are Ritz parameters.

We know that,

$$\text{Total potential energy of the beam, } \pi = \text{U} - \text{H} \quad \ldots (2)$$

where, U → Strain energy.

H → Work done by external force.

The strain energy, U, of the beam due to bending is given by,

$$\text{U} = \frac{\text{EI}}{2} \int_0^l \left(\frac{d^2y}{dx^2}\right)^2 dx \quad \ldots (3)$$

(5M)

$$\boxed{\int_0^l a_1^2 \sin^2 \frac{\pi x}{l} dx = \frac{a_1^2 l}{2}}$$

$$\boxed{\int_0^l 81\, a_2^2 \sin^2 \frac{3\pi x}{l} dx = \frac{81\, a_2^2 l}{2}}$$

$$\Rightarrow \boxed{\int_0^l 18\, a_1 a_2 \sin \frac{\pi x}{l} \sin \frac{3\pi x}{l} = 0} \quad \ldots (8)$$

Substitute (6), (7) and (8) in equation (5),

$$(5) \Rightarrow \quad \text{U} = \frac{\text{EI}}{2} \frac{\pi^4}{l^4} \left[\frac{a_1^2 l}{2} + \frac{81\, a_2^2 l}{2} + 0 \right]$$

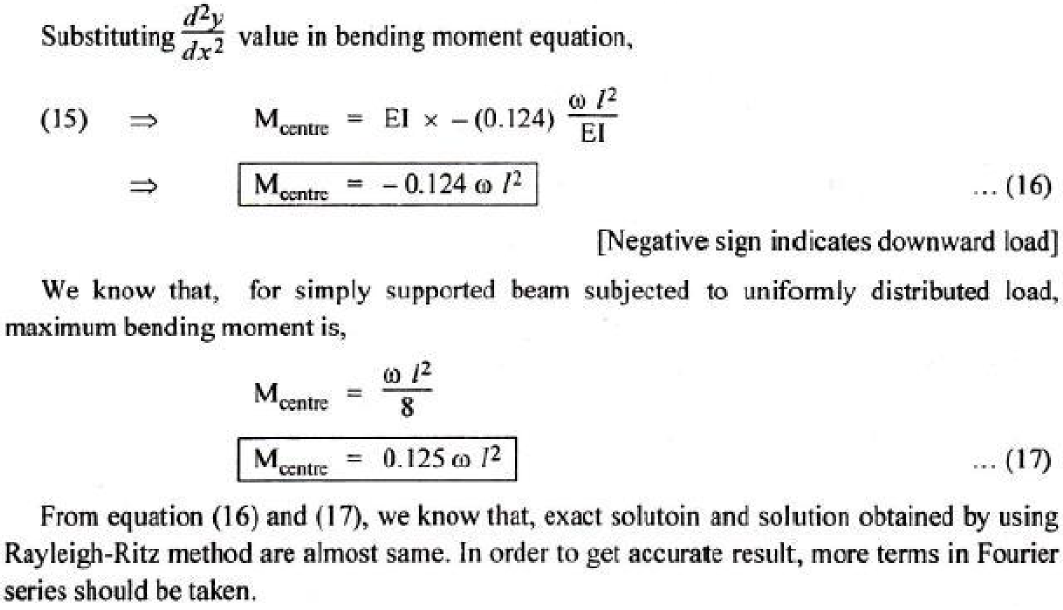
$$\text{U} = \frac{\text{EI}\, \pi^4 l}{4\, l^4} [\, a_1^2 + 81\, a_2^2 \,]$$

$$\boxed{\text{Strain energy, U} = \frac{\text{EI}\, \pi^4}{4\, l^3} [\, a_1^2 + 81\, a_2^2 \,]} \quad \ldots (9)$$

We know that,

$$\text{Work done by external force, H} = \int_0^l \omega\, y\, dx = \int_0^l \omega \left(a_1 \sin \frac{\pi x}{l} + a_2 \sin \frac{3\pi x}{l} \right) dx$$

(5M)



Substituting $\frac{d^2y}{dx^2}$ value in bending moment equation,

$$(15) \Rightarrow \quad M_{centre} = EI \times -(0.124)\,\frac{\omega\, l^2}{EI}$$

$$\Rightarrow \quad \boxed{M_{centre} = -0.124\,\omega\, l^2} \qquad \dots (16)$$

[Negative sign indicates downward load]

We know that, for simply supported beam subjected to uniformly distributed load, maximum bending moment is,

$$M_{centre} = \frac{\omega\, l^2}{8}$$

$$\boxed{M_{centre} = 0.125\,\omega\, l^2} \qquad \dots (17)$$

From equation (16) and (17), we know that, exact solutoin and solution obtained by using Rayleigh-Ritz method are almost same. In order to get accurate result, more terms in Fourier series should be taken.

(5M)

3

The differential equation of a physical phenomenon is given by d2y/dx2 + 500x2=0 ;0<x<1 by using the trial function, Y=a1(x-x3) + a2(x-x5), calculate the value of the parameter a1 and a2 by the following methods. (15M)(NOVEMBER 2019)BTL2

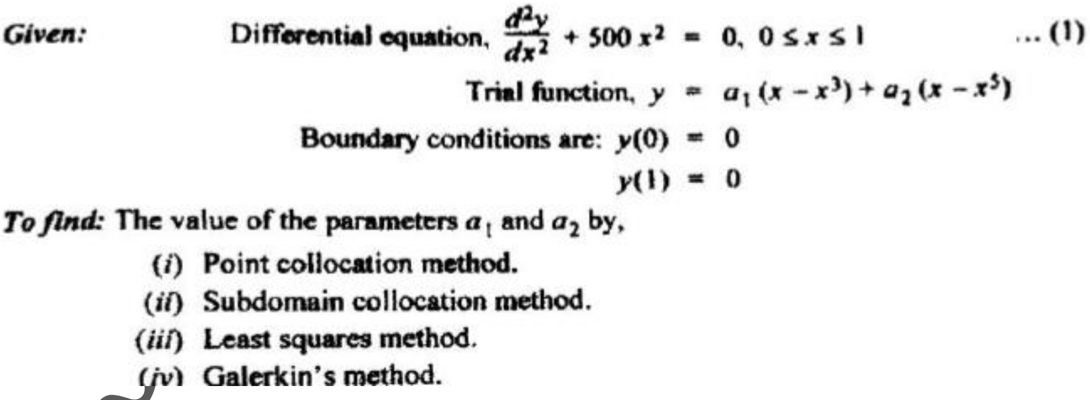
(i)point collocation

(ii)subdomain method

(iii)least square

(iv)galerkins

Answer: page – 1.17 Dr. S.Senthil



Given: Differential equation, $\frac{d^2y}{dx^2} + 500\,x^2 = 0,\ 0 \le x \le 1 \qquad \dots (1)$

Trial function, $y = a_1(x - x^3) + a_2(x - x^5)$

Boundary conditions are: $y(0) = 0$

$y(1) = 0$

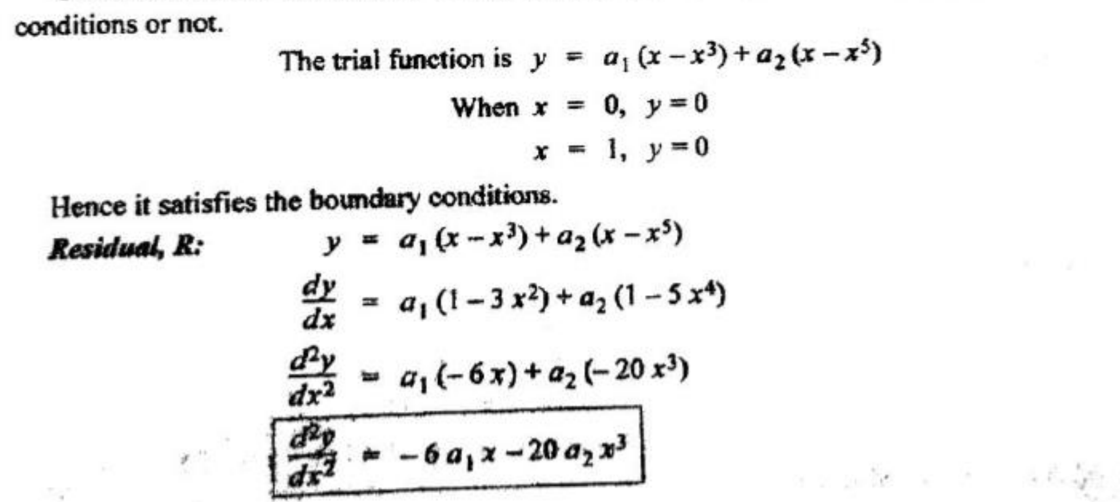
To find: The value of the parameters a_1 and a_2 by,

(*i*) Point collocation method.

(*ii*) Subdomain collocation method.

(*iii*) Least squares method.

(*iv*) Galerkin's method.



☺ ***Solution:*** First we have to verify, whether the trial function satisfies **the boundary** conditions or not.

The trial function is $y = a_1(x - x^3) + a_2(x - x^5)$

When $x = 0, \; y = 0$

$x = 1, \; y = 0$

Hence it satisfies the boundary conditions.

Residual, R:

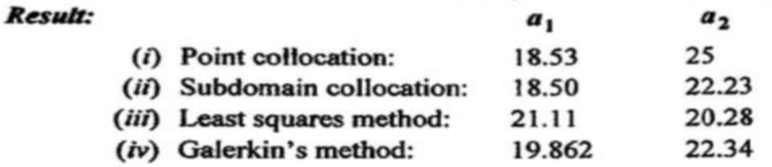
$$y = a_1(x - x^3) + a_2(x - x^5)$$

$$\frac{dy}{dx} = a_1(1 - 3x^2) + a_2(1 - 5x^4)$$

$$\frac{d^2y}{dx^2} = a_1(-6x) + a_2(-20x^3)$$

$$\boxed{\frac{d^2y}{dx^2} = -6a_1x - 20a_2x^3}$$

(10M)



Result:

	a_1	a_2
(*i*) Point collocation:	18.53	25
(*ii*) Subdomain collocation:	18.50	22.23
(*iii*) Least squares method:	21.11	20.28
(*iv*) Galerkin's method:	19.862	22.34

(5M)

UNIT II ONE-DIMENSIONALPROBLEMS

One Dimensional Second Order Equations – Discretization – Element types- Linear and Higher order elements – Derivation of Shape functions and Stiffness matrices and force vectors- Assembly of Matrices - Solution of problems from solid mechanics and heat transfer. Longitudinal vibration frequencies and mode shapes. Fourth Order Beam Equation –Transverse deflections and Natural frequencies of beams.

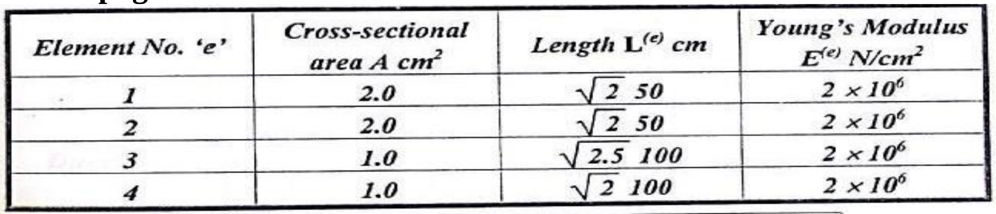
PART * A

Q.No.	Questions
1.	**When do we resort to 1 D quadratic spar elements? (APRIL 2011)** BTL1 (i) Better accuracy. (ii) Representation of curved boundaries. (iii) Faster convergence.
2	**What is the difference between static and dynamic analysis?(APRIL 2019)** BTL1 a. Static analysis: The solution of the problem does not vary with time is known as static analysis Example: stress analysis on a beam b. Dynamic analysis: The solution of the problem varies with time is known as dynamic analysis. Example: vibration analysis problem.
3	**Differentiate between global and local axes.** BTL1 a. Local axes are established in an element. Since it is in the element level, they change with the change in orientation of the element. The direction differs from element to element. b. Global axes are defined for the entire system. They are same indirection for all the elements even though the elements are differently oriented.
4	**Name any four FEA software.** BTL1 a. ANSYS b. NASTRAN c. COSMOS
5	**List the two advantages of post processing.** BTL1 a. Required result can be obtained in graphical form. b. Contour diagrams can be used to understand the solution easily and quickly.
6	**During discretization, mention the places where it is necessary to place anode?** BTL1 a. Concentrated load acting point b. Cross-section changing point c. Different material interjections d. Sudden change in point load
7	**Distinguish between potential energy function and potential energy functional.** BTL1 If a system has finite number of degree of freedom (q1, q2,and q3), then the potential energy expressed as, π = f (q1, q2, and q3) It is known as function. If a system has infinite degrees of freedom, then the potential

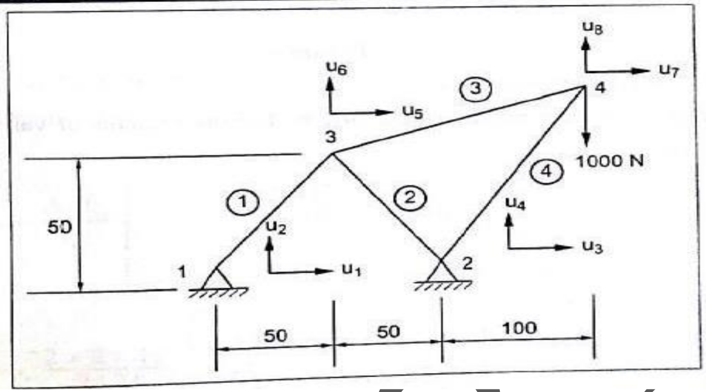
8	**What are the types of loading acting on the structure?** BTL1 a. Body force (f) b. Traction force (T) c. Point load (P)
9	**Define traction force.** BTL1 Traction force is defined as distributed force acting on the surface of the body. Unit: Force per unit area. Example: Frictional resistance, viscous drag, surface shear
10	**Define the body force.** BTL1 A body force is distributed force acting on every elemental volume of the body Unit: Force per unit volume. Example: Self weight due to gravity
11	**What is point load?** BTL1 Point load is force acting at a particular point which causes displacement
12	**What are the basic steps involved in the finite element modeling.(NOVEMBER 2009)**BTL1 a. Discretization of structure. b. Numbering of nodes.
13	**What is discretization?** BTL1 The art of subdividing a structure in to a convenient number of smaller components is known as discretization.
14	**What are the classifications of coordinates?(APRIL 2011)** BTL1 a. Global coordinates b. Local coordinates c. Natural coordinates
15	**What is Global coordinates?** BTL1 The points in the entire structure are defined using coordinates system is known as global coordinate system.
17	**How do you calculate the size of the global stiffness matrix?(APRIL 2011)** BTL1 Global stiffness matrix size = Number of nodes X Degrees of freedom per node
18	**What is natural coordinates?** BTL1 A natural coordinate system is used to define any point inside theelement by a set of dimensionless number whose magnitude neverexceeds unity. This system is very useful in assembling of stiffness matrices.
19	**Define shape function.** BTL1 Approximate relation φ (x,y) = N1 (x,y) φ1 + N2 (x,y) φ2 + N3(x,y) φ3 Where φ1, φ2, and φ3 are the values of the field variable at the nodes N1, N2, and N3 are the interpolation functions. N1, N2, and N3 are also called shape functions because they are used to express the geometry or shape of the element.
20	**What are the characteristic of shape function?(APRIL 2019)**BTL1 a. It has unit value at one nodal point and zero value at other nodalpoints. b. The sum of shape function is equal to one.
	PART * B
1	**Find the nodal displacement developed in the planer truss shown in figure when a**

	vertically downward load of 1000 N is applied at node 4. The required data are given in the Table 1. (13M) (NOVEMBER 2014)BTL2

Answer: page – 2.07 Dr. S.Senthil



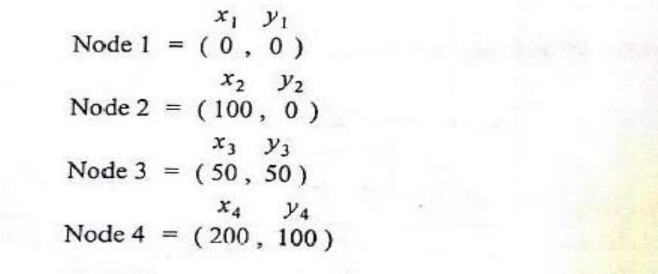
Element No. 'e'	*Cross-sectional area A cm^2*	*Length $L^{(e)}$ cm*	*Young's Modulus $E^{(e)}$ N/cm^2*
1	2.0	$\sqrt{2}$ 50	2×10^6
2	2.0	$\sqrt{2}$ 50	2×10^6
3	1.0	$\sqrt{2.5}$ 100	2×10^6
4	1.0	$\sqrt{2}$ 100	2×10^6



Find

Nodal displacements

Solution



Node 1 = $(x_1, y_1) = (0, 0)$

Node 2 = $(x_2, y_2) = (100, 0)$

Node 3 = $(x_3, y_3) = (50, 50)$

Node 4 = $(x_4, y_4) = (200, 100)$

(8M)

Result

Nodal displacements

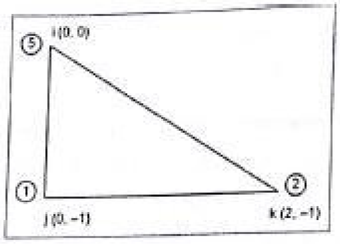
U_5=0.0265 cm

U_6= 0.0088 cm

U_7= 0.3479 cm

U_8= -0.5600 cm(5M)

2	**Consider the triangular element shown in figure. The element is extracted from a thin plate of thickness 0.5 cm. The material is hot rolled low carbon steel. The nodal coordinates are $x_1 = 0$, $y_1 = 0$; x_j 0; y_j – 1, x_k =2, y_k = -2. Determine the elemental stiffness matrix. Assuming plane stress analysis, take μ = 0.3 and E = 2.1 x 10^7 N/cm^2. (13M) (NOVEMBER 2010)**BTL2 **Answer: page – 2.17 Dr. S.Senthil**



Solution

$$
\begin{aligned}
q_1 &= y_j - y_k = (-1+1) = 0\\
q_2 &= y_k - y_i = (-1-0) = 1\\
q_3 &= y_i - y_j = (0+1) = 1\\
r_1 &= x_k - x_j = (2-0) = 2\\
r_2 &= x_i - x_k = (0-2) = -2\\
r_3 &= x_j - x_i = (0-0) = 0
\end{aligned}
$$

(5M)

Result

$$
2.307 \times 10^7 \begin{bmatrix} 0.35 & 0 & -0.35 & -0.175 & 0 & 0.175 \\ 0 & 1 & -0.15 & -1 & 0.15 & 0 \\ -0.35 & -0.15 & 0.6 & 0.325 & -0.25 & -0.175 \\ -0.175 & -1 & 0.325 & 1.0875 & -0.15 & -0.0875 \\ 0 & 0.15 & -0.25 & -0.15 & 0.25 & 0 \\ 0.175 & 0 & -0.175 & -0.0875 & 0 & 0.0875 \end{bmatrix}
$$

(8M)

3

What is one dimensional element? Explain their types? (13M) (MAY 2010,NOVEMBER 2019)BTL2

Answer: page – 2.27 Dr. S.Senthil

Bar and beam elements are considered as One Dimensional elements. These Elements are often used to model trusses and frame structures.

1.Bar, Beam and Truss

Bar is a member which resists only axial loads. A beam can resist axial, lateral and twisting loads. A truss is an assemblage of bars with pin joints and a frame is an assemblage of beam elements.

2.Stress, Strain and Displacement

Stress is denoted in the form of vector by the variable x as σx, Strain is denoted in the form of vector by the variable x as ex, Displacement is denoted in the form of vector by the variable x as ux.(5M)

3. Types of Loading

(1) Body force (f)

It is a distributed force acting on every elemental volume of the body. Unit is Force / Unit volume. Ex: Self weight due to gravity.

(2) Traction (T)

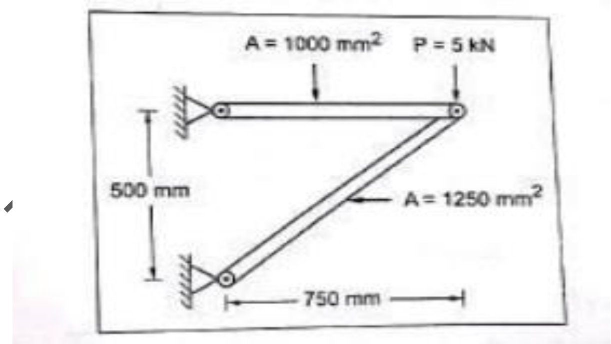
It is a distributed force acting on the surface of the body. Unit is Force / Unit area. But for one dimensional problem, unit is Force / Unit length. Ex: Frictional resistance, viscous drag and Surface shear.

(3) Point load (P)
It is a force acting at a particular point which causes displacement.

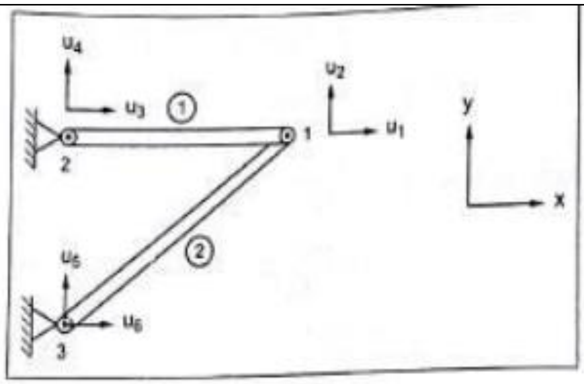
(4)Finite Element Modeling
It has two processes.
(1) Discretization of structure
(2) Numbering of nodes(8M)

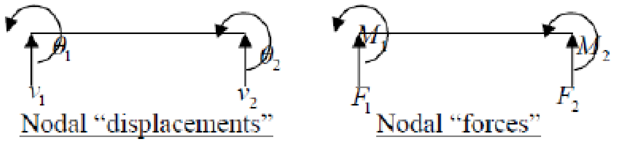
4

The loading and other parameters for a two bar truss element is shown in Fig. Determine
(i) the element stiffness matrix for each element
(ii) global stiffness matrix
(m) nodal displacements
(iv) reaction forces
(v) the stresses induced in the elements. Assume E = 200 GPa.(13M) BTL 2
Answer: page – 2.32 Dr. S.Senthil



Solution

	 (3M) ***(iii) Nodal displacements:*** $u_1 = 0.0284$ mm $\quad u_4 = 0$ $u_2 = -0.102$ mm $\quad u_5 = 0$ $u_3 = 0 \quad u_6 = 0$ ***(iv) Reaction forces:*** $R_1 = 0 \quad R_4 = 0$ $R_2 = 0 \quad R_5 = 7500$ N $R_3 = -7500$ N $\quad R_6 = 5000$ N ***(v) The stress induced in the elements:*** $\sigma_1 = 7.57$ N/mm^2 [Tensile] $\sigma_2 = -7.299$ N/mm^2 [Compressive] (10M)
5	**Explain about the beam element and formulate the stiffness matrix. (13M) (NOVEMBER 2009)** BTL 2 **Answer: page – 2.36 Dr. S.Senthil** - A beam is a long, slender structural member generally subjected to transverse loading that produces significant bending effects as opposed to twisting or axial effects. An elemental length of a long beam subjected to arbitrary loading is considered for analysis. - For this elemental beam length L, we assign two points of interest, i.e., the ends of the beam, which become the nodes of the beam element. - The bending deformation is measured as a transverse (vertical) displacement and a rotation (slope). Hence, for each node, we have a vertical displacement and a rotation (slope) – two degrees of freedom at each node. - For a single 2- noded beam element, we have a total of 4 degrees of freedom. The associated “forces” are shear force and bending moment at each node.(6M)



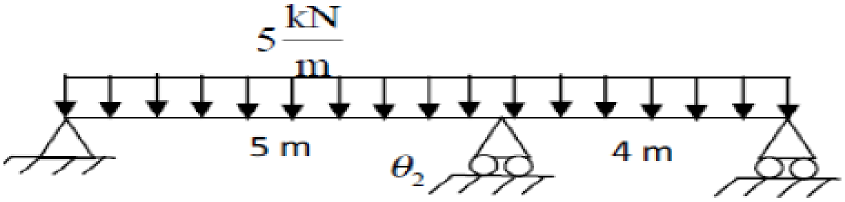
1st degree of freedom	vertical displacement at node i	1	v_i or v_1	corres-ponding to	shear force at node i	F_i or F_1	1
2nd degree of freedom	slope or rotation at node i	2	θ_i or θ_1		bending moment at node i	M_i or M_1	2
3rd degree of freedom	vertical displacement at node j	3	v_j or v_2		shear force at node i	F_j or F_2	3
4th degree of freedom	slope or rotation at node j	4	θ_j or θ_2		bending moment at node j	M_j or M_2	4

(7M)

PART * C

1 **Find the slopes at the supports and support reaction forces and support reaction moments for the beam shown in Figure. Take E=210 GPa, I = 2×10-4 m^4(15M) (MAY 2009)**BTL3

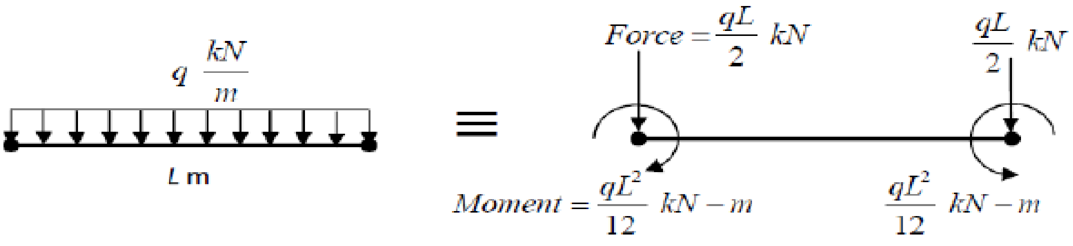
Answer: page – 2.25 Dr. S.Senthil



Finite element representation of the problem

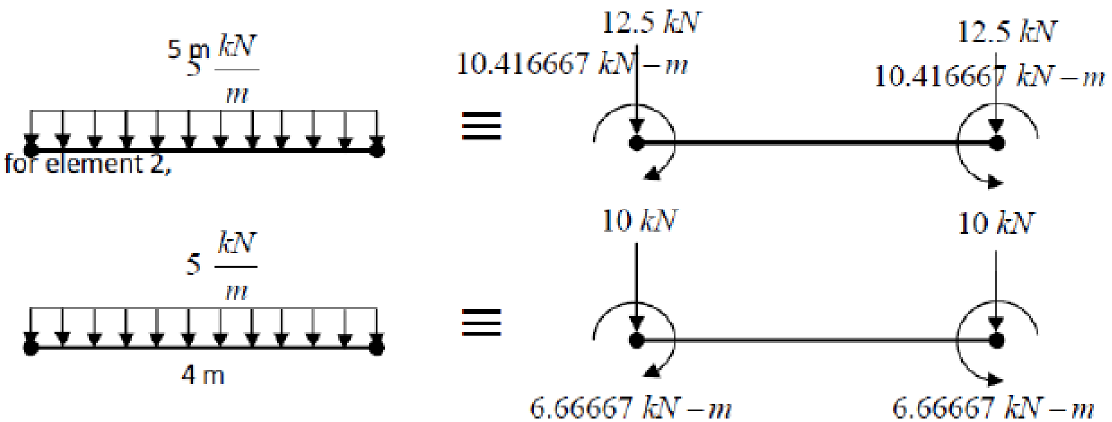
v_2

Conversion of UDL into nodal forces and nodal moments



(6M)

for element 1,



$$EI = 210 \text{ GPa} \times 2\times10^{-4} \text{ m}^4 = 210\times10^6 \frac{kN}{m^2} \times 2\times10^{-4} \text{ m}^4 = 42000 \text{ kN-m}^2$$

(6M)

Element 1

$$F_1^{(1)} = \left\{10,080\times\left(-3.59623\times10^{-4}\right)\right\} + \left\{10,080\times9.92\times10^{-5}\right\} = -2.624832 \text{ kN}$$

$$M_1^{(1)} = \left\{33,600\times\left(-3.59623\times10^{-4}\right)\right\} + \left\{16,800\times9.92\times10^{-5}\right\} = -10.416 \text{ kN-m}$$

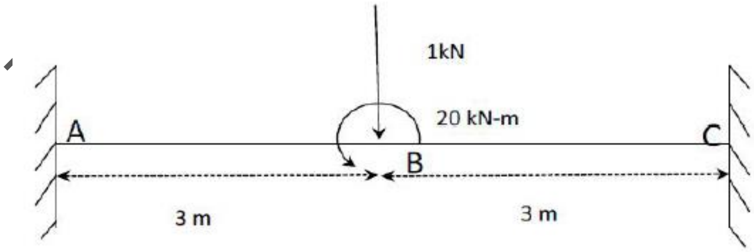
$$F_2^{(1)} = \left\{-10,080\times\left(-3.59623\times10^{-4}\right)\right\} - \left\{10,080\times9.92\times10^{-5}\right\} = 2.624832 \text{ kN}$$

$$M_2^{(1)} = \left\{16,800\times\left(-3.59623\times10^{-4}\right)\right\} + \left\{33,600\times9.92\times10^{-5}\right\} = -2.70816 \text{ kN-m}$$

(3M)

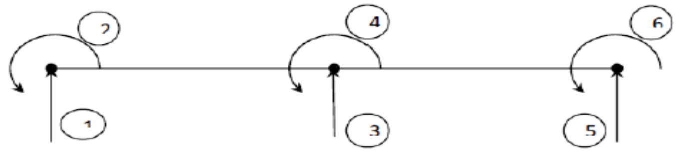
2 **Given that E=210 GPa and I=4×10-4m4, cross section of the beam is constant. Determine the deflection and slope at point C. calculate the reaction forces and moments. (15M) (NOVEMBER 2015)**BTL2

Answer: page – 2.28 Dr. S.Senthil

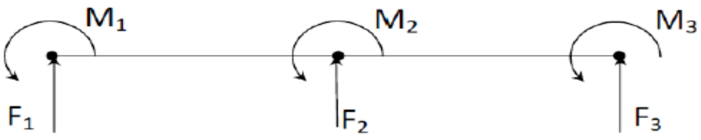


Solution:-

Degree of freedom in numbers:-

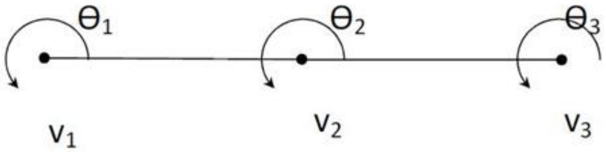


Degree of freedom of forces and moments:-



(5M)

Degree of freedom of displacement and rotation:-



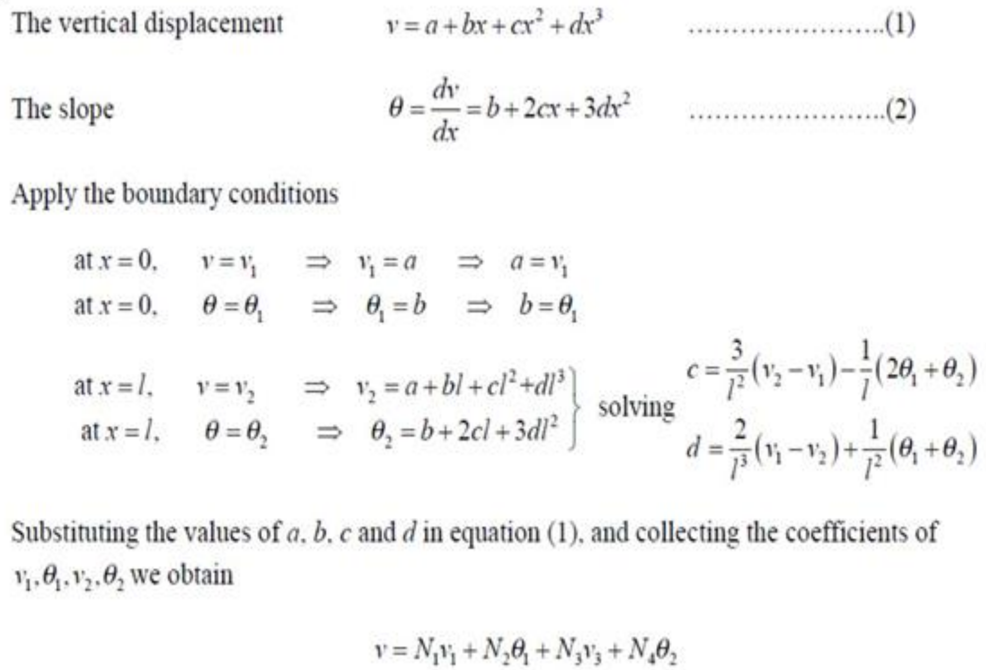
$$[K]^1=[K]^2=\begin{bmatrix}\frac{12EI}{l^3} & \frac{6EI}{l^2} & -\frac{12EI}{l^3} & \frac{6EI}{l^2}\\ \frac{6EI}{l^2} & \frac{4EI}{l} & -\frac{6EI}{l^2} & \frac{2EI}{l}\\ -\frac{12EI}{l^3} & -\frac{6EI}{l^2} & \frac{12EI}{l^3} & -\frac{6EI}{l^2}\\ \frac{6EI}{l^2} & \frac{2EI}{l} & -\frac{6EI}{l^2} & \frac{4EI}{l}\end{bmatrix}$$

$$[K]^1=[K]^2=3.1\times10^6\begin{bmatrix}12 & 18 & -12 & 18\\ 18 & 36 & -18 & 18\\ -12 & -18 & 12 & -18\\ 18 & 18 & -18 & 36\end{bmatrix}$$

Assembling:-

$$\begin{Bmatrix}F_1\\ M_1\\ F_2\\ M_2\\ F_3\\ M_3\end{Bmatrix}=3.1\times10^6\begin{bmatrix}12 & 18 & -12 & 18 & 0 & 0\\ 18 & 36 & -18 & 18 & 0 & 0\\ -12 & -18 & 24 & 0 & 0 & 0\\ 18 & 18 & 0 & 72 & -18 & 18\\ 0 & 0 & -12 & -18 & 12 & -18\\ 0 & 0 & 18 & 18 & -18 & 36\end{bmatrix}\begin{Bmatrix}v_1\\ \theta_1\\ v_2\\ \theta_2\\ v_3\\ \theta_3\end{Bmatrix}$$

	Boundary condition:- F_2=-10 kN; M_2=20 kN-m $v_1 = v_3 = \Theta_1 = \Theta_3 = 0$ Therefore first, second, fifth, sixth columns are ineffective and hence the reduced matrix is given by $\begin{Bmatrix} F_2 \\ m_2 \end{Bmatrix} = 3.1\times10^6 \begin{bmatrix} 24 & 0 \\ 0 & 72 \end{bmatrix} \begin{Bmatrix} v_2 \\ \theta_2 \end{Bmatrix}$ Deflection and slope at point c:- V_2= -1.34×10^{-4} m = -0.134 mm Θ_2= 8.96×10^{-5} rad (5M) Reaction forces and moments:- $\begin{Bmatrix} F_2 \\ m_2 \\ F_3 \\ m_3 \end{Bmatrix} = 3.1\times10^6 \begin{bmatrix} -12 & 18 \\ -18 & 18 \\ -12 & -18 \\ 18 & 18 \end{bmatrix}$ F_1=10000N M_1=12500N-m (5M)
3	**Derive the 1-d 2-noded cubic beam element matrices. (15M) (MAY 2009) BTL2** **Answer: page – 2.42 Dr. S.Senthil** • A single 1-d 2-noded cubic beam element has two nodes, with two degrees of freedom at each node (one vertical displacement and one rotation or slope). • There is a total of 4 dof and the displacement polynomial function assumed should have 4 terms, so we choose a cubic polynomial for the vertical deflection. • Slope is a derivative of the vertical deflections. (4M)



The vertical displacement $v = a + bx + cx^2 + dx^3$ ……………………(1)

The slope $\theta = \frac{dv}{dx} = b + 2cx + 3dx^2$ ……………………(2)

Apply the boundary conditions

$$\begin{aligned}
&\text{at } x = 0, \quad v = v_1 \quad \Rightarrow \quad v_1 = a \quad \Rightarrow \quad a = v_1\\
&\text{at } x = 0, \quad \theta = \theta_1 \quad \Rightarrow \quad \theta_1 = b \quad \Rightarrow \quad b = \theta_1
\end{aligned}$$

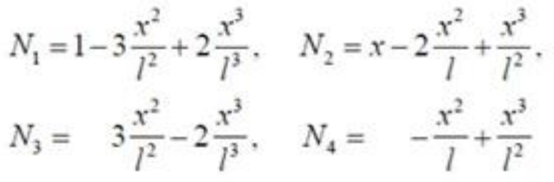
$$\left.\begin{aligned}
&\text{at } x = l, \quad v = v_2 \quad \Rightarrow \quad v_2 = a + bl + cl^2 + dl^3\\
&\text{at } x = l, \quad \theta = \theta_2 \quad \Rightarrow \quad \theta_2 = b + 2cl + 3dl^2
\end{aligned}\right\} \text{solving} \quad
\begin{aligned}
c &= \frac{3}{l^2}(v_2 - v_1) - \frac{1}{l}(2\theta_1 + \theta_2)\\
d &= \frac{2}{l^3}(v_1 - v_2) + \frac{1}{l^2}(\theta_1 + \theta_2)
\end{aligned}$$

Substituting the values of a, b, c and d in equation (1), and collecting the coefficients of $v_1, \theta_1, v_2, \theta_2$ we obtain

$$v = N_1 v_1 + N_2 \theta_1 + N_3 v_3 + N_4 \theta_2$$

(8M)

where



$$N_1 = 1 - 3\frac{x^2}{l^2} + 2\frac{x^3}{l^3}, \quad N_2 = x - 2\frac{x^2}{l} + \frac{x^3}{l^2},$$

$$N_3 = \quad 3\frac{x^2}{l^2} - 2\frac{x^3}{l^3}, \quad N_4 = \quad -\frac{x^2}{l} + \frac{x^3}{l^2}$$

(3M)

UNIT III TWO DIMENSIONAL SCALAR VARIABLE PROBLEMS

Second Order 2D Equations involving Scalar Variable Functions – Variational formulation –Finite Element formulation – Triangular elements – Shape functions and element matrices and vectors. Application to Field Problems - Thermal problems – Torsion of Non circular shafts –Quadrilateral elements – Higher Order Elements.

PART * A

Q.No.	Questions
1.	**What are higher order elements and why are they preferred? (APRIL 2011)** BTL1 • For any element, if the interpolation polynomial is the order of two or more, that element is known as higher order elements. • It is used to represent the curved boundaries. • The number of elements is reduced when compared with straight edge elements to model geometry
2	**State the properties of stiffness matrix.** BTL1 • It is a symmetric matrix. • The sum of elements in any column must be equal to zero • It is an unstable element. So, the determinant is equal to zero.
3	**Write down the expression of shape function N and displacement u for one dimensional bar element.(APRIL 2011)** BTL1 U= N1u1+N2u2 N1= 1-X / l N2 = X / l
4	**Define total potential energy.** Total potential energy, π = Strain energy (U) + potential energy of the external forces(w)
5	**State the principle of minimum potential energy.(November 2015)**BTL1 Among all the displacement equations that satisfied internal compatibility and the boundary condition those that also satisfy the equation of equilibrium make the potential energy a minimum is a stable system.
6	**What is truss?** BTL1 A truss is defined as a structure made up of several bars, riveted or welded together.
7	**States the assumption are made while finding the forces in a truss.(APRIL 2012)** BTL1 • All the members are pin jointed. The truss is loaded only at the joint • The self weight of the members is neglected unless stated.
8	**State the principles of virtual energy?** BTL1 A body is in equilibrium if the internal virtual work equals the external virtual work for the every kinematically admissible displacement field
9	**What is essential boundary condition?** BTL1 Primary boundary condition or EBC Boundary condition which in terms of field variable is known as Primary boundary condition.
10	**Naturalboundary conditions?** BTL1 Secondary boundary natural boundary conditions which are in the differential form of field variable is known as secondary boundary condition

11	**How do you define two dimensional elements?(APRIL 2013)** BTL1 • Two dimensional elements are defined by three or more nodes in a two dimensional plane. • The basic element useful for two dimensional analysis is the triangular element.
12	**What is CST element?** BTL1 • Three noded triangular elements are known as CST. • It has six unknown displacement degrees of freedom (u1, v1, u2, v2, u3, v3). • The element is called CST because it has a constant strain throughout it.
13	**What is LST element?(November 2012)**BTL1 • Six nodded triangular elements are known as LST. • It has twelve unknown displacement degrees of freedom. • The displacement function for the elements are quadratic instead of linear as in the CST.
14	**What is QST element?(November 2012)**BTL1 Ten nodded triangular elements are known as Quadratic strain triangle. It is also called as cubic displacement triangle.
15	**What meant by plane stress analysis?** BTL1 Plane stress is defined to be a state of stress in which the normal stress and shear stress directed perpendicular to the plane are assumed to be zero
16	**Define plane strain analysis.(November 2015)**BTL1 Plane strain is defined to be state of strain normal to the xy plane and the shear strains are assumed to be zero.
17	**State the assumption in the theory of pure torsion. (November 2012)**BTL1 • The material of the shaft is homogeneous, perfectly elastic and obeys Hooks law. • Twist is uniform along the length of the shaft. • The stress does not exceed the limit of proportionality. • Strain and deformation are small.
18	**Write down the stress-strain relationship matrix for plane strain condition. (November 2012)** BTL 1 For plane strain problems, stress-strain relationship matrix is $[D] = \frac{E}{(1+v)\,(1-2v)} \begin{bmatrix} (1-v) & v & 0 \\ v & (1-v) & 0 \\ 0 & 0 & \frac{1-2v}{2} \end{bmatrix}$ Where, E = Youngs modulus V = Poisson’s ratio
19	**Write a strain-displacement matrix for CST element. (November 2012)** BTL2

Strain-displacement matrix for CST element is,

$$[B] = \frac{1}{2A}\begin{bmatrix} q_1 & 0 & q_2 & 0 & q_3 & 0 \\ 0 & r_1 & 0 & r_2 & 0 & r_3 \\ r_1 & q_1 & r_2 & q_2 & r_3 & q_3 \end{bmatrix}$$

Where, A = Area of the element

$q_1 = y_2 - y_3;\quad q_2 = y_3 - y_1;\quad q_3 = y_1 - y_2;$

$r_1 = x_3 - x_2;\quad r_2 = x_1 - x_3;\quad r_3 = x_2 - x_1;$

20 **Write down the expression for the shape function for a constant straintriangular element.**BTL2

For CST element,

Shape function,

$$N_1 = \frac{p_1 + q_1x + r_1y}{2A}$$
$$N_2 = \frac{p_2 + q_2x + r_2y}{2A}$$
$$N_2 = \frac{p_2 + q_2x + r_2y}{2A}$$

Where, $p_1 = x_2y_3 - x_3y_2$

$p_2 = x_3y_1 - x_1y_3$

$p_3 = x_1y_2 - x_2y_1$

$q_1 = y_2 - y_3;\quad q_2 = y_3 - y_1;\quad q_3 = y_1 - y_2;$

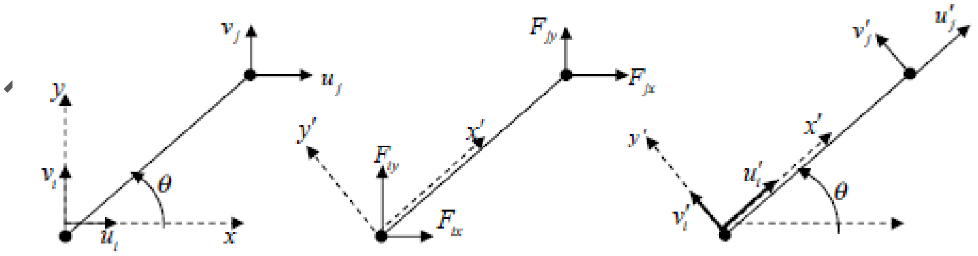
$r_1 = x_3 - x_2;\quad r_2 = x_1 - x_3;\quad r_3 = x_2 - x_1;$

PART * B

1 **Derivation of stiffness matrix and finite element equation for a truss element.(13M) (NOVEMBER 2009)** BTL2

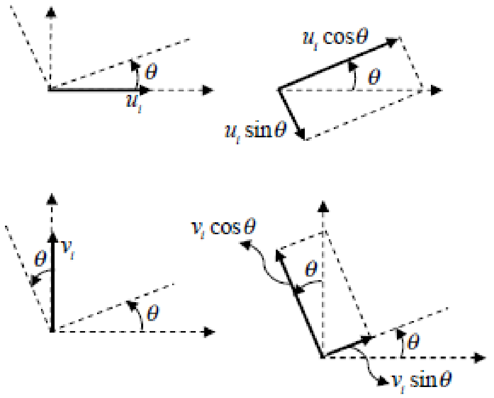
Answer: page – 3.07 Dr. S.Senthil

There are two joints for an arbitrarily inclined single truss element (at an angle θ, positivecounter-clockwise from +vex-axis). For each joint *i*, there are two degrees of freedom, i.e.,a joint can have horizontal displacement (u1)and vertical displacement (v1). Hence, for asingle truss element, there are 4 degrees of freedom. The nodal displacement degrees offreedom and the nodal force degrees of freedom are shown in the following figure.



(3M)

Note that the deformations occurring in the truss members are so small that they are only axial. The axial displacement of the truss can be resolved along horizontal *x*-axis and vertical *y*-axis. But in our derivation, let us resolve the horizontal and vertical displacements (in *xy*-axes) of a joint along and perpendicular to the truss member (in *x y* □ -axes). Refer to the Figure in the next page. Note sin θcomponent acting towards negative *y*□ -direction and all other components acting towards in +ve*x* and *y* directions.



$$u_i' = u_i \cos\theta + v_i \sin\theta$$
$$v_i' = -u_i \sin\theta + v_i \cos\theta$$

$$u_j' = u_j \cos\theta + v_j \sin\theta$$
$$v_j' = -u_j \sin\theta + v_j \cos\theta$$

(5M)

The above equations can be written in the matrix form as follows

$$\begin{Bmatrix} u' \\ v_i' \\ u_j' \\ v_j' \end{Bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 0 & 0 \\ -\sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & \cos\theta & \sin\theta \\ 0 & 0 & -\sin\theta & \cos\theta \end{bmatrix} \begin{Bmatrix} u_i \\ v_i \\ u_j \\ v_j \end{Bmatrix}$$

$\{u'\} = [T]\{u\}$ where $[T]$ is the transformation matrix

Similarly, we resolve forces along the length of the member (positive x' direction) and perpendicular to the length of the member (positive y' direction)

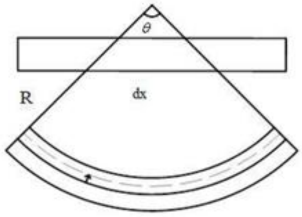
$$\begin{Bmatrix} F_{ix}' \\ F_{iy}' \\ F_{jx}' \\ F_{jy}' \end{Bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 0 & 0 \\ -\sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & \cos\theta & \sin\theta \\ 0 & 0 & -\sin\theta & \cos\theta \end{bmatrix} \begin{Bmatrix} F_{ix} \\ F_{iy} \\ F_{jx} \\ F_{jy} \end{Bmatrix}$$

$\{F'\} = [T]\{F\}$ where $[T]$ is the transformation matrix

(5M)

2 **Formulate the development of element equation. (13M) (NOVEMBER 2009)** BTL2

Answer: page – 3.107 Dr. S.Senthil

	 $dx = R\theta$ $\in_x = \frac{(R-y)\theta - R\theta}{R\theta} = \frac{-y}{R} = -y\frac{d^2y}{dx^2}$ $v = N_1v_1 + N_2\theta_1 + N_3v_2 + N_4\theta_2$ (6M) $\in_x = -y\frac{d^2v}{dx^2} = -y\frac{d^2}{dx^2}(N_1v_1 + N_2\theta_1 + N_3v_2 + N_4\theta_2)$ $\in_x = -y\underbrace{\left(\frac{d^2N_1}{dx^2} \quad \frac{d^2N_2}{dx^2} \quad \frac{d^2N_3}{dx^2} \quad \frac{d^2N_4}{dx^2}\right)}_{[B]}\underbrace{\begin{pmatrix} v_1 \\ \theta_1 \\ v_2 \\ \theta_2 \end{pmatrix}}_{\{a\}}$ $\in_x = [B]\{a\}$ (7M)
3	**Derive the shape function for the constant strain triangular element. (13M) (November 2012) BTL2** **Answer: page – 3.127 Dr. S.Senthil**

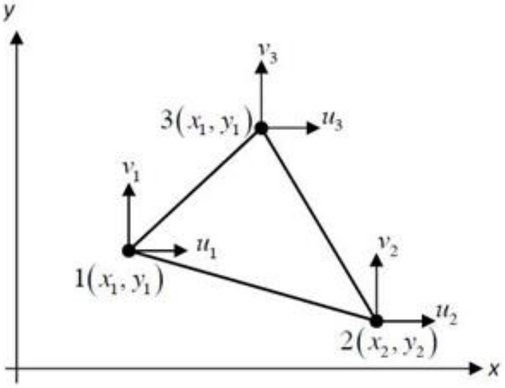


Figure shows a 2-D two-variable linear triangular element with three nodes and the two dof at each node. The nodes are placed at the corners of the triangle. The two variables (dof) are displacement in *x*-direction (*u*) and displacement in *y*-direction (*v*). Since each node has two dof, a single element has 6 dof. The nodal displacement vector is given by

$$\{U\} = \begin{Bmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \\ u_3 \\ v_3 \end{Bmatrix}$$

We select a linear displacement function for each dof as

$$u(x, y) = c_1 + c_2 x + c_3 y$$
$$v(x, y) = c_4 + c_5 x + c_6 y$$

(5M)

The above two algebraic equations can also be written as

$$\begin{Bmatrix} u \\ v \end{Bmatrix} = \begin{bmatrix} 1 & x & y & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & x & y \end{bmatrix} \begin{Bmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \\ c_6 \end{Bmatrix}$$

	Using steps we had developed for the 2-D single-variable linear triangular element, we can write $\begin{Bmatrix} c_1 \\ c_2 \\ c_3 \end{Bmatrix} = \frac{1}{2A} \begin{bmatrix} \alpha_1 & \alpha_2 & \alpha_3 \\ \beta_1 & \beta_2 & \beta_3 \\ \gamma_1 & \gamma_2 & \gamma_3 \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix}$ $\begin{Bmatrix} c_4 \\ c_5 \\ c_6 \end{Bmatrix} = \frac{1}{2A} \begin{bmatrix} \alpha_1 & \alpha_2 & \alpha_3 \\ \beta_1 & \beta_2 & \beta_3 \\ \gamma_1 & \gamma_2 & \gamma_3 \end{bmatrix} \begin{Bmatrix} v_1 \\ v_2 \\ v_3 \end{Bmatrix}$ and using the interpolation functions we had developed for the 2-D single-variable linear triangularelement, we can write (5M) $u(x, y) = N_1 u_1 + N_2 u_2 + N_3 u_3$ $v(x, y) = N_1 v_1 + N_2 v_2 + N_3 v_3$ where $N_i = \frac{1}{2A}(\alpha_i + \beta_i x + \gamma_i y), \qquad i = 1, 2, 3$ Writing the above equations in matrix form $\begin{Bmatrix} u(x,y) \\ v(x,y) \end{Bmatrix} = \begin{bmatrix} N_1 & 0 & N_2 & 0 & N_3 & 0 \\ 0 & N_1 & 0 & N_2 & 0 & N_3 \end{bmatrix} \begin{Bmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \\ u_3 \\ v_3 \end{Bmatrix}$ $\{U\} = [N]\{a\}$ (3M)
4	**Determine the stiffness matrix for the straight-sided triangular element of thickness t = 1 mm, as shown. Use E = 70 GPa, n = 0.3 and assume a plane stress condition. (13M) (November 2012)** BTL2 **Answer: page – 3.37 Dr. S.Senthil**

Solution:

Element stiffness matrix is given by

$$[k]^e = t_e A_e [B]^T [D] \cdot [B] \qquad \text{(i)}$$

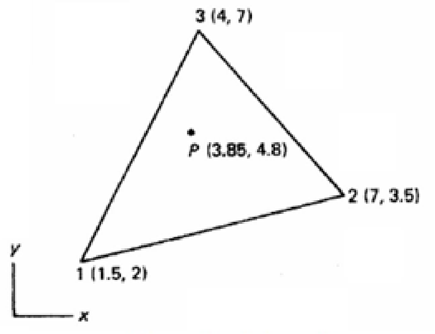
where,

$$t_e = 1 \text{ mm}$$

$$A_e = \frac{1}{2}\left|\det[J]\right| = \frac{1}{2}\left|x_{13}.y_{23} - x_{23}.y_{13}\right|$$

$$= \frac{1}{2}|23.75|$$

$$A_e = 11.875 \text{ mm}^2$$



(Dimension is in mm)

(5M)

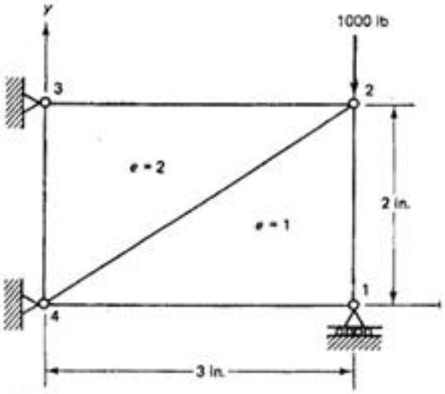
The *strain-displacement matrix*, [B] is given by

$$[B] = \frac{1}{\det[J]}\begin{bmatrix} y_{23} & 0 & y_{31} & 0 & y_{12} & 0 \\ 0 & x_{32} & 0 & x_{13} & 0 & x_{21} \\ x_{32} & y_{23} & x_{13} & y_{31} & x_{21} & y_{12} \end{bmatrix}$$

$$= \frac{1}{23.75}\begin{bmatrix} 3.5-7 & 0 & 7-2 & 0 & 2-3.5 & 0 \\ 0 & 4-7 & 0 & 1.5-4 & 0 & 7-1.5 \\ 4-7 & 3.5-7 & 1.5-4 & 7-2 & 7-1.5 & 2-3.5 \end{bmatrix}$$

$$[B] = \frac{1}{23.75}\begin{bmatrix} -3.5 & 0 & 5 & 0 & -1.5 & 0 \\ 0 & -3 & 0 & -2.5 & 0 & 5.5 \\ -3 & -3.5 & -2.5 & 5 & -5.5 & -1.5 \end{bmatrix}$$

(5M)

	Multiplying and simplifying, we obtain $$[k]^e = 10^4 \cdot \begin{array}{c} \begin{array}{cccccc} q_1 & q_2 & q_3 & q_4 & q_5 & q_6 \end{array} \\ \begin{bmatrix} 2.494 & 1.105 & -2.409 & -0.425 & -0.085 & -0.68 \\ & 2.152 & -0.233 & 0.223 & -0.873 & -2.374 \\ & & 4.403 & -1.316 & -1.994 & 1.549 \\ & & & 2.429 & 1.741 & -2.652 \\ & & & & 2.079 & -0.868 \\ symmetry & & & & & 5.026 \end{bmatrix} \end{array}$$ (3M)
5	**Consider a thin plate having thickness *t*= 0.5 in. being modeled using two CST elements, as shown. Assuming plane stress condition, (a) determine the displacements of nodes 1 and 2, and (b) estimate the stresses in both elements. (13M)(November 2012)** BTL2 **Answer: page – 3.47 Dr. S.Senthil**  Thickness $t = 0.5$ in., $E = 30 \times 10^6$ psi, $\nu = 0.25$

Solution

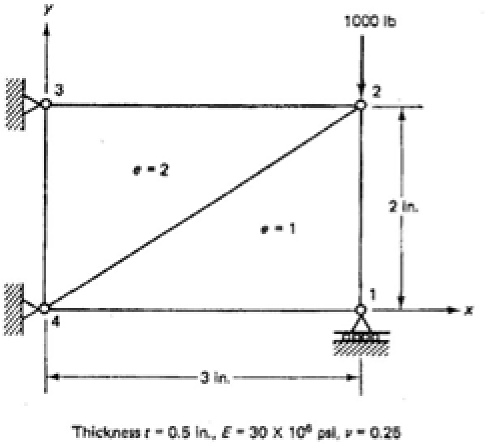
Element connectivity

	Local Nodes		
Element No	**1**	**2**	**3**
1	1	2	4
2	3	4	2

For **plane stress** problem, the *materials matrix* is given by

$$[D]=\frac{E}{1-\nu^2}\begin{bmatrix}1 & \nu & 0\\ \nu & 1 & 0\\ 0 & 0 & \frac{1}{2}(1-\nu)\end{bmatrix}$$

$$[D]=32\times10^6\begin{bmatrix}1 & 0.25 & 0\\ 0.25 & 1 & 0\\ 0 & 0 & 0.375\end{bmatrix}$$



Thickness t = 0.5 in., E = 30 X 10^6 psi, ν = 0.25

(5M)

Element 1

Area of element, $A_1=\frac{1}{2}\left|\det[J]\right|=\frac{1}{2}(6)=3\text{ in}^2$

The strain-displacement matrix,

$$[B]=\frac{1}{\det[J]}\begin{bmatrix}y_{23} & 0 & y_{31} & 0 & y_{12} & 0\\ 0 & x_{32} & 0 & x_{13} & 0 & x_{21}\\ x_{32} & y_{23} & x_{13} & y_{31} & x_{21} & y_{12}\end{bmatrix}=\frac{1}{6}\begin{bmatrix}2 & 0 & -3 & 0 & -2 & 0\\ 0 & -3 & 0 & 3 & 0 & 0\\ -3 & 2 & 3 & 0 & 0 & -2\end{bmatrix}$$

Multiplying matrices [*D*][*B*] we get,

$$[D][B]^{(1)}=10^7\cdot\begin{bmatrix}1.067 & -0.4 & 0 & 0.4 & -1.067 & 0\\ 0.267 & -1.6 & 0 & 1.6 & -0.267 & 0\\ -0.6 & 0.4 & 0.6 & 0 & 0 & -0.4\end{bmatrix}$$

The *stiffness matrix* is given by,

$$[k]^{(1)} = t_1 A_1 [B]_1^T [D][B]_1$$

Substitute all parameters and multiplying the matrices, yields

$$[k]^{(1)} = 10^7 \begin{array}{c} \begin{array}{cccccc} Q_1 & Q_2 & Q_3 & Q_4 & Q_7 & Q_8 \end{array} \\ \begin{bmatrix} 0.983 & -0.5 & -0.45 & 0.2 & -0.533 & 0.3 \\ & 1.4 & 0.3 & -1.2 & 0.2 & -0.2 \\ & & 0.45 & 0 & 0 & -0.3 \\ & & & 1.2 & -0.2 & 0 \\ & \text{symmetric} & & & 0.533 & 0 \\ & & & & & 0.2 \end{bmatrix} \end{array}$$

(5M)

Element 2

Area of element, $A_2 = \frac{1}{2}\left|\det[J]\right| = \frac{1}{2}(6) = 3 \text{ in}^2$

The *strain-displacement* matrix is

$$[B] = \frac{1}{\det[J]} \begin{bmatrix} y_{23} & 0 & y_{31} & 0 & y_{12} & 0 \\ 0 & x_{32} & 0 & x_{13} & 0 & x_{21} \\ x_{32} & y_{23} & x_{13} & y_{31} & x_{21} & y_{12} \end{bmatrix} = \frac{1}{6} \begin{bmatrix} -2 & 0 & 0 & 0 & 2 & 0 \\ 0 & 3 & 0 & -3 & 0 & 0 \\ 3 & -2 & -3 & 0 & 0 & 2 \end{bmatrix}$$

Multiplying matrices [*D*][*B*] we get,

$$[D][B]^{(2)} = 10^7 \cdot \begin{bmatrix} -1.067 & 0.4 & 0 & -0.4 & 1.067 & 0 \\ -0.267 & 1.6 & 0 & -1.6 & 0.267 & 0 \\ 0.6 & -0.4 & -0.6 & 0 & 0 & 0.4 \end{bmatrix}$$

The *stiffness matrix* is given by,

$$[k]^{(2)} = t_2 A_2 [B]_2^T [D][B]_2$$

Substituting all parameters and multiplying the matrices yield

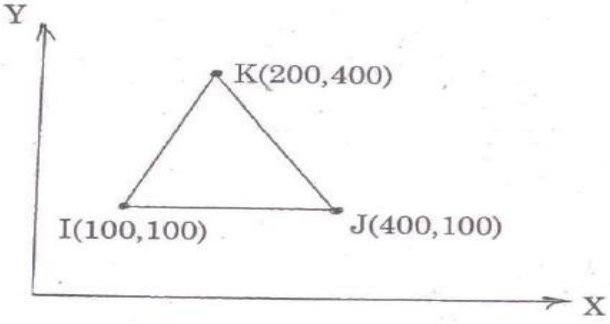
$$[k]^{(2)} = 10^7 \begin{array}{c} \\ \left[\begin{array}{cccccc} Q_5 & Q_6 & Q_7 & Q_8 & Q_3 & Q_4 \\ 0.983 & -0.5 & -0.45 & 0.2 & -0.533 & 0.3 \\ & 1.4 & 0.3 & -1.2 & 0.2 & -0.2 \\ & & 0.45 & 0 & 0 & -0.3 \\ & & & 1.2 & -0.2 & 0 \\ & \text{symmetric} & & & 0.533 & 0 \\ & & & & & 0.2 \end{array}\right] \end{array}$$

(3M)

PART * C

1 **For the constant strain triangular element shown in figure. Assemble strain-displacement matrix. Take t = 20 mm, E = 2 X 10^5 N / mm^2. (15M)(November 2012)**BTL3

Answer: page – 3.07 Dr. S.Senthil



Given data:

$x_1 = 100$ $y_1 = 100$

$x_2 = 400$ $y_2 = 100$

$x_3 = 200$ $y_3 = 400$

Young's modulus, E = 2 X 10^5 N / mm^2

Thickness, t = 20 mm

To find: Strain-displacement matrix [B]

Solution: We know that,

Strain-displacement matrix for CST element is,

$$[B] = \frac{1}{2A}\begin{bmatrix} q_1 & 0 & q_2 & 0 & q_3 & 0 \\ 0 & r_1 & 0 & r_2 & 0 & r_3 \\ r_1 & q_1 & r_2 & q_2 & r_3 & q_3 \end{bmatrix}$$

Where, A = Area of the element

$q_1 = y_2 - y_3 = 100 - 400 = -300$

$q_2 = y_3 - y_1 = 400 - 100 = 300$

$q_3 = y_1 - y_2 = 100 - 100 = 0$

$r_1 = x_3 - x_2 = 200 - 400 = -200$

$r_2 = x_1 - x_3 = 100 - 200 = -100$

$r_3 = x_2 - x_1 = 400 - 100 = 300$

Substitute the above values in eqation (1)

(5M)

$$[B] = \frac{1}{2A}\begin{bmatrix} -300 & 0 & 300 & 0 & 0 & 0 \\ 0 & -200 & 0 & -100 & 0 & 300 \\ -200 & -300 & -100 & 300 & 300 & 0 \end{bmatrix}$$ …. (

Where, A = Area of the element

$$A = \frac{1}{2}\begin{vmatrix} 1 & x_1 & y_1 \\ 1 & x_2 & y_2 \\ 1 & x_3 & y_3 \end{vmatrix}$$

$$A = \frac{1}{2}\begin{vmatrix} 1 & 100 & 100 \\ 1 & 400 & 100 \\ 1 & 200 & 400 \end{vmatrix}$$

$$A = \frac{1}{2} X [1(400 X 400 - 200 X 100) - 100(400 X 1 - 100 X 1) + 100(200 X 1 - 400 X 1)]$$

$A = 45000 \text{ mm}^2$

(5M)

Substitute A value in equation (2)

$$[B] = \frac{1}{2 X 45000}\begin{bmatrix} -300 & 0 & 300 & 0 & 0 & 0 \\ 0 & -200 & 0 & -100 & 0 & 300 \\ -200 & -300 & -100 & 300 & 300 & 0 \end{bmatrix}$$

$$[B] = \frac{1}{900}\begin{bmatrix} -3 & 0 & 3 & 0 & 0 & 0 \\ 0 & -2 & 0 & -1 & 0 & 3 \\ -2 & -3 & -1 & 3 & 3 & 0 \end{bmatrix}$$

Result :

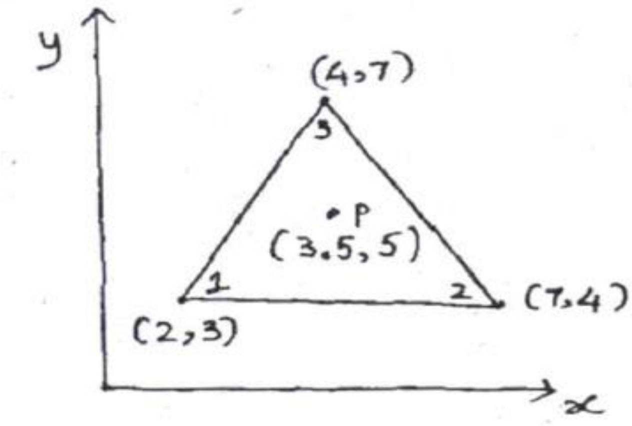
Strain-displacement matrix

$$[B] = \frac{1}{900}\begin{bmatrix} -3 & 0 & 3 & 0 & 0 & 0 \\ 0 & -2 & 0 & -1 & 0 & 3 \\ -2 & -3 & -1 & 3 & 3 & 0 \end{bmatrix}$$

(5M)

2 **Determine the shape functions N_1, N_2 and N_3 at the interior point P for the triangular element shown in figure. (15M)(November 2012)** BTL3

Answer: page – 3.17 Dr. S.Senthil



Given data:

$x_1 = 2$ $y_1 = 3$
$x_2 = 7$ $y_2 = 4$
$x_3 = 4$ $y_3 = 7$
$x = 3.5$ $y = 5$

To find: Shape functions N_1, N_2 and N_3 at the interior point P

Solution: We know that,

$$x = (x_1 - x_3)N_1 + (x_2 - x_3)N_2 + x_3 \quad \text{...(1)}$$

$$y = (y_1 - y_3)N_1 + (y_2 - y_3)N_2 + y_3 \quad \text{...(2)}$$

Substituting the co-ordinates values,

$$3.5 = (2 - 4)N_1 + (7 - 4)N_2 + 4 \quad \text{...(3}$$

$$5 = (3 - 7)N_1 + (4 - 7)N_2 + 7 \quad \text{...(4)}$$

Equation (3) becomes,

$$3.5 = -2N_1 + 3N_2 + 4$$

$$-0.5 = -2N_1 + 3N_2$$

$$2N_1 - 3N_2 = 0.5 \quad \text{...(5)}$$

Equation (4) becomes,

$$5 = -4N_1 - 3N_2 + 7$$

(5M)

$$-2 = -4N_1 - 3N_2$$

$$4N_1 + 3N_2 = 2 \qquad \ldots(6)$$

Solving equation (5) and (6)

$$2N_1 - 3N_2 = 0.5$$

$$4N_1 + 3N_2 = 2$$

Solving, $6N_1 = 2.5$

$$\boldsymbol{N_1 = 0.4166}$$

Substituting N_1 value in equation (5) or equation (6),

$$2N_1 - 3N_2 = 0.5$$

$$2\,X\,(0.4166) - 3N_2 = 0.5$$

$$\boldsymbol{N_2 = 0.1111}$$

we know that, $N_1+N_2+N_3 = 1$

$$0.4166+0.1111+N_3 = 1$$

(8M)

Result

Shape functions N_1, N_2 and N_3 at the interior point P

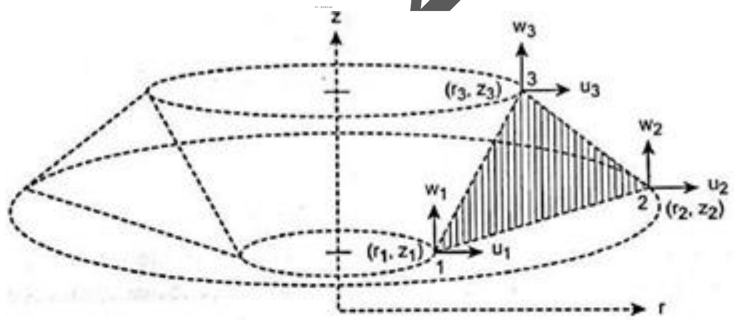
$$N_1 = 0.4166$$

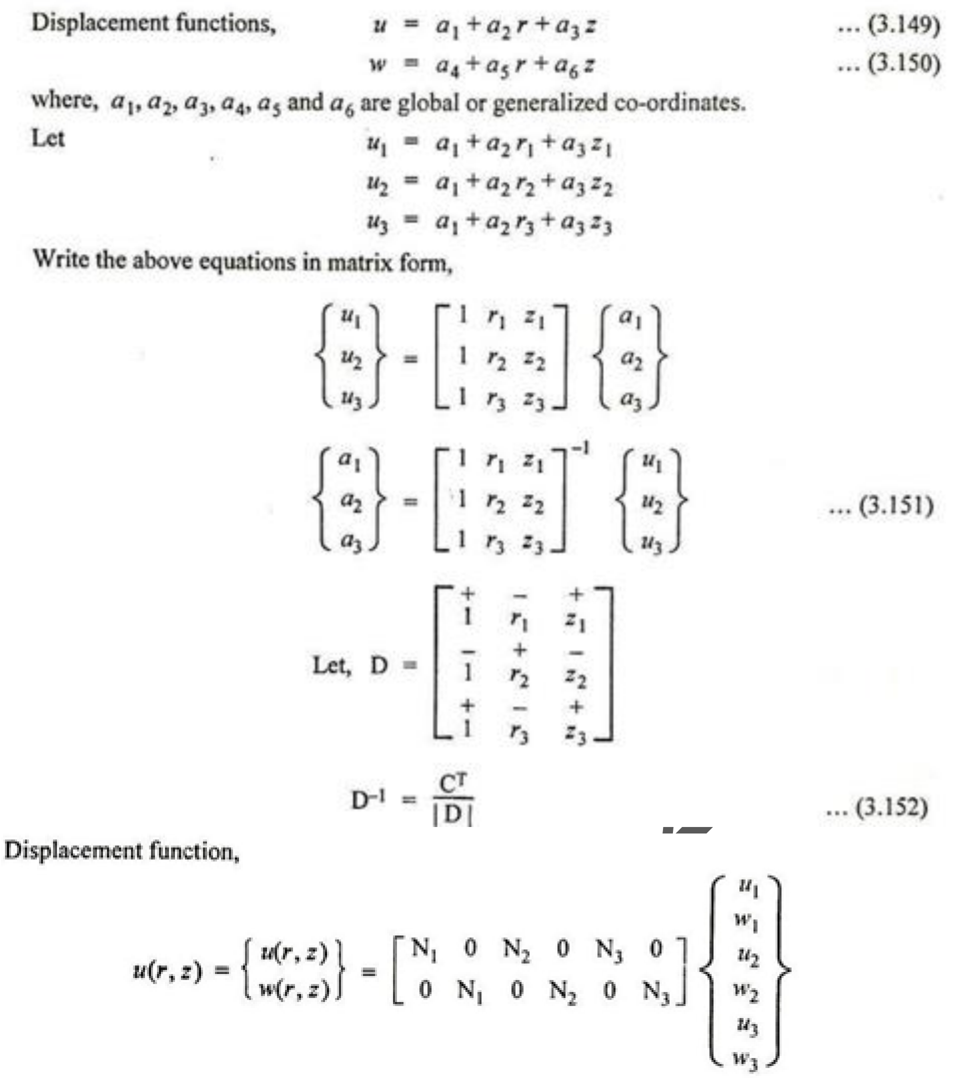
$$N_2 = 0.1111$$

$$N_3 = 0.4723$$

(2M)

UNIT IV TWO DIMENSIONAL VECTOR VARIABLE PROBLEMS	
Equations of elasticity – Plane stress, plane strain and axisymmetric problems – Body forces and temperature effects – Stress calculations - Plate and shell elements.	
PART * A	
Q.No.	**Questions**
1.	**What is axisymmetric element?(MAY 2008)**BTL1 Many three dimensional problem in engineering exhibit symmetry about an axis of rotation such type of problem are solved by special two dimensional element called the axisymmetric element
2	**What are the conditions for a problem to be axisymmetric?**BTL1 a. The problem domain must be symmetric about the axis of revolution b. All boundary condition must be symmetric about the axis of revolution c. All loading condition must be symmetric about the axis of revolution
3	**What is the purpose of Isoparametric element?** BTL1 It is difficult to represent the curved boundaries by straight edges finite elements. A large number of finite elements may be used to obtain reasonable resemblance between original body and the assemblage.
4	**Define super parametric element.(MAY 2008)**BTL1 If the number of nodes used for defining the geometry is more than of nodes used for defining the displacement is known as super parametric element.
5	**Define sub parametric element.** BTL1 If the number of nodes used for defining the geometry is less than number of nodes used for defining the displacement is known as sub parametric element.
6	**What is meant by Isoparametric element?** BTL1 If the number of nodes used for defining the geometry is same as number of nodes used for defining the displacement is known as Isoparametric element.
7	**Is beam element an Isoparametric element?(MAY 2009)**BTL1 Beam element is not an Isoparametric element since the geometry and displacement are defined by different order interpretation functions.
8	**What is simple natural coordinate?** BTL1 A simple natural coordinate is one whose value between -1 and 1.
9	**Give example for essential boundary conditions.** The geometry boundary condition are displacement, slope.
10	**Write down the shape functions for 4 noded rectangular elements using natural coordinate system.(MAY 2010)**BTL1 *N*1 = 1 (1-e)(1-h) *N*2 = 1 (1+e)(1-h)4 4 *N*3 = 1 (1 +e)(1+h) *N*4 = 1 (1 -e)(1 +h)4 4
11	**Give example for non essential boundary conditions.** BTL1 The natural boundary conditions are bending moment, shear force
12	**What is meant by degrees of freedom?** BTL1 When the force or reaction act at nodal point node is subjected to deformation. The deformation includes displacement rotation, and or strains. These are collectively known as degrees of freedom.

13	**What is QST element?** BTL1 Ten noded triangular elements are known as Quadratic strain triangle. It is also called as cubic displacement triangle.
14	**Write down the stiffness matrix equation for two dimensional CST elements.(MAY 2012)**BTL1 Stiffness matrix [*K*]=[*B*]*T* [*D*][*B*] [*B*]*T* -Strain displacement [*D*]-Stress strain matrix [*B*]-Strain displacement matrix
15	**State the assumptions made in the case of truss element. (MAY 2008)** The following assumptions are made in the case of truss element, • All the members are pin jointed. • The truss is loaded only at the joints • The self weight of the members are neglected unless stated.
	PART * B
1	**Derive the shape function equation for the Axisymmetric element. (13M) (Nov/Dec'10)** BTL2 **Answer: page – 4.17 Dr. S.Senthil**  Consider an axisymmetric triangular element with nodes 1, 2 and 3 as shown in Fig.3.31. Let the nodal displacements be u_1 w_1, u_2 w_2, and u_3 w_3. Displacement, $\{ u \} = \begin{Bmatrix} u_1 \\ w_1 \\ u_2 \\ w_2 \\ u_3 \\ w_3 \end{Bmatrix}$ (6M)

	 Displacement functions, $u = a_1 + a_2 r + a_3 z$ ... (3.149) $w = a_4 + a_5 r + a_6 z$ ... (3.150) where, a_1, a_2, a_3, a_4, a_5 and a_6 are global or generalized co-ordinates. Let $u_1 = a_1 + a_2 r_1 + a_3 z_1$ $u_2 = a_1 + a_2 r_2 + a_3 z_2$ $u_3 = a_1 + a_2 r_3 + a_3 z_3$ Write the above equations in matrix form, $\begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix} = \begin{bmatrix} 1 & r_1 & z_1 \\ 1 & r_2 & z_2 \\ 1 & r_3 & z_3 \end{bmatrix} \begin{Bmatrix} a_1 \\ a_2 \\ a_3 \end{Bmatrix}$ $\begin{Bmatrix} a_1 \\ a_2 \\ a_3 \end{Bmatrix} = \begin{bmatrix} 1 & r_1 & z_1 \\ 1 & r_2 & z_2 \\ 1 & r_3 & z_3 \end{bmatrix}^{-1} \begin{Bmatrix} u_1 \\ u_2 \\ u_3 \end{Bmatrix}$ ... (3.151) Let, $D = \begin{bmatrix} \overset{+}{1} & \overset{-}{r_1} & \overset{+}{z_1} \\ \overset{-}{1} & \overset{+}{r_2} & \overset{-}{z_2} \\ \overset{+}{1} & \overset{-}{r_3} & \overset{+}{z_3} \end{bmatrix}$ $D^{-1} = \frac{C^T}{\lvert D \rvert}$ ... (3.152) (5M) Displacement function, $u(r,z) = \begin{Bmatrix} u(r,z) \\ w(r,z) \end{Bmatrix} = \begin{bmatrix} N_1 & 0 & N_2 & 0 & N_3 & 0 \\ 0 & N_1 & 0 & N_2 & 0 & N_3 \end{bmatrix} \begin{Bmatrix} u_1 \\ w_1 \\ u_2 \\ w_2 \\ u_3 \\ w_3 \end{Bmatrix}$ (2M)
2	**Derive the Strain Displacement Matrix for the Axisymmetric element. (13M) (November 2011)** BTL2 **Answer: page – 4.17 Dr. S.Senthil**

Displacement function for axisymmetric triangular element is given by,

$$\text{Displacement function, } u(r,z) = \begin{Bmatrix} u(r,z) \\ w(r,z) \end{Bmatrix} = \begin{bmatrix} N_1 & 0 & N_2 & 0 & N_3 & 0 \\ 0 & N_1 & 0 & N_2 & 0 & N_3 \end{bmatrix} \begin{Bmatrix} u_1 \\ w_1 \\ u_2 \\ w_2 \\ u_3 \\ w_3 \end{Bmatrix}$$

or

We can write,

$$u = N_1 u_1 + N_2 u_2 + N_3 u_3 \quad \dots (3.164)$$

$$w = N_1 w_1 + N_2 w_2 + N_3 w_3 \quad \dots (3.165)$$

The strain components are,

$$\text{Radial strain, } e_r = \frac{\partial u}{\partial r} = \frac{\partial N_1}{\partial r} u_1 + \frac{\partial N_2}{\partial r} u_2 + \frac{\partial N_3}{\partial r} u_3$$

$$\Rightarrow \boxed{e_r = \frac{\partial N_1}{\partial r} u_1 + \frac{\partial N_2}{\partial r} u_2 + \frac{\partial N_3}{\partial r} u_3} \quad \dots (3.166)$$

$$\text{Circumferential strain, } e_\theta = \frac{u}{r}$$

$$\boxed{e_\theta = \frac{N_1}{r} u_1 + \frac{N_2}{r} u_2 + \frac{N_3}{r} u_3} \quad \dots (3.167)$$

(6M)

$$\text{Longitudinal strain, } e_z = \frac{\partial w}{\partial z}$$

$$\Rightarrow \boxed{e_z = \frac{\partial N_1}{\partial z} w_1 + \frac{\partial N_2}{\partial z} w_2 + \frac{\partial N_3}{\partial z} w_3} \quad \dots (3.168)$$

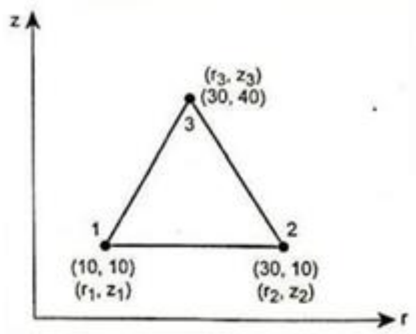
$$\text{Shear strain, } \gamma_{rz} = \frac{\partial u}{\partial z} + \frac{\partial w}{\partial r}$$

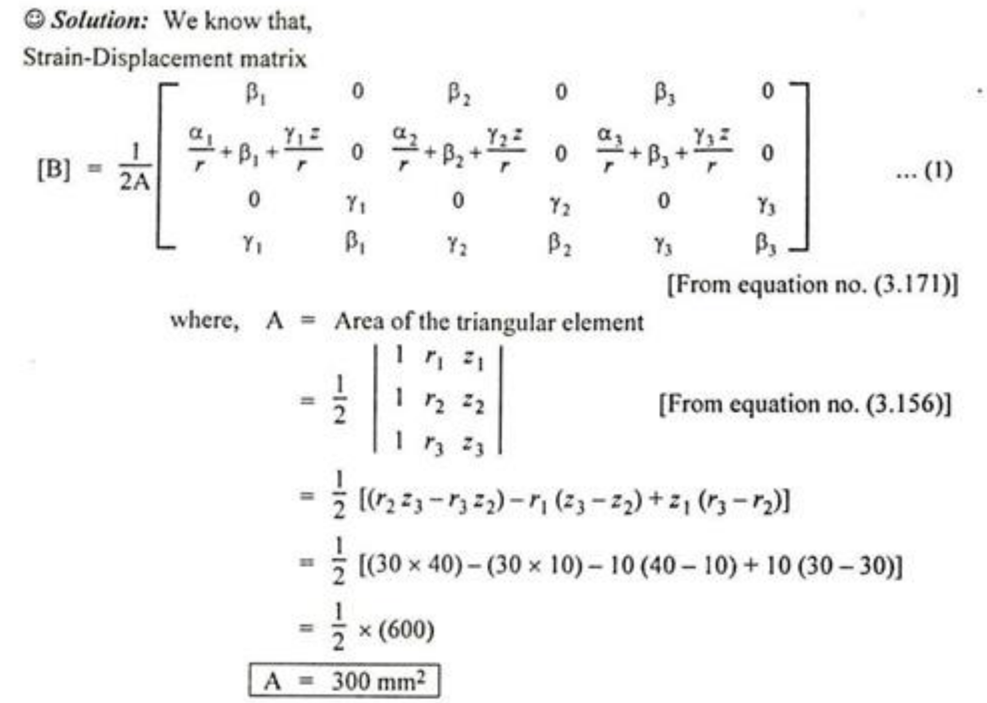
$$\boxed{\gamma_{rz} = \frac{\partial N_1}{\partial z} u_1 + \frac{\partial N_2}{\partial z} u_2 + \frac{\partial N_3}{\partial z} u_3 + \frac{\partial N_1}{\partial r} w_1 + \frac{\partial N_2}{\partial r} w_2 + \frac{\partial N_3}{\partial r} w_3} \quad \dots (3.169)$$

Arranging equations (3.166), (3.167), (3.168) and (3.169) in matrix form,

$$\Rightarrow \begin{Bmatrix} e_r \\ e_\theta \\ e_z \\ \gamma_{rz} \end{Bmatrix} = \begin{bmatrix} \frac{\partial N_1}{\partial r} & 0 & \frac{\partial N_2}{\partial r} & 0 & \frac{\partial N_3}{\partial r} & 0 \\ \frac{N_1}{r} & 0 & \frac{N_2}{r} & 0 & \frac{N_3}{r} & 0 \\ 0 & \frac{\partial N_1}{dz} & 0 & \frac{\partial N_2}{\partial z} & 0 & \frac{\partial N_3}{\partial z} \\ \frac{\partial N_1}{\partial z} & \frac{\partial N_1}{\partial r} & \frac{\partial N_2}{\partial z} & \frac{\partial N_2}{\partial r} & \frac{\partial N_3}{\partial z} & \frac{\partial N_3}{\partial r} \end{bmatrix} \begin{Bmatrix} u_1 \\ w_1 \\ u_2 \\ w_2 \\ u_3 \\ w_3 \end{Bmatrix} \quad \dots (3.170)$$

	Substitute $\frac{\partial N_1}{\partial r}$, $\frac{\partial N_2}{\partial r}$, $\frac{\partial N_3}{\partial r}$, $\frac{N_1}{r}$, $\frac{N_2}{r}$, $\frac{N_3}{r}$, $\frac{\partial N_1}{\partial z}$, $\frac{\partial N_2}{\partial z}$ and $\frac{\partial N_3}{\partial z}$ values in equation (3.170). $(3.170) \Rightarrow \begin{Bmatrix} e_r \\ e_\theta \\ e_z \\ \gamma_{rz} \end{Bmatrix} = \frac{1}{2A} \begin{bmatrix} \beta_1 & 0 & \beta_2 & 0 & \beta_3 & 0 \\ \frac{\alpha_1}{r}+\beta_1+\frac{\gamma_1 z}{r} & 0 & \frac{\alpha_2}{r}+\beta_2+\frac{\gamma_2 z}{r} & 0 & \frac{\alpha_3}{r}+\beta_3+\frac{\gamma_3 z}{r} & 0 \\ 0 & \gamma_1 & 0 & \gamma_2 & 0 & \gamma_3 \\ \gamma_1 & \beta_1 & \gamma_2 & \beta_2 & \gamma_3 & \beta_3 \end{bmatrix} \begin{Bmatrix} u_1 \\ w_1 \\ u_2 \\ w_2 \\ u_3 \\ w_3 \end{Bmatrix}$ (7M)
3	**Derive the Stress Strain Relationship matrix for the Axisymmetric triangular element. (13M) (November 2013)** BTL2 **Answer: page – 4.27 Dr. S.Senthil** $\sigma_x = \frac{E}{(1+\nu)(1-2\nu)} [e_x(1-\nu)+\nu e_y+\nu e_z]$ $\sigma_y = \frac{E}{(1+\nu)(1-2\nu)} [\nu e_x+(1-\nu)e_y+\nu e_z]$ $\sigma_z = \frac{E}{(1+\nu)(1-2\nu)} [\nu e_x+\nu e_y+(1-\nu)e_z]$ $\tau_{xz} = \frac{E}{(1+\nu)(1-2\nu)} \times \left(\frac{1-2\nu}{2}\right) \times \gamma_{xz}$ (3M) Substitute $x = r$ and $y = \theta$ in the above equations, $\Rightarrow$ Radial stress, $\sigma_r = \frac{E}{(1+\nu)(1-2\nu)} [e_r(1-\nu)+\nu e_\theta+\nu e_z]$ ... (3.172) Circumferential stress, $\sigma_\theta = \frac{E}{(1+\nu)(1-2\nu)} [\nu e_r+(1-\nu) e_\theta+\nu e_z]$ ... (3.173) Longitudinal stress, $\sigma_z = \frac{E}{(1+\nu)(1-2\nu)} [\nu e_r+\nu e_\theta+(1-\nu) e_z]$ ... (3.174) Shear stress, $\tau_{rz} = \frac{E}{(1+\nu)(1-2\nu)} \times \left(\frac{1-2\nu}{2}\right) \times \gamma_{rz}$ ... (3.175) Arranging the above equations, (3.172), (3.173), (3.174) and (3.175) in matrix form, $\begin{Bmatrix} \sigma_r \\ \sigma_\theta \\ \sigma_z \\ \tau_{rz} \end{Bmatrix} = \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1-\nu & \nu & \nu & 0 \\ \nu & 1-\nu & \nu & 0 \\ \nu & \nu & 1-\nu & 0 \\ 0 & 0 & 0 & \frac{1-2\nu}{2} \end{bmatrix} \begin{Bmatrix} e_r \\ e_\theta \\ e_z \\ \gamma_{rz} \end{Bmatrix}$ ... (3.176) (6M)

	The above equation is in the form of, $\{\sigma\} = [D]\{e\}$ where, $[D]$ = Stress-Strain relationship matrix $= \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1-\nu & \nu & \nu & 0 \\ \nu & 1-\nu & \nu & 0 \\ \nu & \nu & 1-\nu & 0 \\ 0 & 0 & 0 & \frac{1-2\nu}{2} \end{bmatrix}$ (4M)
4	**The nodal co-ordinates for an axisymmetric triangular element are given below. r_1= 10 mm, r_2= 30 mm, r_3= 30 mm z_1 = 10 mm, z_2 = 10 mm, z_3 = 40 mm. Evaluate [B] Matrix for the element. (13M) (November 2014)** BTL2 **Answer: page – 4.317 Dr. S.Senthil**  ***Given:*** Co-ordinates: $r_1 = 10$ mm; $z_1 = 10$ mm $r_2 = 30$ mm; $z_2 = 10$ mm $r_3 = 30$ mm; $z_3 = 40$ mm ***To find:*** Strain-Displacement matrix [B].



☺ ***Solution:*** We know that,

Strain-Displacement matrix

$$[B] = \frac{1}{2A}\begin{bmatrix} \beta_1 & 0 & \beta_2 & 0 & \beta_3 & 0 \\ \frac{\alpha_1}{r}+\beta_1+\frac{\gamma_1 z}{r} & 0 & \frac{\alpha_2}{r}+\beta_2+\frac{\gamma_2 z}{r} & 0 & \frac{\alpha_3}{r}+\beta_3+\frac{\gamma_3 z}{r} & 0 \\ 0 & \gamma_1 & 0 & \gamma_2 & 0 & \gamma_3 \\ \gamma_1 & \beta_1 & \gamma_2 & \beta_2 & \gamma_3 & \beta_3 \end{bmatrix} \quad \ldots (1)$$

[From equation no. (3.171)]

where, A = Area of the triangular element

$$= \frac{1}{2}\begin{vmatrix} 1 & r_1 & z_1 \\ 1 & r_2 & z_2 \\ 1 & r_3 & z_3 \end{vmatrix}$$

[From equation no. (3.156)]

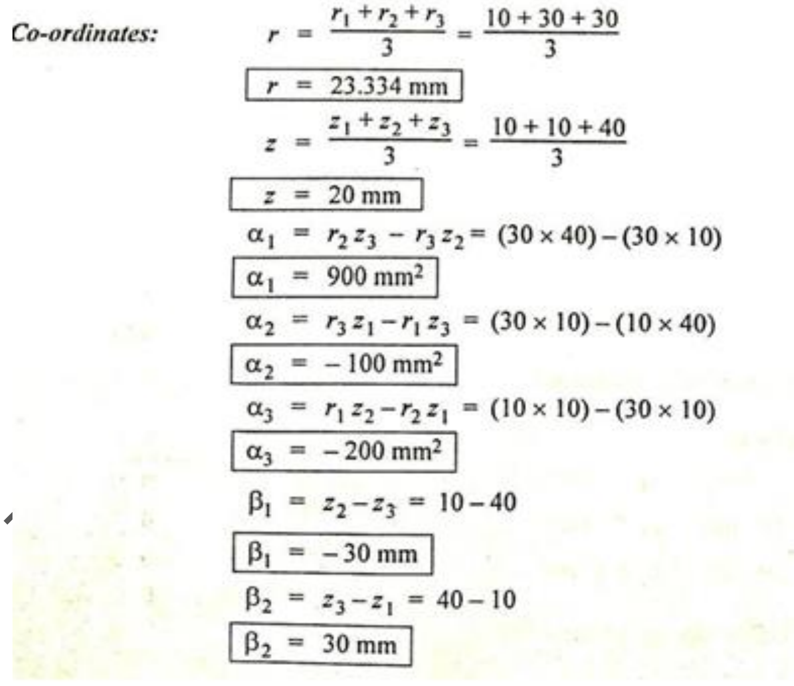
$$= \frac{1}{2}\,[(r_2 z_3 - r_3 z_2) - r_1(z_3 - z_2) + z_1(r_3 - r_2)]$$

$$= \frac{1}{2}\,[(30 \times 40) - (30 \times 10) - 10\,(40 - 10) + 10\,(30 - 30)]$$

$$= \frac{1}{2} \times (600)$$

$$\boxed{A = 300 \text{ mm}^2}$$

(7M)



Co-ordinates:

$$r = \frac{r_1 + r_2 + r_3}{3} = \frac{10 + 30 + 30}{3}$$

$$\boxed{r = 23.334 \text{ mm}}$$

$$z = \frac{z_1 + z_2 + z_3}{3} = \frac{10 + 10 + 40}{3}$$

$$\boxed{z = 20 \text{ mm}}$$

$$\alpha_1 = r_2 z_3 - r_3 z_2 = (30 \times 40) - (30 \times 10)$$

$$\boxed{\alpha_1 = 900 \text{ mm}^2}$$

$$\alpha_2 = r_3 z_1 - r_1 z_3 = (30 \times 10) - (10 \times 40)$$

$$\boxed{\alpha_2 = -100 \text{ mm}^2}$$

$$\alpha_3 = r_1 z_2 - r_2 z_1 = (10 \times 10) - (30 \times 10)$$

$$\boxed{\alpha_3 = -200 \text{ mm}^2}$$

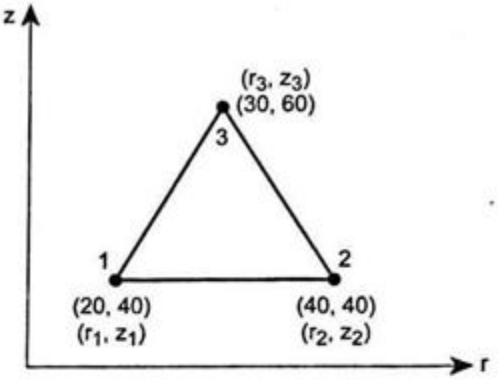
$$\beta_1 = z_2 - z_3 = 10 - 40$$

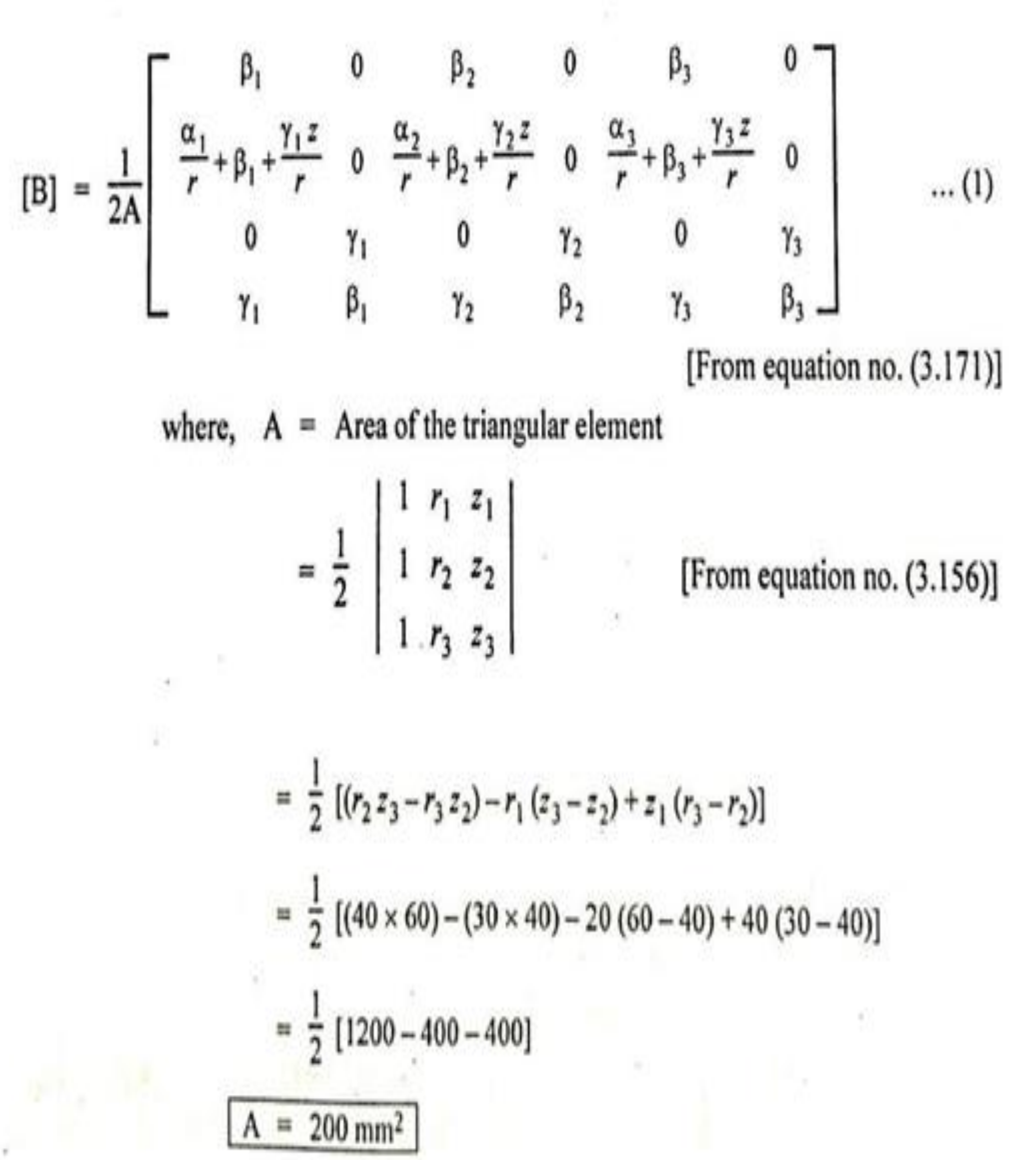
$$\boxed{\beta_1 = -30 \text{ mm}}$$

$$\beta_2 = z_3 - z_1 = 40 - 10$$

$$\boxed{\beta_2 = 30 \text{ mm}}$$

(4M)

	Result: Strain-Displacement matrix, $[B] = \begin{bmatrix} -0.05 & 0 & 0.05 & 0 & 0 & 0 \\ 0.0142 & 0 & 0.0142 & 0 & 0.0142 & 0 \\ 0 & 0 & 0 & -0.0333 & 0 & 0.0333 \\ 0 & -0.05 & -0.0333 & 0.05 & 0.0333 & 0 \end{bmatrix}$ (2M)
5	**The nodal coordinates for an Axisymmetric triangular element are given below r_1= 20 mm, r_2= 40 mm , r_3= 30 mm z_1 = 40 mm, z_2 = 40 mm, z_3 = 60 mm. Evaluate [B] Matrix for the element. (13M) (November 2015)** BTL2 **Answer: page – 4.107 Dr. S.Senthil**  ***Given:*** Co-ordinates: $r_1 = 20$ mm; $z_1 = 40$ mm $r_2 = 40$ mm; $z_2 = 40$ mm $r_3 = 30$ mm; $z_3 = 60$ mm ***To find:*** Strain-Displacement matrix [B]. ☺ ***Solution:*** We know that, Strain-Displacement matrix



$$[B] = \frac{1}{2A}\begin{bmatrix} \beta_1 & 0 & \beta_2 & 0 & \beta_3 & 0 \\ \frac{\alpha_1}{r}+\beta_1+\frac{\gamma_1 z}{r} & 0 & \frac{\alpha_2}{r}+\beta_2+\frac{\gamma_2 z}{r} & 0 & \frac{\alpha_3}{r}+\beta_3+\frac{\gamma_3 z}{r} & 0 \\ 0 & \gamma_1 & 0 & \gamma_2 & 0 & \gamma_3 \\ \gamma_1 & \beta_1 & \gamma_2 & \beta_2 & \gamma_3 & \beta_3 \end{bmatrix} \quad \ldots(1)$$

[From equation no. (3.171)]

where, A = Area of the triangular element

$$= \frac{1}{2}\begin{vmatrix} 1 & r_1 & z_1 \\ 1 & r_2 & z_2 \\ 1 & r_3 & z_3 \end{vmatrix}$$

[From equation no. (3.156)]

$$= \frac{1}{2}[(r_2 z_3 - r_3 z_2) - r_1(z_3 - z_2) + z_1(r_3 - r_2)]$$

$$= \frac{1}{2}[(40 \times 60) - (30 \times 40) - 20(60 - 40) + 40(30 - 40)]$$

$$= \frac{1}{2}[1200 - 400 - 400]$$

$$\boxed{A = 200 \text{ mm}^2}$$

(6M)

Co-ordinates:

$$r = \frac{r_1 + r_2 + r_3}{3} = \frac{20 + 40 + 30}{3}$$

$$\boxed{r = 30 \text{ mm}}$$

$$z = \frac{z_1 + z_2 + z_3}{3} = \frac{40 + 40 + 60}{3}$$

$$\boxed{z = 46.667 \text{ mm}}$$

$$\alpha_1 = r_2 z_3 - r_3 z_2 = (40 \times 60) - (30 \times 40)$$

$$\boxed{\alpha_1 = 1200 \text{ mm}^2}$$

$$\alpha_2 = r_3 z_1 - r_1 z_3 = (30 \times 40) - (20 \times 60)$$

$$\boxed{\alpha_2 = 0}$$

$$\alpha_3 = r_1 z_2 - r_2 z_1 = (20 \times 40) - (40 \times 40)$$

$$\boxed{\alpha_3 = -800 \text{ mm}^2}$$

$$\beta_1 = z_2 - z_3 = 40 - 60$$

$$\boxed{\beta_1 = -20 \text{ mm}}$$

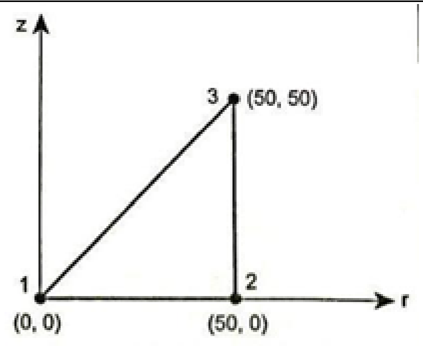
(5M)

Result: Strain-Displacement matrix

$$[B] = \begin{bmatrix} -0.05 & 0 & 0.05 & 0 & 0 & 0 \\ 0.0111 & 0 & 0.0111 & 0 & 0.0111 & 0 \\ 0 & -0.025 & 0 & -0.025 & 0 & 0.05 \\ -0.025 & -0.05 & -0.025 & 0.05 & 0.05 & 0 \end{bmatrix}$$

(2M)

	PART * C
1	**For the element shown in fig, determine the stiffness matrix. Take E = 200Gpa and v = 0.25. The co-ordinates shown in fig are in millimeters. (15M) (November 2013)** BTL2 **Answer: page – 4.26 Dr. S.Senthil**

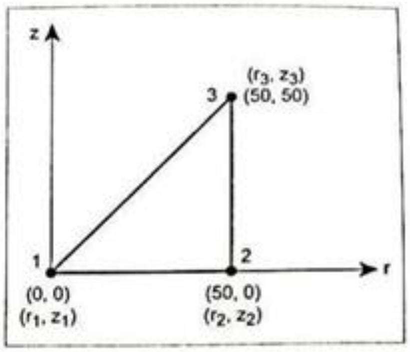


Given: Co-ordinates:

$r_1 = 0$ mm; $z_1 = 0$ mm

$r_2 = 50$ mm; $z_2 = 0$ mm

$r_3 = 50$ mm; $z_3 = 50$ mm



Young's modulus, $E = 200$ GPa

$= 200 \times 10^9$ Pa

$= 200 \times 10^9$ N/m^2

$= 200 \times 10^3$ N/mm^2

$E = 2 \times 10^5$ N/mm^2

Poisson's ratio, $\nu = 0.25$

To find: Element stiffness matrix [K].

☺ ***Solution:*** For axisymmetric triangular element, stiffness matrix [K] is given by,

$$[K] = 2\pi r A [B]^T [D] [B] \qquad \ldots (1)$$

[From equation no. (3.178)]

where, A = Area of the triangular element

$$= \frac{1}{2} \begin{vmatrix} 1 & r_1 & z_1 \\ 1 & r_2 & z_2 \\ 1 & r_3 & z_3 \end{vmatrix}$$

(3M)

We know that,

$$\text{Stress-Strain relationship matrix, } [D] = \frac{E}{(1+\nu)(1-2\nu)}\begin{bmatrix} 1-\nu & \nu & \nu & 0 \\ \nu & 1-\nu & \nu & 0 \\ \nu & \nu & 1-\nu & 0 \\ 0 & 0 & 0 & \frac{1-2\nu}{2} \end{bmatrix}$$

[From equation no. (3.177)]

$$\Rightarrow \quad [D] = \frac{2\times 10^5}{(1+0.25)(1-(2\times 0.25))}\begin{bmatrix} 1-0.25 & 0.25 & 0.25 & 0 \\ 0.25 & 1-0.25 & 0.25 & 0 \\ 0.25 & 0.25 & 1-0.25 & 0 \\ 0 & 0 & 0 & \frac{1-2\,(0.25)}{2} \end{bmatrix}$$

$$= 320\times 10^3\begin{bmatrix} 0.75 & 0.25 & 0.25 & 0 \\ 0.25 & 0.75 & 0.25 & 0 \\ 0.25 & 0.25 & 0.75 & 0 \\ 0 & 0 & 0 & 0.25 \end{bmatrix} = 320\times 10^3 \times 0.25\begin{bmatrix} 3 & 1 & 1 & 0 \\ 1 & 3 & 1 & 0 \\ 1 & 1 & 3 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$[D] = 80\times 10^3\begin{bmatrix} 3 & 1 & 1 & 0 \\ 1 & 3 & 1 & 0 \\ 1 & 1 & 3 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad \ldots (5)$$

(6M)

$$[B] = \frac{1}{2A}\begin{bmatrix} -50 & 0 & 50 & 0 & 0 & 0 \\ 25 & 0 & 25 & 0 & 25 & 0 \\ 0 & 0 & 0 & -50 & 0 & 50 \\ 0 & -50 & -50 & 50 & 50 & 0 \end{bmatrix}$$

Substitute Area A, value

$$[B] = \frac{1}{2\times 1250}\begin{bmatrix} -50 & 0 & 50 & 0 & 0 & 0 \\ 25 & 0 & 25 & 0 & 25 & 0 \\ 0 & 0 & 0 & -50 & 0 & 50 \\ 0 & -50 & -50 & 50 & 50 & 0 \end{bmatrix} \qquad \ldots (7)$$

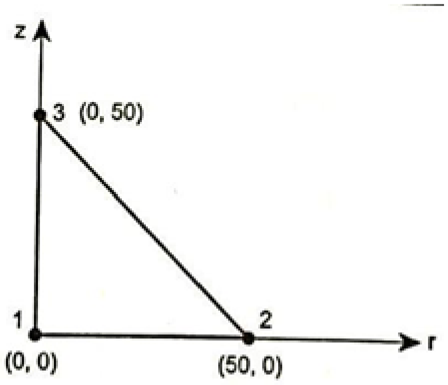
Result: Stiffness matrix, $[K] = 2.094\times 10^6\begin{bmatrix} 11 & 0 & -9 & 2 & 1 & -2 \\ 0 & 4 & 4 & -4 & -4 & 0 \\ -9 & 4 & 23 & -10 & 1 & 6 \\ 2 & -4 & -10 & 16 & 2 & -12 \\ 1 & -4 & 1 & 2 & 7 & 2 \\ -2 & 0 & 6 & -12 & 2 & 12 \end{bmatrix}$ N/mm

(6M)

2 **For the axisymmetric elements shown in fig, determine the stiffness matrix. Let E = 2.1 x**

10^5 N/mm^2 and v = 0.25. The co-ordinates shown in fig are in millimeters. (15M) (November 2012) BTL2

Answer: page – 4.117 Dr. S.Senthil



We know that,

$$\text{Stress-Strain relationship matrix, } [D] = \frac{E}{(1+v)(1-2v)}\begin{bmatrix} 1-v & v & v & 0 \\ v & 1-v & v & 0 \\ v & v & 1-v & 0 \\ 0 & 0 & 0 & \frac{1-2v}{2} \end{bmatrix}$$

[From equation no. (3.177)]

$$\Rightarrow \quad [D] = \frac{2.1 \times 10^5}{(1+0.25)(1-(2 \times 0.25))}\begin{bmatrix} 1-0.25 & 0.25 & 0.25 & 0 \\ 0.25 & 1-0.25 & 0.25 & 0 \\ 0.25 & 0.25 & 1-0.25 & 0 \\ 0 & 0 & 0 & \frac{1-(2 \times 0.25)}{2} \end{bmatrix}$$

(4M)

Given: Co-ordinates: $r_1 = 0$ mm; $z_1 = 0$ mm

$r_2 = 50$ mm; $z_2 = 0$ mm

$r_3 = 0$ mm; $z_3 = 50$ mm

Young's modulus, $E = 2.1 \times 10^5$ N/mm²

Poisson's ratio, $\nu = 0.25$

To find: Stiffness matrix, [K].

☺ ***Solution:*** For axisymmetric triangular element, stiffness matrix [K] is given by,

$$[K] = 2\pi r A\ [B]^T [D] [B] \quad \dots (1)$$

[From equation no. (3.178)]

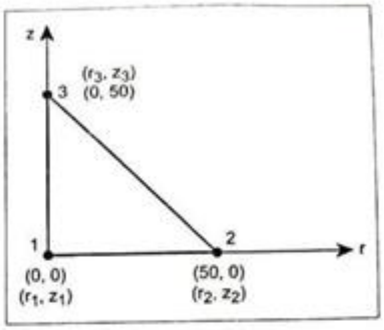


Fig. (ii)

Area of the triangular element, $A = \frac{1}{2} \times \text{Breadth} \times \text{Height} = \frac{1}{2} \times 50 \times 50$

$$\boxed{A = 1250 \text{ mm}^2} \quad \dots (2)$$

$$\text{Co-ordinate, } r = \frac{r_1 + r_2 + r_3}{3} = \frac{0 + 50 + 0}{3}$$

$$\boxed{r = 16.667 \text{ mm}} \quad \dots (3)$$

$$z = \frac{z_1 + z_2 + z_3}{3} = \frac{0 + 0 + 50}{3}$$

$$\boxed{z = 16.667 \text{ mm}} \quad \dots (4)$$

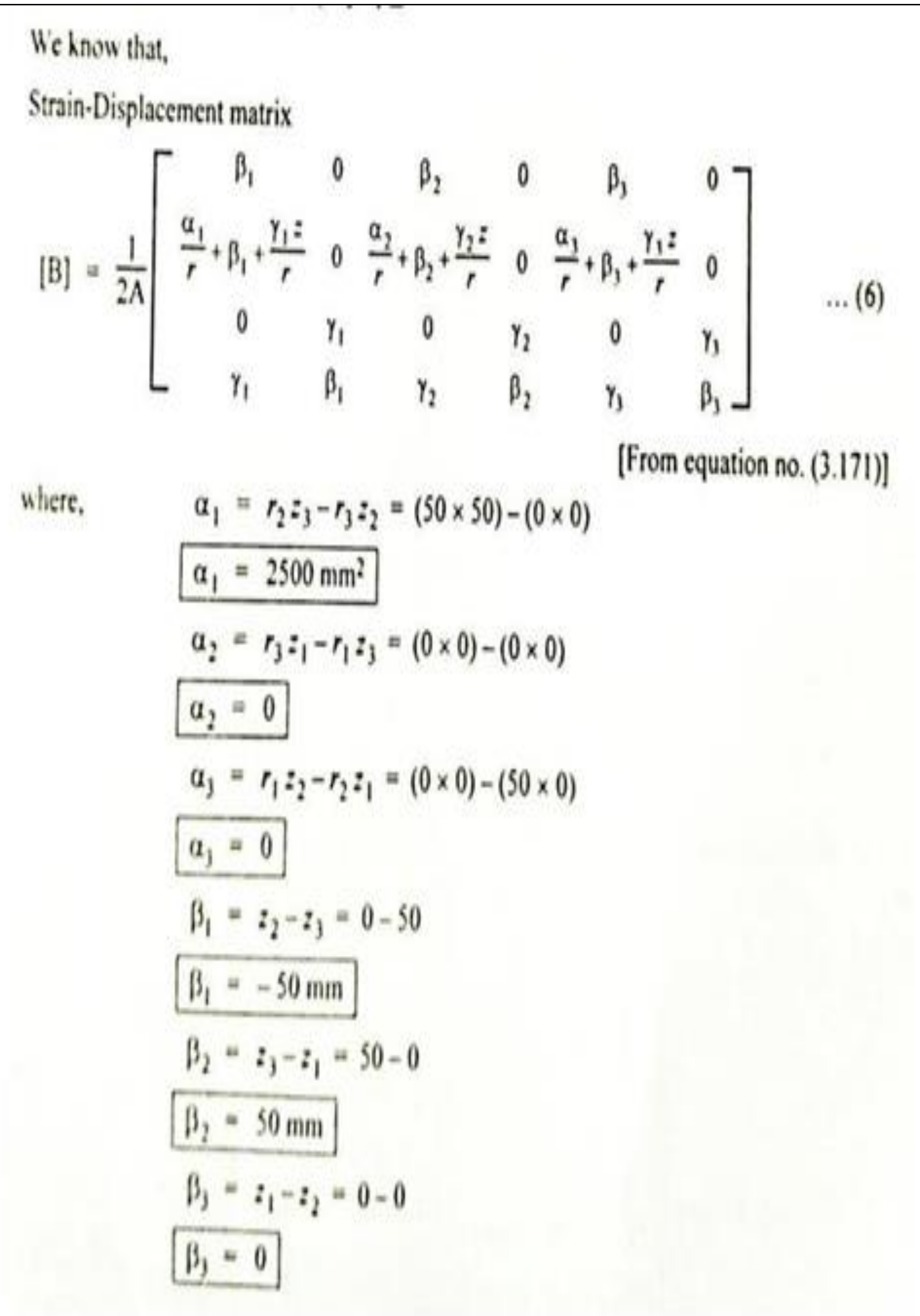
(5M)

We know that,

$$\text{Stress-Strain relationship matrix, } [D] = \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1-\nu & \nu & \nu & 0 \\ \nu & 1-\nu & \nu & 0 \\ \nu & \nu & 1-\nu & 0 \\ 0 & 0 & 0 & \frac{1-2\nu}{2} \end{bmatrix}$$

[From equation no. (3.177)]

$$\Rightarrow \quad [D] = \frac{2.1 \times 10^5}{(1+0.25)(1-(2\times 0.25))} \begin{bmatrix} 1-0.25 & 0.25 & 0.25 & 0 \\ 0.25 & 1-0.25 & 0.25 & 0 \\ 0.25 & 0.25 & 1-0.25 & 0 \\ 0 & 0 & 0 & \frac{1-(2\times 0.25)}{2} \end{bmatrix}$$



We know that,

Strain-Displacement matrix

$$[B] = \frac{1}{2A}\begin{bmatrix} \beta_1 & 0 & \beta_2 & 0 & \beta_3 & 0 \\ \frac{\alpha_1}{r}+\beta_1+\frac{\gamma_1 z}{r} & 0 & \frac{\alpha_2}{r}+\beta_2+\frac{\gamma_2 z}{r} & 0 & \frac{\alpha_3}{r}+\beta_3+\frac{\gamma_1 z}{r} & 0 \\ 0 & \gamma_1 & 0 & \gamma_2 & 0 & \gamma_3 \\ \gamma_1 & \beta_1 & \gamma_2 & \beta_2 & \gamma_3 & \beta_3 \end{bmatrix} \quad \dots (6)$$

[From equation no. (3.171)]

where, $\alpha_1 = r_2 z_3 - r_3 z_2 = (50 \times 50) - (0 \times 0)$

$$\boxed{\alpha_1 = 2500 \text{ mm}^2}$$

$\alpha_2 = r_3 z_1 - r_1 z_3 = (0 \times 0) - (0 \times 0)$

$$\boxed{\alpha_2 = 0}$$

$\alpha_3 = r_1 z_2 - r_2 z_1 = (0 \times 0) - (50 \times 0)$

$$\boxed{\alpha_3 = 0}$$

$\beta_1 = z_2 - z_3 = 0 - 50$

$$\boxed{\beta_1 = -50 \text{ mm}}$$

$\beta_2 = z_3 - z_1 = 50 - 0$

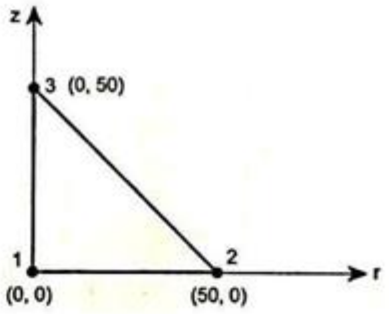
$$\boxed{\beta_2 = 50 \text{ mm}}$$

$\beta_3 = z_1 - z_2 = 0 - 0$

$$\boxed{\beta_3 = 0}$$

(3M)

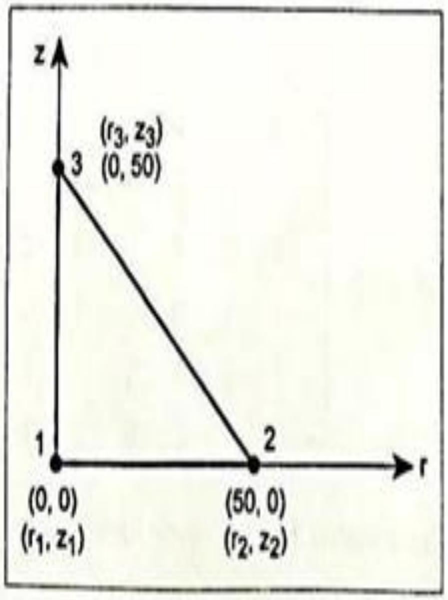
	Substitute $[B]^T [D] [B]$ value in equation (1), $\Rightarrow \; [K] = 2\pi r A \times 33.6 \begin{bmatrix} 5 & 1 & 0 & -1 & 1 & 0 \\ 1 & 4 & -2 & -1 & -2 & -3 \\ 0 & -2 & 8 & 0 & 4 & 2 \\ -1 & -1 & 0 & 1 & 1 & 0 \\ 1 & -2 & 4 & 1 & 4 & 1 \\ 0 & -3 & 2 & 0 & 1 & 3 \end{bmatrix}$ $= 2 \times \pi \times 16.667 \times 1250 \times 33.6 \begin{bmatrix} 5 & 1 & 0 & -1 & 1 & 0 \\ 1 & 4 & -2 & -1 & -2 & -3 \\ 0 & -2 & 8 & 0 & 4 & 2 \\ -1 & -1 & 0 & 1 & 1 & 0 \\ 1 & -2 & 4 & 1 & 4 & 1 \\ 0 & -3 & 2 & 0 & 1 & 3 \end{bmatrix}$ $[\because r = 16.667 \text{ mm}; \; A = 1250 \text{ mm}^2]$ $[K] = 4.39 \times 10^6 \begin{bmatrix} 5 & 1 & 0 & -1 & 1 & 0 \\ 1 & 4 & -2 & -1 & -2 & -3 \\ 0 & -2 & 8 & 0 & 4 & 2 \\ -1 & -1 & 0 & 1 & 1 & 0 \\ 1 & -2 & 4 & 1 & 4 & 1 \\ 0 & -3 & 2 & 0 & 1 & 3 \end{bmatrix} \text{N/mm}$ It may be noted that stiffness matrix [K] is symmetric. ***Result:*** Stiffness matrix, $[K] = 4.39 \times 10^6 \begin{bmatrix} 5 & 1 & 0 & -1 & 1 & 0 \\ 1 & 4 & -2 & -1 & -2 & -3 \\ 0 & -2 & 8 & 0 & 4 & 2 \\ -1 & -1 & 0 & 1 & 1 & 0 \\ 1 & -2 & 4 & 1 & 4 & 1 \\ 0 & -3 & 2 & 0 & 1 & 3 \end{bmatrix} \text{N/mm}$ (3M)
3	**For the axisymmetric elements shown in fig. Determine the element stresses. Let E = 210 Gpa and v = 0.25. The coordinates are in millimeters. The nodal displacements are u_1= 0.05 mm, u_2= 0.02 mm, u_3= 0 mm, w_1 = 0.03 mm, w_2 = 0.02 mm, w_3 = 0 mm. (13M) (November 2014)** BTL3 **Answer: page – 4.127 Dr. S.Senthil**

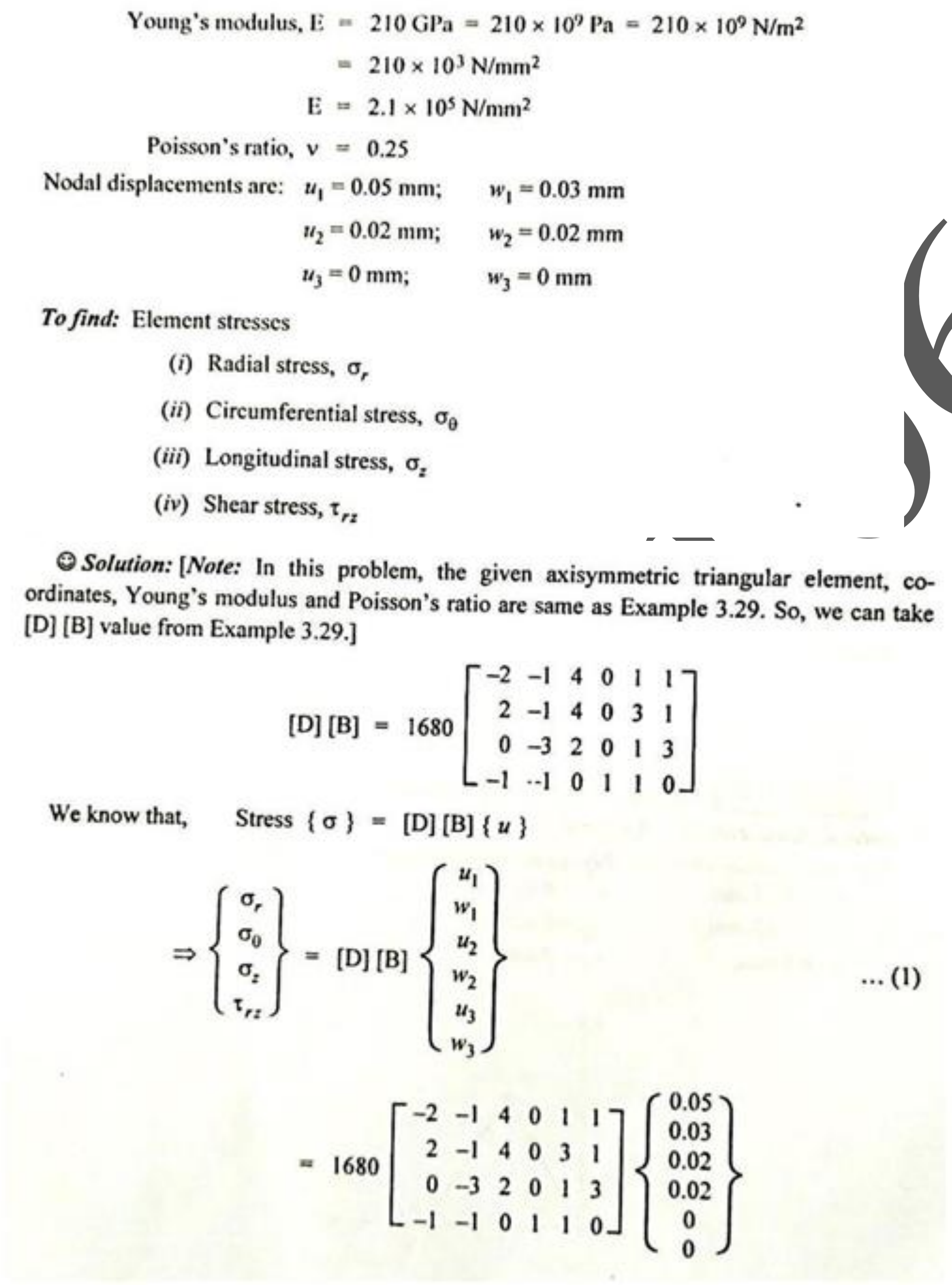


Given: Co-ordinates: $r_1 = 0$ mm; $z_1 = 0$ mm

$r_2 = 50$ mm; $z_2 = 0$ mm

$r_3 = 0$ mm; $z_3 = 50$ mm





Young's modulus, $E = 210\ \text{GPa} = 210 \times 10^9\ \text{Pa} = 210 \times 10^9\ \text{N/m}^2$

$= 210 \times 10^3\ \text{N/mm}^2$

$E = 2.1 \times 10^5\ \text{N/mm}^2$

Poisson's ratio, $\nu = 0.25$

Nodal displacements are: $u_1 = 0.05$ mm; $w_1 = 0.03$ mm

$u_2 = 0.02$ mm; $w_2 = 0.02$ mm

$u_3 = 0$ mm; $w_3 = 0$ mm

To find: Element stresses

(*i*) Radial stress, σ_r

(*ii*) Circumferential stress, σ_θ

(*iii*) Longitudinal stress, σ_z

(*iv*) Shear stress, τ_{rz}

☺ ***Solution:*** [***Note:*** In this problem, the given axisymmetric triangular element, co-ordinates, Young's modulus and Poisson's ratio are same as Example 3.29. So, we can take [D] [B] value from Example 3.29.]

$$[D]\,[B] = 1680 \begin{bmatrix} -2 & -1 & 4 & 0 & 1 & 1 \\ 2 & -1 & 4 & 0 & 3 & 1 \\ 0 & -3 & 2 & 0 & 1 & 3 \\ -1 & -1 & 0 & 1 & 1 & 0 \end{bmatrix}$$

We know that, Stress $\{\sigma\} = [D]\,[B]\,\{u\}$

$$\Rightarrow \begin{Bmatrix} \sigma_r \\ \sigma_\theta \\ \sigma_z \\ \tau_{rz} \end{Bmatrix} = [D]\,[B] \begin{Bmatrix} u_1 \\ w_1 \\ u_2 \\ w_2 \\ u_3 \\ w_3 \end{Bmatrix} \quad \ldots (1)$$

$$= 1680 \begin{bmatrix} -2 & -1 & 4 & 0 & 1 & 1 \\ 2 & -1 & 4 & 0 & 3 & 1 \\ 0 & -3 & 2 & 0 & 1 & 3 \\ -1 & -1 & 0 & 1 & 1 & 0 \end{bmatrix} \begin{Bmatrix} 0.05 \\ 0.03 \\ 0.02 \\ 0.02 \\ 0 \\ 0 \end{Bmatrix}$$

(5M)

$$= 1680 \begin{bmatrix} (-2 \times 0.05) + (-1 \times 0.03) + (4 \times 0.02) + 0 + 0 + 0 \\ (2 \times 0.05) + (-1 \times 0.03) + (4 \times 0.02) + 0 + 0 + 0 \\ 0 + (-3 \times 0.03) + (2 \times 0.02) + 0 + 0 + 0 \\ -0.05 + (-0.03) + 0 + 0.02 + 0 + 0 \end{bmatrix}$$

[*Note:* $(4 \times \underbrace{6) \times (6}_{} \times 1) = (4 \times 1)$]

$$= 1680 \begin{Bmatrix} -0.05 \\ 0.15 \\ -0.05 \\ -0.06 \end{Bmatrix}$$

$$\begin{Bmatrix} \sigma_r \\ \sigma_\theta \\ \sigma_z \\ \tau_{rz} \end{Bmatrix} = \begin{Bmatrix} -84 \\ 252 \\ -84 \\ -100.8 \end{Bmatrix}$$

$\Rightarrow$ Radial stress, $\sigma_r = -84$ N/mm^2

Circumferential stress, $\sigma_\theta = 252$ N/mm^2

Longitudinal stress, $\sigma_z = -84$ N/mm^2

Shear stress, $\tau_{rz} = -100.8$ N/mm^2

Result: Element stresses: $\sigma_r = -84$ N/mm^2

$\sigma_\theta = 252$ N/mm^2

$\sigma_z = -84$ N/mm^2

$\tau_{rz} = -100.8$ N/mm^2

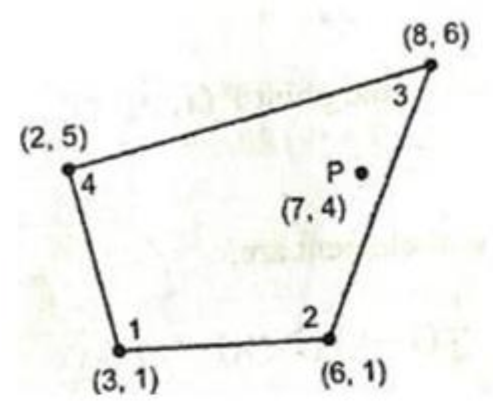
(10M)

UNIT V ISOPARAMETRIC FORMULATION

Natural co-ordinate systems – Iso parametric elements – Shape functions for iso parametric elements – One and two dimensions – Serendipity elements – Numerical integration and application to plane stress problems - Matrix solution techniques – Solutions Techniques to Dynamic problems – Introduction to Analysis Software.

PART * A

Q.No	Questions
1.	**What meant by plane stress analysis?(November 2014)**BTL1 Plane stress is defined to be a state of stress in which the normal stress and shear stress directed perpendicular to the plane are assumed to be zero.
2	**Define plane strain analysis.** BTL1 Plane strain is defined to be state of strain normal to the x,y plane and the shear strains are assumed to be zero.
3	**What is truss element?** BTL1 The truss elements are the part of a truss structure linked together by point joint which transmits only axial force to the element.
4	**List the two advantages of post processing. (November 2013)** BTL1 a. Required result can be obtained in graphical form. b. Contour diagrams can be used to understand the solution easily and quickly.
5	**What are the h and p versions of finite element method?(NOVEMBER 2019)**BTL1 It is used to improve the accuracy of the finite element method. In h version, the order of polynomial approximation for all elements is kept constant and the numbers of elements are increased. In p version, the numbers of elements are maintained constant and the order of polynomial approximation of element is increased.
6	**During discretization, mention the places where it is necessary to place a node?** BTL1 a. Concentrated load acting point b. Cross-section changing point c. Different material inter junction point d. Sudden change in point load
7	**What is the difference between static and dynamic analysis?** BTL1 Static analysis: The solution of the problem does not vary with time is known as static analysis Example: stress analysis on a beam Dynamic analysis: The solution of the problem varies with time is known as dynamic analysis Example: vibration analysis problem.
8	**What is meant by discretization and assemblage?** BTL1 The art of subdividing a structure in to convenient number of smaller components is known as discretization. These smaller components are then put together. The process of uniting the various elements together is called assemblage.
9	**What is Rayleigh-Ritz method?(November 2014)**BTL1 It is integral approach method which is useful for solving complex structural problem, encountered in finite element analysis. This method is possible only if a suitable function is available.

10	**How do you define two dimensional elements?** BTL1 Two dimensional elements are defined by three or more nodes in a two dimensional plane. The basic element useful for two dimensional analysis is the triangular element.
11	**State the principles of virtual energy? (November 2015)** BTL1 A body is in equilibrium if the internal virtual work equals the external virtual work for the every kinematically admissible displacement field.
12	**Define Eigen value problem.** BTL1 The problem of determining the constant is called eigen value problem.
13	**What is non-homogeneous form?** BTL1 When the specified values of dependent variables are non-zero, the boundary condition said to be non-homogeneous.
14	**What is homogeneous form?** BTL1 When the specified values of dependent variables is zero, the boundary condition are said to be homogeneous.
15	**Define initial value problem.** BTL1 An initial value problem is one in which the dependent variable and possibly is derivatives are specified initially.
16	**Define boundary value problem.** BTL1 A differential equation is said to describe a boundary value problem if the dependent variable and its derivatives are required to take specified values on the boundary.
	PART * B
1	**For the isoparametric quadrilateral element shown in fig determine the local co-ordinates of the point P which has Cartesian co-ordinates (7,4). (13M)(November 2014)**BTL2 **Answer: page – 5.17 Dr. S.Senthil** 

Cartesian co-ordinates of point P,

$$x = 7; \qquad y = 4$$

Cartesian co-ordinates of point 1, 2, 3 and 4

$$x_1 = 3; \qquad y_1 = 1$$
$$x_2 = 6; \qquad y_2 = 1$$
$$x_3 = 8; \qquad y_3 = 6$$
$$x_4 = 2; \qquad y_4 = 5$$

To find: Local co-ordinates of the point P, *i.e.,* ε and η.

☺ ***Solution:*** We know that,

Shape functions for quadrilateral element are,

$$N_1 = \frac{1}{4}(1-\varepsilon)(1-\eta)$$
$$N_2 = \frac{1}{4}(1+\varepsilon)(1-\eta)$$
$$N_3 = \frac{1}{4}(1+\varepsilon)(1+\eta)$$
$$N_4 = \frac{1}{4}(1-\varepsilon)(1+\eta)$$

Cartesian co-ordinates of point P (x, y),

$$x = N_1 x_1 + N_2 x_2 + N_3 x_3 + N_4 x_4 \qquad \ldots (1)$$
$$y = N_1 y_1 + N_2 y_2 + N_3 y_3 + N_4 y_4 \qquad \ldots (2)$$

(3M)

Substitute N_1, N_2, N_3, N_4, x, x_1, x_3 and x_4 values in equation (1),

$$\Rightarrow \quad 7 = \frac{1}{4}[(1-\varepsilon)(1-\eta)\times 3 + (1+\varepsilon)(1-\eta)\times 6 + (1+\varepsilon)(1+\eta)\times 8 + (1-\varepsilon)(1+\eta)\times 2]$$

$$\Rightarrow 28 = [(1-\eta-\varepsilon+\varepsilon\eta)3 + (1-\eta+\varepsilon-\varepsilon\eta)6 + (1+\eta+\varepsilon+\varepsilon\eta)8 + (1+\eta-\varepsilon-\varepsilon\eta)2]$$

$$\Rightarrow 28 = 3 - 3\eta - 3\varepsilon + 3\varepsilon\eta + 6 - 6\eta + 6\varepsilon - 6\varepsilon\eta + 8 + 8\eta + 8\varepsilon + 8\varepsilon\eta + 2 + 2\eta - 2\varepsilon - 2\varepsilon\eta$$

$$28 = 19 + \eta + 9\varepsilon + 3\varepsilon\eta$$

$$\Rightarrow \boxed{\eta + 9\varepsilon + 3\,\varepsilon\eta = 9} \qquad \ldots (3)$$

Substitute N_1, N_2, N_3, N_4, y, y_1, y_2, y_3 and y_4 values in equation (2),

$$4 = \frac{1}{4}[(1-\varepsilon)(1-\eta)\times 1 + (1+\varepsilon)(1-\eta)\times 1 + (1+\varepsilon)(1+\eta)\times 6 + (1-\varepsilon)(1+\eta)\times 5]$$

$$= \frac{1}{4}[1 - \eta - \varepsilon + \varepsilon\eta + 1 - \eta + \varepsilon - \varepsilon\eta + 6 + 6\eta + 6\varepsilon + 6\varepsilon\eta + 5 + 5\,\eta - 5\,\varepsilon - 5\,\varepsilon\eta]$$

$$4 = \frac{1}{4}[13 + 9\eta + \varepsilon + \varepsilon\eta]$$

(5M)

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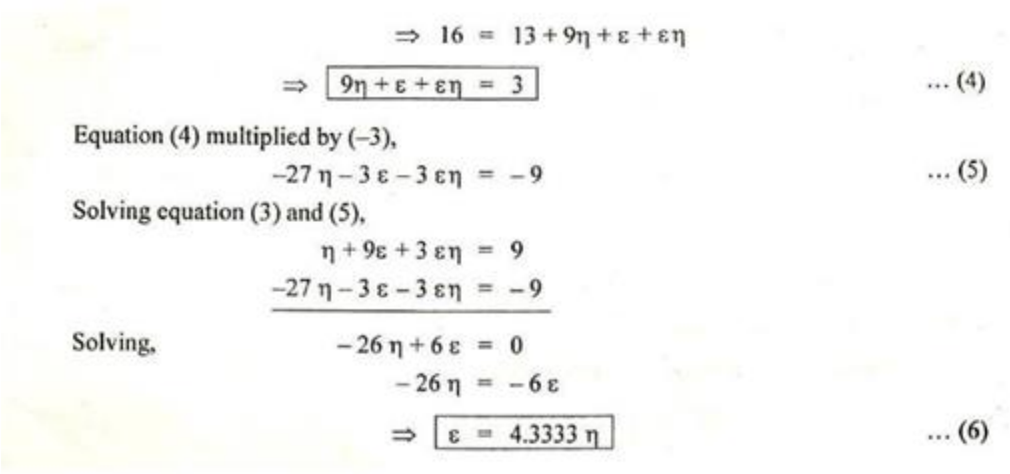


$$\Rightarrow \quad 16 = 13 + 9\eta + \varepsilon + \varepsilon\eta$$

$$\Rightarrow \quad \boxed{9\eta + \varepsilon + \varepsilon\eta = 3} \qquad \ldots (4)$$

Equation (4) multiplied by (–3),

$$-27\,\eta - 3\,\varepsilon - 3\,\varepsilon\eta = -9 \qquad \ldots (5)$$

Solving equation (3) and (5),

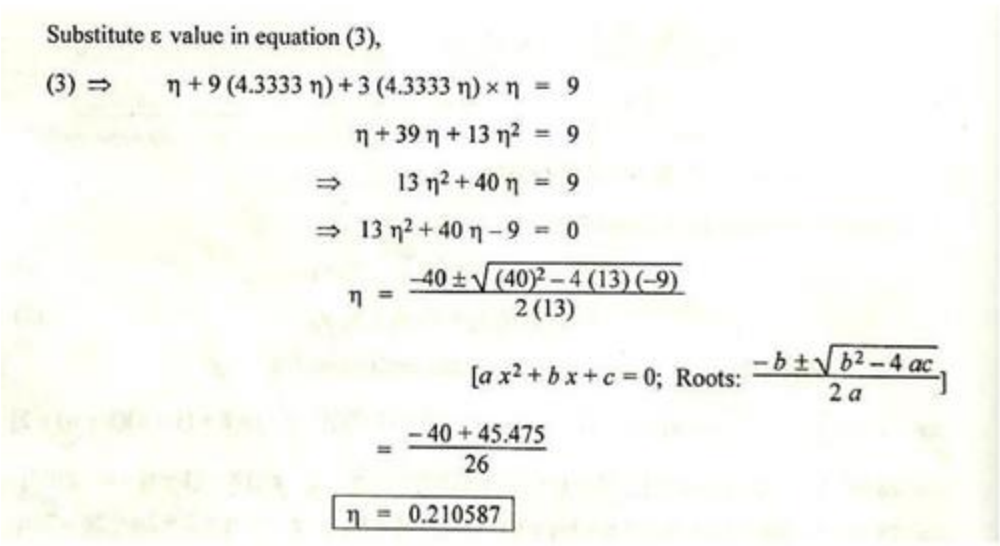
$$\begin{aligned} \eta + 9\varepsilon + 3\,\varepsilon\eta &= 9 \\ -27\,\eta - 3\,\varepsilon - 3\,\varepsilon\eta &= -9 \end{aligned}$$

Solving,

$$-26\,\eta + 6\,\varepsilon = 0$$

$$-26\,\eta = -6\,\varepsilon$$

$$\Rightarrow \quad \boxed{\varepsilon = 4.3333\,\eta} \qquad \ldots (6)$$



Substitute ε value in equation (3),

$$(3) \Rightarrow \quad \eta + 9\,(4.3333\,\eta) + 3\,(4.3333\,\eta) \times \eta = 9$$

$$\eta + 39\,\eta + 13\,\eta^2 = 9$$

$$\Rightarrow \quad 13\,\eta^2 + 40\,\eta = 9$$

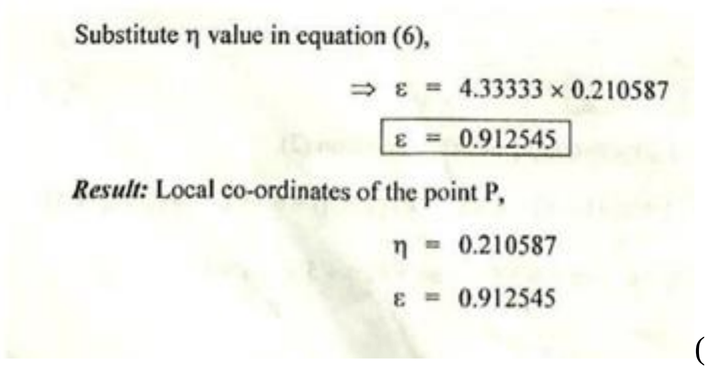
$$\Rightarrow \quad 13\,\eta^2 + 40\,\eta - 9 = 0$$

$$\eta = \frac{-40 \pm \sqrt{(40)^2 - 4\,(13)\,(-9)}}{2\,(13)}$$

$$\left[a\,x^2 + b\,x + c = 0;\ \text{Roots: } \frac{-b \pm \sqrt{b^2 - 4\,ac}}{2\,a}\right]$$

$$= \frac{-40 + 45.475}{26}$$

$$\boxed{\eta = 0.210587}$$



Substitute η value in equation (6),

$$\Rightarrow \quad \varepsilon = 4.33333 \times 0.210587$$

$$\boxed{\varepsilon = 0.912545}$$

Result: Local co-ordinates of the point P,

$$\eta = 0.210587$$

$$\varepsilon = 0.912545$$

(5M)

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Evaluate the integeral $I = \int_{-1}^{1}(2 + x + x^2)$ and compare with exact solution.(13M)BTL2

Answer: page – 5.137 Dr. S.Senthil

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</table>

Given integral $\boldsymbol{I = \int_{-1}^{1}(2 + x + x^2)}$

$$\Rightarrow f(x) = 2 + x + x^2$$

To find: Evaluate the integral by using Gauss quadrature.

☺ ***Solution:*** We know that, the given integrand is a polynomial of order 2.
So, $2\,n - 1 = 2$.

$$\Rightarrow 2\,n = 3$$
$$\Rightarrow n = 1.5 \approx 2$$

We should use two sampling points.
For two point Gaussian quadrature,

$$x_1 = +\sqrt{\frac{1}{3}} = 0.577350269$$
$$x_2 = -\sqrt{\frac{1}{3}} = -0.577350269$$
$$w_1 = 1$$
$$w_2 = 1$$

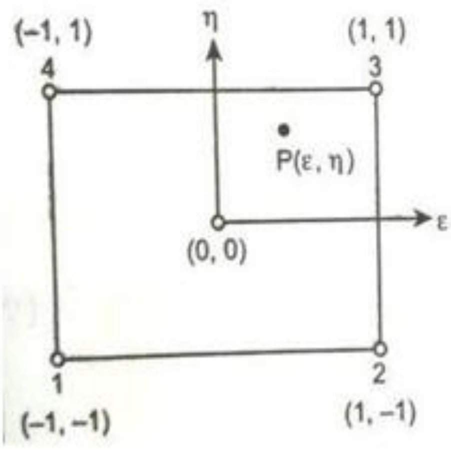
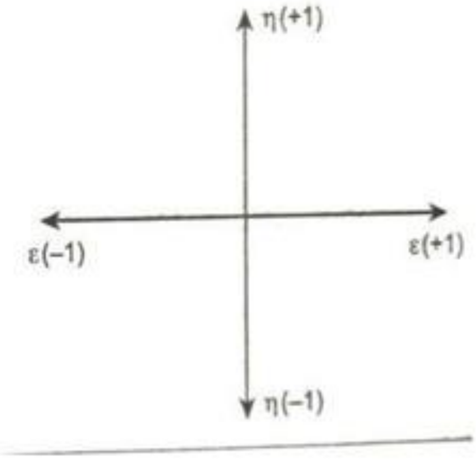
[Refer Table 3.1]

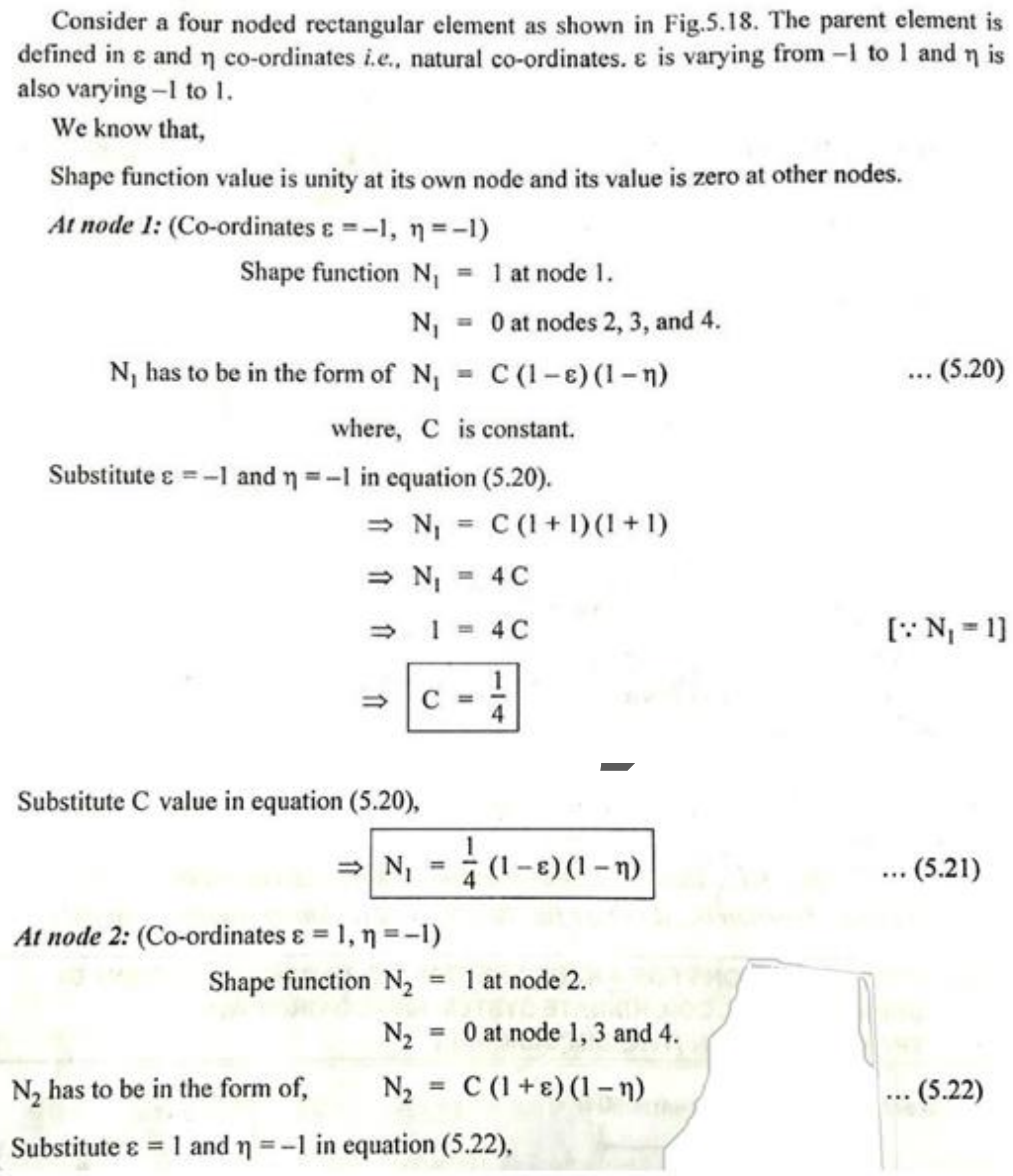
(3M)

We know that, $f(x) = 2 + x + x^2$

$$f(x_1) = 2 + x_1 + x_1^2$$
$$= 2 + (0.577350269) + (0.577350219)^2$$
$$f(x_1) = 2.9106836$$
$$w_1\, f(x_1) = 1 \times 2.9106836$$
$$\boxed{w_1\, f(x_1) = 2.9106836} \quad \ldots (1)$$
$$f(x_2) = 2 + x_2 + x_2^2$$
$$= 2 - 0.577350269 + (-0.577350269)^2$$
$$f(x_2) = 1.755983$$
$$w_2\, f(x_2) = 1 \times 1.755983$$
$$\boxed{w_2\, f(x_2) = 1.755983} \quad \ldots (2)$$

(6M)

	Adding (1) and (2), $w_1 f(x_1) + w_2 f(x_2) = 2.9106836 + 1.755983 = 4.666666$ $\Rightarrow \int_{-1}^{1} (2+x+x^2)\,dx = 4.666666$ *Exact solution:* $\int_{-1}^{1} (2+x+x^2)\,dx = 2\left[x\right]_{-1}^{+1} + \frac{1}{2}\left[x^2\right]_{-1}^{+1} + \frac{1}{3}\left[x^3\right]_{-1}^{+1}$ $= 2[1-(-1)] + \frac{1}{2}[1-(1)] + \frac{1}{3}[1-(-1)]$ $= 4.666666$ *Result:* $\int_{-1}^{1} (2+x+x^2)\,dx = 4.666666$ [By two point Gaussian quadrature] $\int_{-1}^{1} (2+x+x^2)\,dx = 4.666666$ [By exact method] (4M)
3	**Derive the shape functions for 4 noded rectangular parent element by using natural co-ordinates system and co-ordinate transformation. (13M)(November 2015)** BTL2 **Answer: page – 5.107 Dr. S.Senthil**  



Consider a four noded rectangular element as shown in Fig.5.18. The parent element is defined in ε and η co-ordinates *i.e.,* natural co-ordinates. ε is varying from −1 to 1 and η is also varying −1 to 1.

We know that,

Shape function value is unity at its own node and its value is zero at other nodes.

At node 1: (Co-ordinates $\varepsilon = -1,\ \eta = -1$)

Shape function $N_1 = 1$ at node 1.

$N_1 = 0$ at nodes 2, 3, and 4.

N_1 has to be in the form of $N_1 = C(1-\varepsilon)(1-\eta)$ ... (5.20)

where, C is constant.

Substitute $\varepsilon = -1$ and $\eta = -1$ in equation (5.20).

$$\Rightarrow N_1 = C(1+1)(1+1)$$

$$\Rightarrow N_1 = 4C$$

$$\Rightarrow 1 = 4C \qquad [\because N_1 = 1]$$

$$\Rightarrow \boxed{C = \frac{1}{4}}$$

(6M)

Substitute C value in equation (5.20),

$$\Rightarrow \boxed{N_1 = \frac{1}{4}(1-\varepsilon)(1-\eta)} \qquad \text{... (5.21)}$$

At node 2: (Co-ordinates $\varepsilon = 1,\ \eta = -1$)

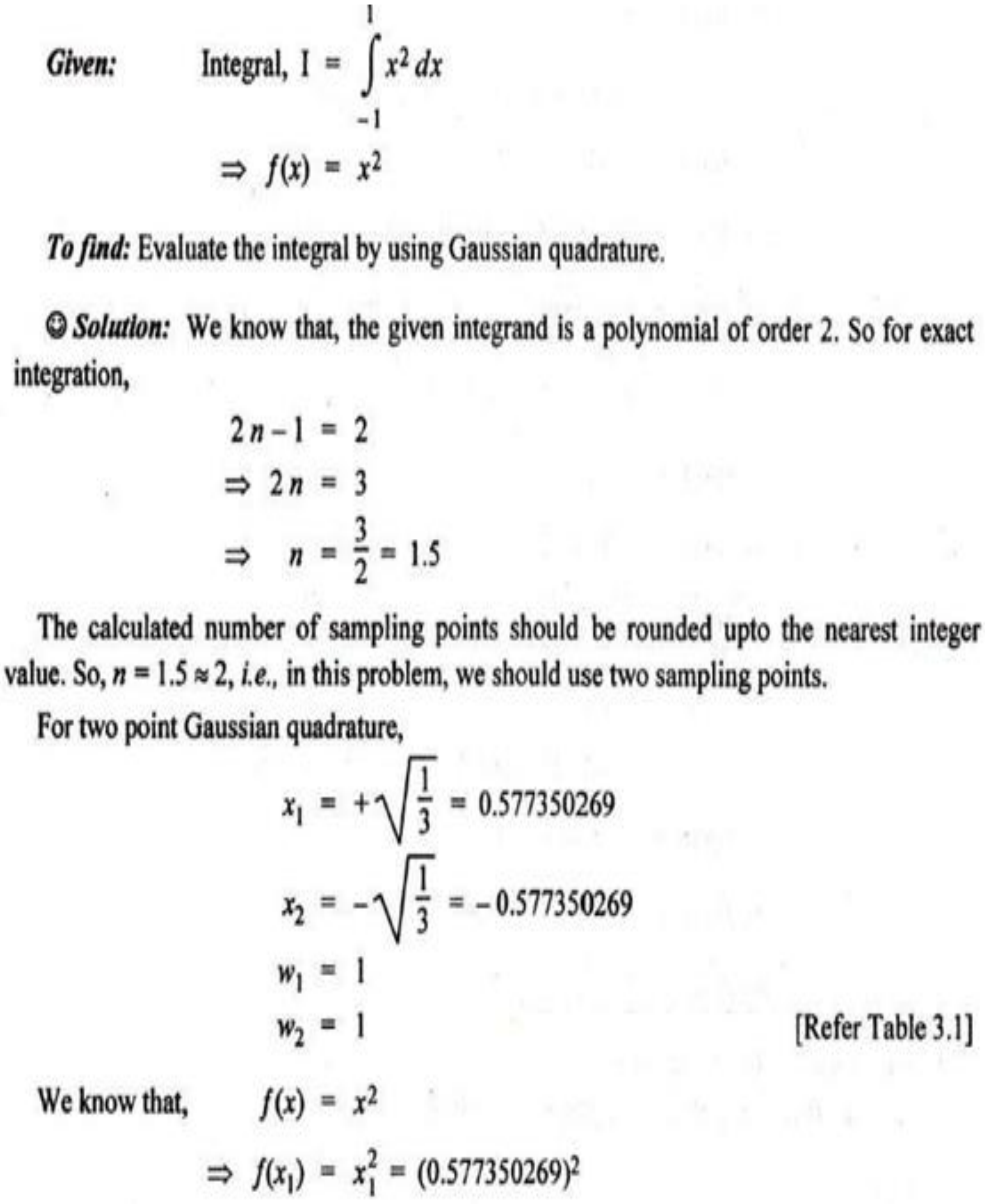
Shape function $N_2 = 1$ at node 2.

$N_2 = 0$ at node 1, 3 and 4.

N_2 has to be in the form of, $N_2 = C(1+\varepsilon)(1-\eta)$ ... (5.22)

Substitute $\varepsilon = 1$ and $\eta = -1$ in equation (5.22),

	$N_2 = C(1+1)(1+1)$ $N_2 = 4C$ $1 = 4C$ $\Rightarrow \boxed{C = \frac{1}{4}}$ Substitute C value in equation (3.63), $\Rightarrow \boxed{N_2 = \frac{1}{4}(1+\varepsilon)(1-\eta)}$ The above equations can be written in matrix form as, $u = \begin{Bmatrix} x \\ y \end{Bmatrix} = \begin{bmatrix} N_1 & 0 & N_2 & 0 & N_3 & 0 & N_4 & 0 \\ 0 & N_1 & 0 & N_2 & 0 & N_3 & 0 & N_4 \end{bmatrix} \begin{Bmatrix} x_1 \\ y_1 \\ x_2 \\ y_2 \\ x_3 \\ y_3 \\ x_4 \\ y_4 \end{Bmatrix}$ (7M)
4	**Evaluate the integral by using Gaussian Quadrature $I = \int_{-1}^{1} x^2 \, dx$. (13M)(November 2010,APRIL 2019)**BTL2 **Answer: page – 5.217 Dr. S.Senthil**



Given: Integral, $I = \int_{-1}^{1} x^2 \, dx$

$$\Rightarrow f(x) = x^2$$

To find: Evaluate the integral by using Gaussian quadrature.

☺ ***Solution:*** We know that, the given integrand is a polynomial of order 2. So for exact integration,

$$2n - 1 = 2$$
$$\Rightarrow 2n = 3$$
$$\Rightarrow n = \frac{3}{2} = 1.5$$

The calculated number of sampling points should be rounded upto the nearest integer value. So, $n = 1.5 \approx 2$, *i.e.*, in this problem, we should use two sampling points.

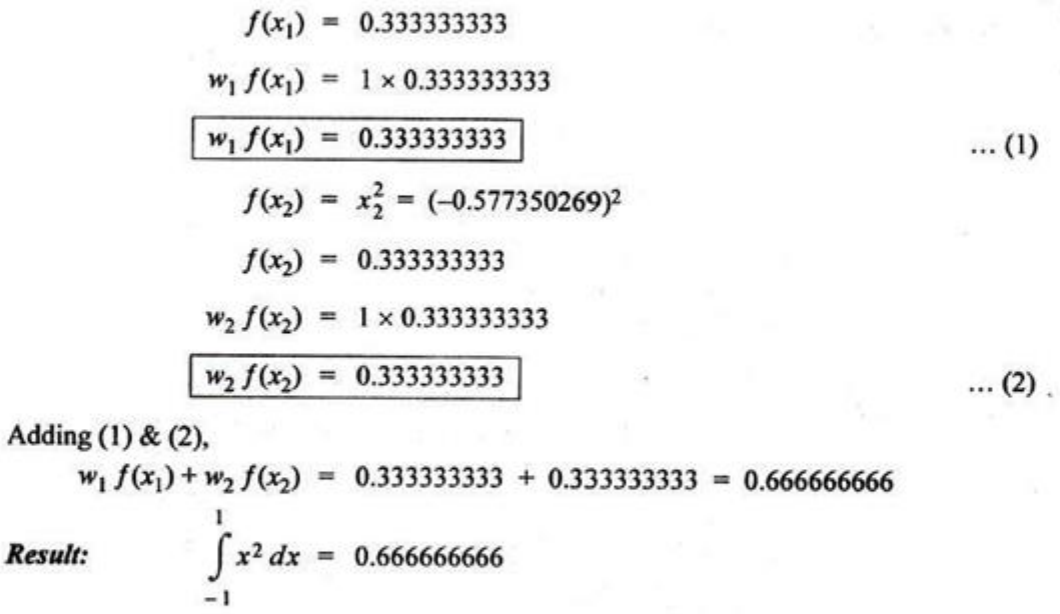
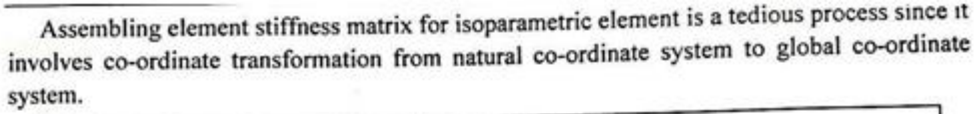
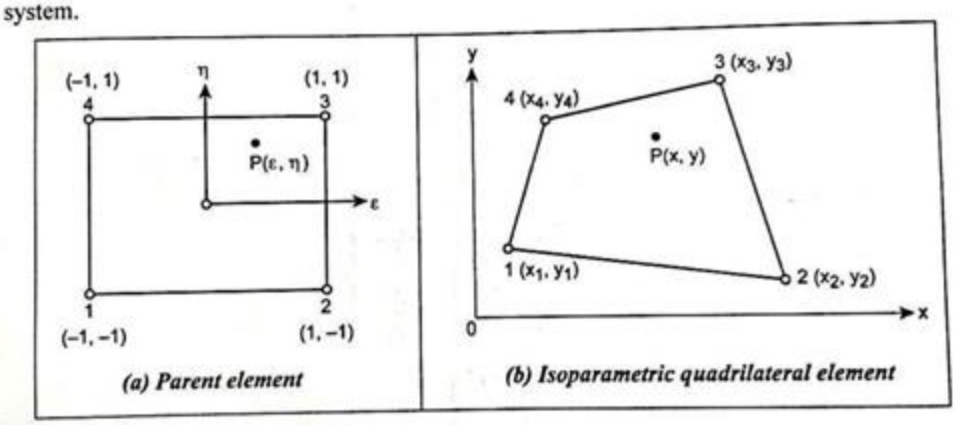
For two point Gaussian quadrature,

$$x_1 = +\sqrt{\frac{1}{3}} = 0.577350269$$
$$x_2 = -\sqrt{\frac{1}{3}} = -0.577350269$$
$$w_1 = 1$$
$$w_2 = 1 \qquad \text{[Refer Table 3.1]}$$

We know that, $f(x) = x^2$

$$\Rightarrow f(x_1) = x_1^2 = (0.577350269)^2$$

(8M)

	$f(x_1) = 0.333333333$ $w_1 f(x_1) = 1 \times 0.333333333$ $\boxed{w_1 f(x_1) = 0.333333333}$ … (1) $f(x_2) = x_2^2 = (-0.577350269)^2$ $f(x_2) = 0.333333333$ $w_2 f(x_2) = 1 \times 0.333333333$ $\boxed{w_2 f(x_2) = 0.333333333}$ … (2) Adding (1) & (2), $w_1 f(x_1) + w_2 f(x_2) = 0.333333333 + 0.333333333 = 0.666666666$ ***Result:*** $\int_{-1}^{1} x^2\,dx = 0.666666666$ (5M)
5	**Derive the element stiffness matrix equation for 4 noded isoparametric quadrilateral element. (13M)(November 2011)**BTL2 **Answer: page – 5.47 Dr. S.Senthil** Assembling element stiffness matrix for isoparametric element is a tedious process since it involves co-ordinate transformation from natural co-ordinate system to global co-ordinate system.  *(a) Parent element* *(b) Isoparametric quadrilateral element* (3M)

$$u = \begin{Bmatrix} u \\ v \end{Bmatrix} = \begin{bmatrix} N_1 & 0 & N_2 & 0 & N_3 & 0 & N_4 & 0 \\ 0 & N_1 & 0 & N_2 & 0 & N_3 & 0 & N_4 \end{bmatrix} \begin{Bmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \\ u_3 \\ v_3 \\ u_4 \\ v_4 \end{Bmatrix}$$

The displacement function u for isoparametric quadrilateral element is given by,

$$u = \begin{Bmatrix} x \\ y \end{Bmatrix} = \begin{bmatrix} N_1 & 0 & N_2 & 0 & N_3 & 0 & N_4 & 0 \\ 0 & N_1 & 0 & N_2 & 0 & N_3 & 0 & N_4 \end{bmatrix} \begin{Bmatrix} x_1 \\ y_1 \\ x_2 \\ y_2 \\ x_3 \\ y_3 \\ x_4 \\ y_4 \end{Bmatrix}$$

We have to express the derivatives of a function in x, y co-ordinates in terms of its derivatives in ε, η co-ordinates. This can be done as follows:

(5M)

$$\text{Let } f = f(x, y)$$

$$f = f[x(\varepsilon, \eta),\ y(\varepsilon, \eta)]$$

The relationship between natural co-ordinates and global co-ordinates can be calculated by using chain rule of partial differentiation.

$$\Rightarrow \frac{\partial f}{\partial \varepsilon} = \frac{\partial f}{\partial x} \times \frac{\partial x}{\partial \varepsilon} + \frac{\partial f}{\partial y} \times \frac{\partial y}{\partial \varepsilon}$$

$$\frac{\partial f}{\partial \eta} = \frac{\partial f}{\partial x} \times \frac{\partial x}{\partial \eta} + \frac{\partial f}{\partial y} \times \frac{\partial y}{\partial \eta}$$

Arranging the above equations in matrix form,

$$\Rightarrow \begin{Bmatrix} \dfrac{\partial f}{\partial \varepsilon} \\ \dfrac{\partial f}{\partial \eta} \end{Bmatrix} = \begin{bmatrix} \dfrac{\partial x}{\partial \varepsilon} & \dfrac{\partial y}{\partial \varepsilon} \\ \dfrac{\partial x}{\partial \eta} & \dfrac{\partial y}{\partial \eta} \end{bmatrix} \begin{Bmatrix} \dfrac{\partial f}{\partial x} \\ \dfrac{\partial f}{\partial y} \end{Bmatrix}$$

$$\Rightarrow \begin{Bmatrix} \dfrac{\partial f}{\partial \varepsilon} \\ \dfrac{\partial f}{\partial \eta} \end{Bmatrix} = [\,J\,] \begin{Bmatrix} \dfrac{\partial f}{\partial x} \\ \dfrac{\partial f}{\partial y} \end{Bmatrix} \qquad \ldots (5.30)$$

where J is the Jacobian matrix.

$$[\,J\,] = \begin{bmatrix} \dfrac{\partial x}{\partial \varepsilon} & \dfrac{\partial y}{\partial \varepsilon} \\ \dfrac{\partial x}{\partial \eta} & \dfrac{\partial y}{\partial \eta} \end{bmatrix} \Rightarrow [\,J\,] = \begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix} \qquad \ldots (5.31)$$

$$\text{where, } J_{11} = \frac{\partial x}{\partial \varepsilon}; \qquad J_{12} = \frac{\partial y}{\partial \varepsilon}$$

$$J_{21} = \frac{\partial x}{\partial \eta}; \qquad J_{22} = \frac{\partial y}{\partial \eta}$$

We know that,

$$\left.\begin{aligned} x &= N_1 x_1 + N_2 x_2 + N_3 x_3 + N_4 x_4 \\ y &= N_1 y_1 + N_2 y_2 + N_3 y_3 + N_4 y_4 \end{aligned}\right\} \qquad \ldots (5.32)$$

$$J_{11} = \frac{\partial x}{\partial \varepsilon} = \frac{\partial N_1}{\partial \varepsilon} x_1 + \frac{\partial N_2}{\partial \varepsilon} x_2 + \frac{\partial N_3}{\partial \varepsilon} x_3 + \frac{\partial N_4}{\partial \varepsilon} x_4 \qquad \ldots (5.33)$$

$$J_{12} = \frac{\partial y}{\partial \varepsilon} = \frac{\partial N_1}{\partial \varepsilon} y_1 + \frac{\partial N_2}{\partial \varepsilon} y_2 + \frac{\partial N_3}{\partial \varepsilon} y_3 + \frac{\partial N_4}{\partial \varepsilon} y_4 \qquad \ldots (5.34)$$

Assembling the equations (5.55), (5.56), (5.57) & (5.58) in matrix form,

$$\Rightarrow \begin{Bmatrix} \frac{\partial u}{\partial \varepsilon} \\ \frac{\partial u}{\partial \eta} \\ \frac{\partial v}{\partial \varepsilon} \\ \frac{\partial v}{\partial \eta} \end{Bmatrix} = \begin{bmatrix} \frac{\partial N_1}{\partial \varepsilon} & 0 & \frac{\partial N_2}{\partial \varepsilon} & 0 & \frac{\partial N_3}{\partial \varepsilon} & 0 & \frac{\partial N_4}{\partial \varepsilon} & 0 \\ \frac{\partial N_1}{\partial \eta} & 0 & \frac{\partial N_2}{\partial \eta} & 0 & \frac{\partial N_3}{\partial \eta} & 0 & \frac{\partial N_4}{\partial \eta} & 0 \\ 0 & \frac{\partial N_1}{\partial \varepsilon} & 0 & \frac{\partial N_2}{\partial \varepsilon} & 0 & \frac{\partial N_3}{\partial \varepsilon} & 0 & \frac{\partial N_4}{\partial \varepsilon} \\ 0 & \frac{\partial N_1}{\partial \eta} & 0 & \frac{\partial N_2}{\partial \eta} & 0 & \frac{\partial N_3}{\partial \eta} & 0 & \frac{\partial N_4}{\partial \eta} \end{bmatrix} \begin{Bmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \\ u_3 \\ v_3 \\ u_4 \\ v_4 \end{Bmatrix} \quad \ldots (5.59)$$

Substitute (5.59) value in equation (5.54),

Strain-Disp

For Isoparametric quadrilateral element,

$$\Rightarrow [K] = t \iint [B]^T [D] [B] \, \partial x \, \partial y$$

For natural co-ordinates,

$$\Rightarrow [K] = t \int_{-1}^{1}\int_{-1}^{1} [B]^T [D] [B] \times |J| \times \partial \varepsilon \times \partial \eta \quad \ldots (5.64)$$

$$[\because \partial x \, \partial y = |J| \, \partial \varepsilon \, \partial \eta]$$

where, t → Thickness of the element

$|J|$ → Determinant of the Jacobian

ε, η → Natural co-ordinates

[B] → Strain-Displacement relationship matrix

[D] → Stress-Strain relationship matrix

For two dimensional problems,

Stress-Strain relationship matrix, $[D] = \frac{E}{1-\nu^2}\begin{bmatrix} 1 & \nu & 0 \\ \nu & 1 & 0 \\ 0 & 0 & \frac{1-\nu}{2} \end{bmatrix}$ [For plane stress conditions]

$$[D] = \frac{E}{(1+\nu)(1-2\nu)}\begin{bmatrix} 1-\nu & \nu & 0 \\ \nu & 1-\nu & 0 \\ 0 & 0 & \frac{1-2\nu}{2} \end{bmatrix}$$

[For plane strain conditions]

where, E → Young's modulus

ν → Poisson's ratio

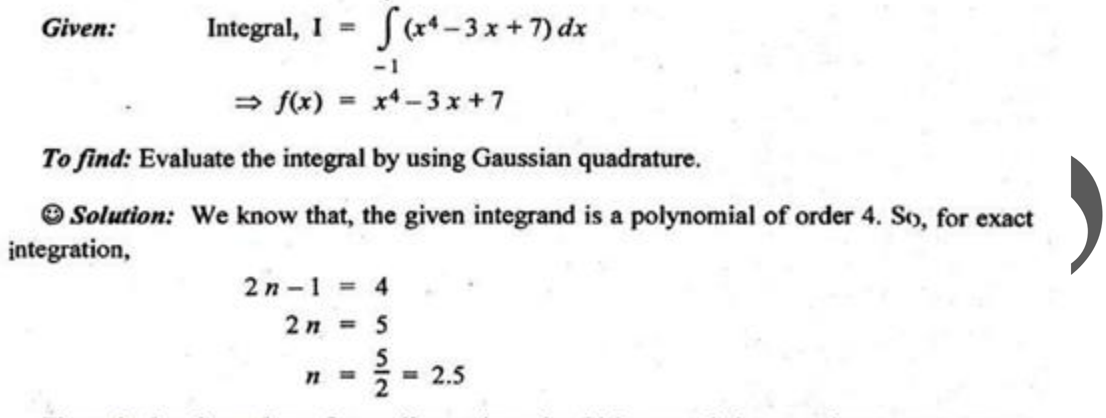
(6M)

PART * C

1

Evaluate the integral $I = \int_{-1}^{1}(x^4 - 3x + 7)\ dx$. (15M)(November 2011)BTL2

Answer: page – 5.147 Dr. S.Senthil



Given: Integral, $I = \int_{-1}^{1}(x^4 - 3x + 7)\,dx$

$$\Rightarrow f(x) = x^4 - 3x + 7$$

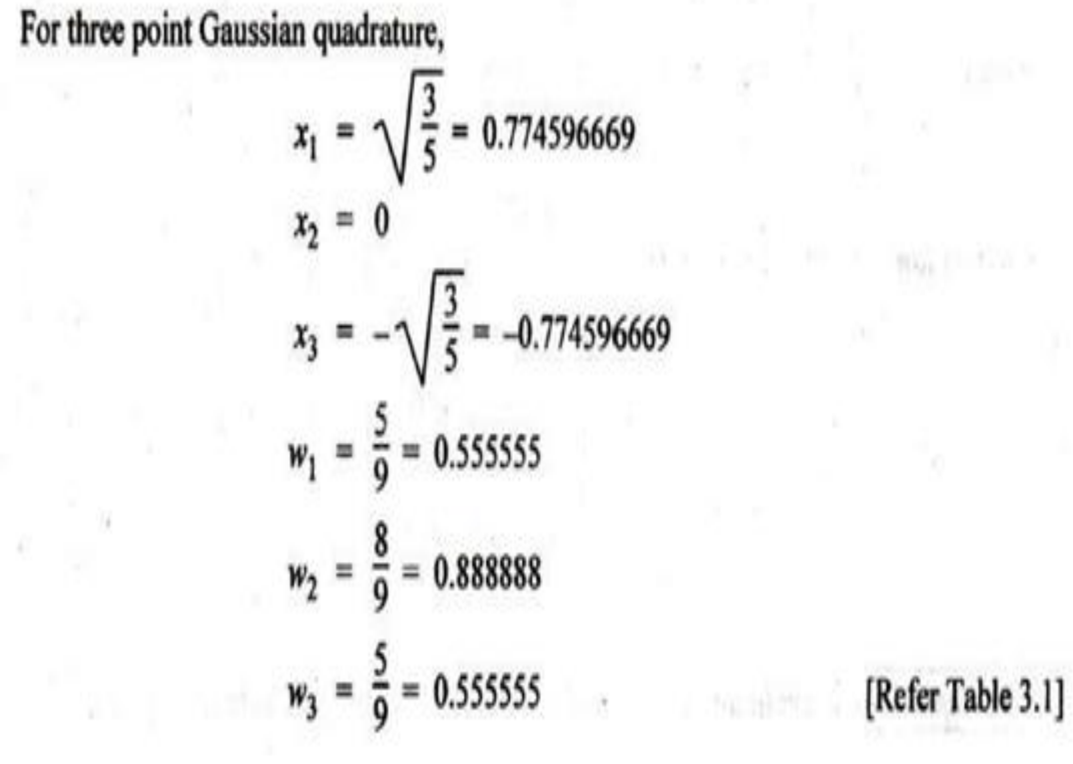
To find: Evaluate the integral by using Gaussian quadrature.

☺ ***Solution:*** We know that, the given integrand is a polynomial of order 4. So, for exact integration,

$$2n - 1 = 4$$
$$2n = 5$$
$$n = \frac{5}{2} = 2.5$$

The calculated number of sampling points should be rounded up to the nearest integer value. So, $n = 2.5 \approx 3$, *i.e.*, in this problem, we should use three sampling points.

(4M)



For three point Gaussian quadrature,

$$x_1 = \sqrt{\frac{3}{5}} = 0.774596669$$
$$x_2 = 0$$
$$x_3 = -\sqrt{\frac{3}{5}} = -0.774596669$$
$$w_1 = \frac{5}{9} = 0.555555$$
$$w_2 = \frac{8}{9} = 0.888888$$
$$w_3 = \frac{5}{9} = 0.555555$$

[Refer Table 3.1]

(3M)

We know that,

$$
\begin{aligned}
f(x) &= x^4 - 3x + 7 \\
f(x_1) &= x_1^4 - 3x_1 + 7 \\
&= (0.774596669)^4 - 3\,(0.77459669) + 7 \\
f(x_1) &= 5.036209992 \\
\Rightarrow w_1 \times f(x_1) &= 0.555555 \times 5.036209992 \\
\boxed{w_1\, f(x_1) = 2.797891} & \qquad \ldots (1) \\
f(x_2) &= x_2^4 - 3\,(x_2) + 7 = (0)^4 - 3(0) + 7 \\
f(x_2) &= 7 \\
\Rightarrow w_2\, f(x_2) &= 0.888888 \times 7 \\
\boxed{w_2\, f(x_2) = 6.222216} & \qquad \ldots (2) \\
f(x_3) &= (x_3)^4 - 3\,(x_3) + 7 \\
&= (-0.774596669)^4 - 3\,(-0.774596669) + 7 \\
f(x_3) &= 9.683790008 \\
\Rightarrow w_3\, f(x_3) &= 0.555555 \times 9.683790008 \\
\boxed{w_3\, f(x_3) = 5.379877} & \qquad \ldots (3)
\end{aligned}
$$

(6M)

Adding equations (1), (2) and (3),

$$
\begin{aligned}
w_1\, f(x_1) + w_2\, f(x_2) + w_3\, f(x_3) &= 2.797891 + 6.222216 + 5.379877 \\
&= 14.399984
\end{aligned}
$$

Result: $\int_{-1}^{1} (x^4 - 3x + 7)\, dx = 14.399984$

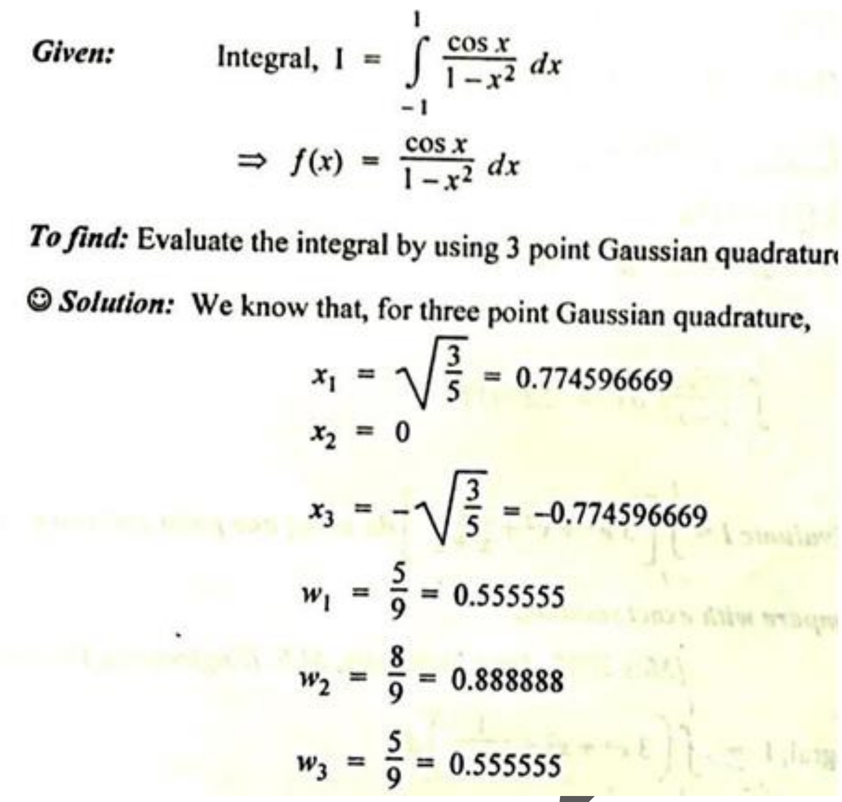
Verification:

$$
\begin{aligned}
\int_{-1}^{1} (x^4 - 3x + 7)\, dx &= \left[\frac{x^5}{5}\right]_{-1}^{+1} - 3\left[\frac{x^2}{2}\right]_{-1}^{+1} + 7\left[x\right]_{-1}^{+1} \\
&= \frac{1}{5}\left[(1)^5 - (-1)^5\right] - \frac{3}{2}\left[(1)^2 - (-1)^2\right] + 7\,(1 - (-1)) \\
&= \frac{1}{5}[2] - 0 + 7\,(2) = 14.4
\end{aligned}
$$

(2M)

2 **Evaluate the integral by applying $I = \int_{-1}^{1} \frac{\cos x}{1-x^2}\, dx$ 3 point Gaussian quadrature. (15M)(November 2011)**BTL2

Answer: page – 5.137 Dr. S.Senthil



Given: Integral, $I = \int_{-1}^{1} \frac{\cos x}{1-x^2}\, dx$

$$\Rightarrow f(x) = \frac{\cos x}{1-x^2}\, dx$$

To find: Evaluate the integral by using 3 point Gaussian quadratur

☺ ***Solution:*** We know that, for three point Gaussian quadrature,

$$x_1 = \sqrt{\frac{3}{5}} = 0.774596669$$

$$x_2 = 0$$

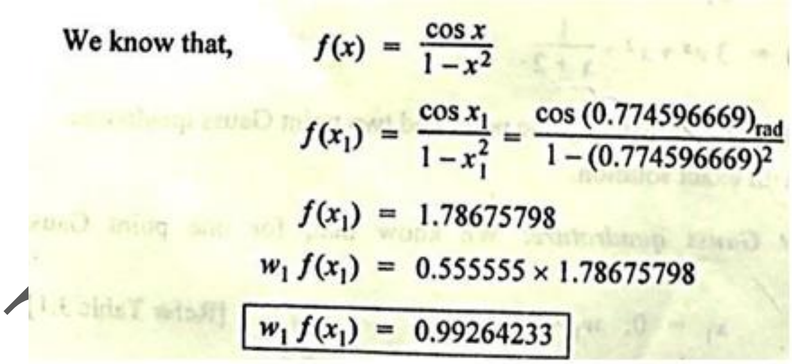
$$x_3 = -\sqrt{\frac{3}{5}} = -0.774596669$$

$$w_1 = \frac{5}{9} = 0.555555$$

$$w_2 = \frac{8}{9} = 0.888888$$

$$w_3 = \frac{5}{9} = 0.555555$$

(5M)



We know that, $f(x) = \frac{\cos x}{1-x^2}$

$$f(x_1) = \frac{\cos x_1}{1-x_1^2} = \frac{\cos (0.774596669)_{\text{rad}}}{1-(0.774596669)^2}$$

$$f(x_1) = 1.78675798$$

$$w_1 f(x_1) = 0.555555 \times 1.78675798$$

$$\boxed{w_1 f(x_1) = 0.99264233}$$

(3M)

	$f(x_2) = \frac{\cos x_2}{1-(x_2)^2} = \frac{\cos (0)_{\text{rad}}}{1-(0)^2}$ $f(x_2) = 1$ $w_2\, f(x_2) = 0.888888 \times 1$ $\boxed{w_2\, f(x_2) = 0.888888}$ ... (2) $f(x_3) = \frac{\cos x_3}{1-(x_3)^2} = \frac{\cos (-0.774596669)_{\text{rad}}}{1-(-0.774596669)^2}$ $f(x_3) = 1.78675798$ $w_3\, f(x_3) = 0.555555 \times 1.78675798$ $\boxed{w_3\, f(x_3) = 0.99264233}$ ... (3) Adding equations (1), (2) and (3), $w_1\, f(x_1) + w_2\, f(x_2) + w_3\, f(x_3) = 0.99264233 + 0.888888 + 0.99264233$ $= 2.87417$ ***Result:*** $\int_{-1}^{1} \frac{\cos x}{1-x^2}\, dx = 2.87417$ (7M)
3	**Evaluate the integral by applying $I = \int_{-1}^{1}(3e^x + x^2 + \frac{1}{x+2})dx$ 3 point Gaussian quadrature. (15M)(November 2014)**BTL2 **Answer: page – 5.47 Dr. S.Senthil** $\Rightarrow f(x) = 3\, e^x + x^2 + \frac{1}{x+2}$ $f(x_1) = 3\, e^{x_1} + x_1^2 + \frac{1}{x_1+2}$ $= 3\, e^0 + 0 + \frac{1}{0+2}$ $f(x_1) = 3.5$ $\Rightarrow w_1\, f(x_1) = 2 \times 3.5$ $\boxed{w_1\, f(x_1) = 7}$ (3M)

$$\Rightarrow \int_{-1}^{1}\left[3\,e^{x}+x^{2}+\frac{1}{(x+2)}\right]dx = 7 \text{ for one point Gauss quadrature.}$$

Two point Gauss quadrature: We know that,

For two point Gauss quadrature,

$$x_1 = +\sqrt{\frac{1}{3}} = 0.577350269$$

$$x_2 = -\sqrt{\frac{1}{3}} = -0.577350269$$

$$w_1 = 1$$

$$w_2 = 1$$

[Refer Table 3.1]

$$f(x) = 3\,e^{x}+x^{2}+\frac{1}{(x+2)}$$

$$f(x_1) = 3\,e^{x_1}+x_1^{2}+\frac{1}{x_1+2}$$

(5M)

$$= 3\,e^{0.577350269} + (0.5777350269)^2 + \frac{1}{0.577350269+2}$$

$$f(x_1) = 6.065265$$

$$w_1\,f(x_1) = 1 \times (6.065265)$$

$$\boxed{w_1\,f(x_1) = 6.065265} \quad \ldots (1)$$

$$f(x_2) = 3\,e^{x_2}+x_2^{2}+\frac{1}{x_2+2}$$

$$= 3\,e^{-0.577350269} + (-0.577350269)^2 + \frac{1}{-0.577350269+2}$$

$$f(x_2) = 2.7203987$$

$$w_2\, f(x_2) = 1 \times 2.7203987$$

$$\boxed{w_2\, f(x_2) = 2.7203987} \qquad \ldots (2)$$

Adding (1) and (2),

$$\Rightarrow \quad w_1\, f(x_1) + w_2\, f(x_2) = 6.065265 + 2.7203987 = 8.7856$$

$$\Rightarrow \quad \int_{-1}^{1} \left(3\, e^x + x^2 + \frac{1}{x+2}\right) dx = 8.7856 \text{ for two point Gauss quadrature.}$$

Exact solution:

$$I = \int_{-1}^{1} \left(3\, e^x + x^2 + \frac{1}{x+2}\right) dx$$

$$= 3\Big[e^x\Big]_{-1}^{+1} + \Big[\frac{x^3}{3}\Big]_{-1}^{+1} + \Big[ln\,(x+2)\Big]_{-1}^{+1}$$

$$= 3\,[e^{+1} - (e^{-1})] + \frac{1}{3}\,[1^3 - (-1)^3] + [ln\,(1+2) - ln\,(-1+2)]$$

$$= 3\,[2.718 - 0.3678] + \frac{1}{3}\,[1+1] + ln\,(3) - ln\,(1)$$

$$\Rightarrow \int_{-1}^{1} \left(3\, e^x + x^2 + \frac{1}{x+2}\right) dx = 8.8158$$

Result:

1. One point Gauss quadrature

$$\int_{-1}^{1} \left(3\, e^x + x^2 + \frac{1}{x+2}\right) dx = 7$$

2. Two point Gauss quadrature

$$\int_{-1}^{1} \left(3\, e^x + x^2 + \frac{1}{x+2}\right) dx = 8.7856$$

3. Exact solution

$$\int_{-1}^{1} \left(3\, e^x + x^2 + \frac{1}{x+2}\right) dx = 8.8158$$

(7M)

ME8693 HEAT AND MASS TRANSFER

L	T	P	C
3	2	0	4

OBJECTIVES:

- To understand the mechanisms of heat transfer under steady and transient conditions.
- To understand the concepts of heat transfer through extended surfaces.
- To learn the thermal analysis and sizing of heat exchangers and to understand the basic concepts of mass transfer.

(Use of standard HMT data book permitted)

UNIT I CONDUCTION 9+6

General Differential equation of Heat Conduction– Cartesian and Polar Coordinates – One Dimensional Steady State Heat Conduction –– plane and Composite Systems – Conduction with Internal Heat Generation – Extended Surfaces – Unsteady Heat Conduction – Lumped Analysis – Semi Infinite and Infinite Solids –Use of Heisler's charts.

UNIT II CONVECTION 9+6

Free and Forced Convection - Hydrodynamic and Thermal Boundary Layer. Free and Forced Convection during external flow over Plates and Cylinders and Internal flow through tubes.

UNIT III PHASE CHANGE HEAT TRANSFER AND HEAT EXCHANGERS 9+6

Nusselt's theory of condensation - Regimes of Pool boiling and Flow boiling. Correlations in boiling and condensation. Heat Exchanger Types - Overall Heat Transfer Coefficient – Fouling Factors - Analysis – LMTD method - NTU method.

UNIT IV RADIATION 9+6

Black Body Radiation – Grey body radiation - Shape Factor – Electrical Analogy – Radiation Shields. Radiation through gases.

UNIT V MASS TRANSFER 9+6

Basic Concepts – Diffusion Mass Transfer – Fick's Law of Diffusion – Steady state Molecular Diffusion – Convective Mass Transfer – Momentum, Heat and Mass Transfer Analogy –Convective Mass Transfer Correlations.

TOTAL : 75 PERIODS

OUTCOMES:

Upon the completion of this course the students will be able to

CO1: Apply heat conduction equations to different surface configurations under steady state and transient conditions and solve problems
CO2: Apply free and forced convective heat transfer correlations to internal and external flows through/over various surface configurations and solve problems
CO3: Explain the phenomena of boiling and condensation, apply LMTD and NTU methods of thermal analysis to different types of heat exchanger configurations and solve problems
CO4: Explain basic laws for Radiation and apply these principles to radiative heat transfer between different types of surfaces to solve problems
CO5: Apply diffusive and convective mass transfer equations and correlations to solve problems for different applications

TEXT BOOKS:

1. Holman, J.P., "Heat and Mass Transfer", Tata McGraw Hill, 2000
2. Yunus A. Cengel, "Heat Transfer A Practical Approach", Tata McGraw Hill, 5th Edition 2015

REFERENCES:

1. Frank P. Incropera and David P. Dewitt, "Fundamentals of Heat and Mass Transfer", John Wiley & Sons, 1998.
2. Kothandaraman, C.P., "Fundamentals of Heat and Mass Transfer", New Age International, New Delhi, 1998.
3. Nag, P.K., "Heat Transfer", Tata McGraw Hill, New Delhi, 2002
4. Ozisik, M.N., "Heat Transfer", McGraw Hill Book Co., 1994.
5. R.C. Sachdeva, “Fundamentals of Engineering Heat & Mass transfer”, New Age International Publishers, 2009

Subject Code : ME6502 **Year/Semester : III/ 06**
Subject Name: Heat and Mass Transfer
Subject Handler: Dr.B.Rajeshkumar & S.Gejendhiran

UNIT I CONDUCTION

General Differential equation of Heat Conduction– Cartesian and Polar Coordinates – One Dimensional Steady State Heat Conduction — plane and Composite Systems – Conduction with Internal Heat Generation – Extended Surfaces – Unsteady Heat Conduction – Lumped Analysis – Semi Infinite and Infinite Solids –Use of Heisler's charts

PART * A

Q.No.	Questions
1.	**Define Heat Transfer.** BTL1 Heat transfer can be defined as the transmission of energy from one region to another region due to temperature difference.
2	**What are the modes of Heat Transfer?(Nov 2018, Dec 2016, May 2013)**BTL2 Conduction , Convection , Radiation
3	**Define Conduction.** BTL2 Heat conduction is a mechanism of heat transfer from a region of high temperature to a region of low temperature within a medium (solid, liquid or gases) or between different medium in direct physical contact. In condition energy exchange takes place by the kinematic motion or direct impact of molecules. Pure conduction is found only in solids.
4	**Explain Convection (Apr 2012).** BTL1 Convection is a process of heat transfer that will occur between a solid surface and a fluid medium when they are at different temperatures. Convection is possible only in the presence of fluid medium.
5	**Define Radiation.** BTL1 The heat transfer from one body to another without any transmitting medium is known as radiation. It is an electromagnetic wave phenomenon.
6	**State Fourier's Law of conduction. (Dec 2019, May 2017, Dec 2016, May 2014)** BTL1 The rate of heat conduction is proportional to the area measured – normal to the direction of heat flow and to the temperature gradient in that direction.

	$Q\alpha$ - A $\frac{dT}{dx}$, $Q =$ - KA $\frac{\mathrm{dT}}{\mathrm{dx}}$, where A – are in m^2 , $\frac{dT}{dx}$ - Temperature gradient in K/m, K – Thermal conductivity W/mK.
7	**Define Thermal Conductivity.(Dec 2016, May 2015)** BTL2 Thermal conductivity is defined as the ability of a substance to conduct heat.
8	**Write down the equation for conduction of heat through a slab or plane wall.** BTL3 Heat transfer $Q = \frac{\Delta T_{overall}}{R}$, Where ΔT = T$_1$ – T$_2$ $R = \frac{L}{KA}$ - Thermal resistance of slab , L = Thickness of slab K = Thermal conductivity of slab, A = Area
9	**State Newton's law of cooling or convection law. (Nov 2018, Dec 2016, May 2013)**BTL2 Heat transfer by convection is given by Newton's law of cooling Q = hA (T$_s$ - T$_\infty$) Where , A – Area exposed to heat transfer in m^2 h - heat transfer coefficient in W/m^{2}K, T$_s$ – Temperature of the surface in K T$_\infty$ - Temperature of the fluid in K.
10	**Write down one dimensional, steady state conduction equation without internal heat generation.** BTL3 $\frac{\partial^2 T}{\partial x^2} = 0$
11	**Write down the general equation for one dimensional steady state heat transfer in slab or plane wall without heat generation.** BTL3 $\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = \frac{1}{\infty} \; \frac{\partial T}{\partial t}$ Where, α thermal diffusivity, Temperature gradient
12	**Define overall heat transfer co-efficient. [April '12]** BTL2 The overall heat transfer by combined modes is usually expressed in terms of an overall conductance or overall heat transfer co-efficient 'U'. Heat transfer Q = UA ΔT.

13	**Write down the general equation for one dimensional steady state heat transfer in slab with heat generation. [Oct. ’16]** BTL3 $\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}+\frac{q}{K}=\frac{1}{\alpha}\ \frac{\partial T}{\partial t}$
14	**What is critical radius of insulation (or) critical thickness? [Oct. ’17]** BTL2 Critical radius = r_c Critical thickness = $r_c - r_1$ Addition of insulating material on a surface does not reduce the amount of heat transfer rate always. In fact under certain circumstances it actually increases the heat loss up to certain thickness of insulation. The radius of insulation for which the heat transfer is maximum is called critical radius of insulation, and the corresponding thickness is called critical thickness.
15	**Explain fins (or) Extended surfaces.** BTL2 It is possible to increase the heat transfer rate by increasing the surface of heat transfer. The surfaces used for increasing heat transfer are called extended surfaces or sometimes known as fins.
16	**Define Fin efficiency. [Nov. ’16, Oct. ’17]** BTL4 The efficiency of a fin is defined as the ratio of actual heat transfer by the fin to the maximum possible heat transferred by the fin. $\eta_{fin}=\frac{Q_{fin}}{Q_{\max}}$
17	**Define Fin effectiveness. [Apr. 2012]** BTL2 Fin effectiveness is the ratio of heat transfer with fin to that without fin Fin effectiveness = $\frac{Q_{with\ fin}}{Q_{without\ fin}}$
18	**What is meant by Transient heat conduction or unsteady state conduction?** BTL2 If the temperature of a body varies with time, it is said to be in a transient state and that type of conduction is known as transient heat conduction or unsteady state conduction.
19	**Explain Lumped heat analysis?[Oct. 16]** BTL2 In a Newtonian heating or cooling process the temperature throughout the solid is considered to be uniform at a given time. Such an analysis is called Lumped heat capacity analysis.
20	**What is the significance of Biot number? [Nov.12]** BTL2 Biot number is used to find Lumped heat analysis, semi-infinite solids and infinite solids If $B_i < 0.1$ L → Lumped heat analysis

$B_i = \infty \rightarrow$ Semi infinite solids

$< B_i < 100 \rightarrow$ Infinite solids.

21 **What are Heisler charts? (Dec 2019, May 2017, Dec 2016, May 2014)**BTL1

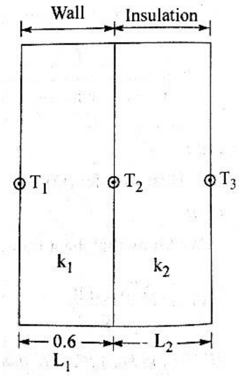
In Heisler chart, the solutions for temperature distributions and heat flows in plane walls, long cylinders and spheres with finite internal and surface resistance are presented. Heisler's charts are nothing but a analytical solutions in the form of graphs.

Part B

1 **A wall of 0.6m thickness having thermal conductivity of 1.2 W/mK. The wall is to be insulated with a material having an average thermal conductivity of 0.3 W/mK. Inner and outer surface temperatures are 1000° C and 10°C. Heat transfer rate is 1400 W/m² calculate the thickness of insulation. (Nov '12)**(13 M)-BTL5

Answer: Page 1.26-Dr.S.Senthil

$$Q = \frac{\Delta T_{overall}}{R}$$ [From equation (13)] (or) [HMT Data book page No. 34]



Where,

$\Delta T = T_a - T_b$ (or) $T_1 - T_3$ (2M)

$$R = \frac{1}{h_a A} + \frac{L_1}{K_1 A} + \frac{L_2}{K_2 A} + \frac{L_3}{K_3 A} + \frac{1}{h_b A}$$ (2M)

$$Q = \frac{[T_1 - T_3]}{\frac{1}{h_a A} + \frac{L_1}{K_1 A} + \frac{L_2}{K_2 A} + \frac{L_3}{K_3 A} + \frac{1}{h_b A}}$$ (2M)

Heat transfer coefficient h_a, h_b and thickness L_3 are not given. So neglect that terms.

$$\Rightarrow Q = \frac{[T_1 - T_3]}{\frac{L_1}{K_1 A} + \frac{L_2}{K_2 A}}$$

$$\Rightarrow \frac{Q}{A} = \frac{[T_1 - T_3]}{\frac{L_1}{K_1} + \frac{L_2}{K_2}} \Rightarrow$$

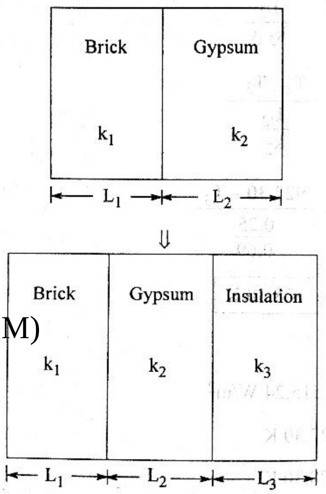
$$1400 = \frac{1273 - 283}{\frac{0.6}{1.2} + \frac{L_2}{0.3}}$$

$$\boxed{L_2 = 0.0621 \text{ m}}$$ (7M)

2

An external wall of a house is made up of 10 cm common brick (K = 0.7 W/mK) followed by a 4 cm layer of zibsum plaster (K = 0.48 W/mK). What thickness of loosely packed insulation (K = 0.065 W/mK) should be added to reduce the heat loss through the wall by 80%.(13 M) **(May 12) -**BTL5

Answer: Page 1.77-Dr.S.Senthil



Heat flow rate $Q = \frac{\Delta T_{overall}}{R}$

Where

$$R = \frac{1}{A}\left[\frac{1}{h_a} + \frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3} + \frac{1}{h_b}\right]$$

[The terms h_a, h_b is not given so neglect that terms]. (3M)

$$R = \frac{1}{A}\left[\frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3}\right]$$

Considering two slabs

$$Q = \frac{\Delta T}{\frac{L_1}{K_1} + \frac{L_2}{K_2}} \text{ [Assume heat transfer (Q) = 100 W]}$$

(4M)

$$100 = \frac{\Delta T}{\frac{0.1}{0.7} + \frac{0.04}{0.48}} \qquad \left[\because \text{ A = 1m}^2\right]$$

$$\boxed{\Delta T = 22.619 \text{ K}}$$

Heat loss is reduced by 80% due to insulation, so heat transfer is 20 W.

$$Q = \frac{\Delta T}{\frac{1}{A}\left[\frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3}\right]} \qquad [\because A = 1m^2]$$

$$20 = \frac{22.619}{\frac{1}{1}\left[\frac{0.1}{0.7} + \frac{0.04}{0.48} + \frac{L_3}{0.065}\right]}$$

$$\boxed{L_3 = 0.0588 \text{ m}}$$

(6M)

3

A thick walled tube of stainless steel [K = 77.85 kJ/hr m°C] 25 mm ID and 50 mm OD is covered with a 25 mm layer of asbestos [K = 0.88 kJ/hr m°C]. If the inside wall temperature of the pipe is maintained at 550°C and the outside of the insulator at 45°C. Calculate the heat loss per meter length of the pipe. (13 M)**(Nov 2018, Dec 2016, May 2013)-**BTL5

Answer: Page 1.15-Dr.S.Senthil

Heat flow through composite cylinder is given by

$$Q = \frac{\Delta T_{overall}}{R} \text{ (2M)}$$

Where

$\Delta T = T_a - T_b$

$$R = \frac{1}{2\pi L}\left[\frac{1}{\mathrm{h_a} r_1} + \frac{In\left[\frac{r_2}{r_1}\right]}{K_1} + \frac{In\left[\frac{r_3}{r_2}\right]}{K_2} + \frac{1}{h_b r_3}\right] \qquad \text{(5M)}$$

Convective heat transfer co-efficient are not given so neglect h_a and h_b terms.

$$\Rightarrow Q = \frac{\mathrm{T_a} - T_b}{\frac{1}{2\pi L}\left[\frac{In\left[\frac{r_2}{r_1}\right]}{K_1} + \frac{In\left[\frac{r_3}{r_2}\right]}{K_2}\right]}$$

(3M)

$$\Rightarrow \text{Q/L} = \frac{\mathrm{T_a} - T_b}{\frac{1}{2\pi}\left[\frac{In\left[\frac{r_2}{r_1}\right]}{K_1} + \frac{In\left[\frac{r_3}{r_2}\right]}{K_2}\right]}$$

$$Q/L = \frac{550 - 45}{\frac{1}{2\pi}\left[\frac{In\left[\frac{0.025}{0.0125}\right]}{21.625} + \frac{In\left[\frac{0.05}{0.025}\right]}{0.244}\right]} \qquad \text{(3M)}$$

$$\boxed{Q/L = 1103.9 \text{ W/m}}$$

4

A hollow sphere (K = 65 W/mK) of 120 mm inner diameter and 350 mm outer diameter is covered 10 mm layer of insulation (K = 10 W/mK). The inside and outside temperatures are 500°C and 50°C respectively. Calculate the rate of heat flow through this sphere.(13 M) **– (Oct '15)** BTL5

Answer: Page 1.160-Dr.S.Senthil

Heat loss through hollow sphere is given by

$$Q = \frac{\Delta T_{overall}}{R} \text{ (2M)}$$

Where

$\Delta T = T_a - T_b$

$$R=\frac{1}{4\pi}\left[\frac{1}{\mathrm{h_a}r_1^2}+\frac{1}{K_1}\left[\frac{1}{r_1}-\frac{1}{r_2}\right]+\frac{1}{K_2}\left[\frac{1}{r_2}-\frac{1}{r_3}\right]+\frac{1}{h_br_3^2}\right]$$

$$\Rightarrow Q=\frac{\mathrm{T_a}-T_b}{\frac{1}{4\pi}\left[\frac{1}{\mathrm{h_a}r_1^2}+\frac{1}{K_1}\left[\frac{1}{r_1}-\frac{1}{r_2}\right]+\frac{1}{K_2}\left[\frac{1}{r_2}-\frac{1}{r_3}\right]+\frac{1}{h_br_3^2}\right]}$$

(5M)

h_a, h_b not given so neglect that terms.

$$\Rightarrow Q=\frac{T_a-T_b}{\frac{1}{4\pi}\left[\frac{1}{K_1}\left[\frac{1}{r_1}-\frac{1}{r_2}\right]+\frac{1}{k_2}\left[\frac{1}{r_2}-\frac{1}{r_3}\right]\right]}$$

$$\Rightarrow \frac{773\text{ -}323}{\frac{1}{4\pi}\left[\frac{1}{65}\left[\frac{1}{0.060}-\frac{1}{0.175}\right]+\frac{1}{10}\left[\frac{1}{0.175}-\frac{1}{0.185}\right]\right]}$$

$$\Rightarrow \boxed{\mathrm{Q = 28361\ W}}$$

Heat transfer = Q = 28361 W (6M)

5

A wire of 6 mm diameter with 2 mm thick insulation (K = 0.11 W/mK). If the convective heat transfer co-efficient between the insulating surface and air is 25 W/m²L, find the critical thickness of insulation. And also find the percentage of change in the heat transfer rate if the critical radius is used.(13 M)**(Dec 2019, May 2017, Dec 2016, May 2014)-**BTL5

Answer: Page 1.171-Dr.S.Senthil

1. Critical radius $r_c=\frac{K}{h}$ (2M)

$$r_c=\frac{0.11}{25}=4.4\times10^{-3}\mathrm{m}$$

(2M)

$$\boxed{r_c=4.4\times10^{-3}\mathrm{m}}$$

Critical thickness = r_c – $\mathbf{r_1}$

$$=4.4\times10^{-3}-0.003$$

$$=1.4\times10^{-3}\ \mathrm{m}$$

$$\boxed{\text{Critical thickness } t_c = 1.4\times10^{-3}\text{ (or) }1.4\text{ mm}}$$ (2M)

2. Heat transfer through an insulated wire is given by

$$Q_1 = \frac{T_a - T_b}{\frac{1}{2\pi L}\left[\frac{\ln\left[\frac{r_2}{r_1}\right]}{K_1} + \frac{1}{h_b r_2}\right]}$$

$\left[\text{From HMT data book Page No.35}\right]$

$$= \frac{2\pi L\ (T_a - T_b)}{\left[\frac{\ln\left[\frac{0.005}{0.003}\right]}{0.11} + \frac{1}{25 \times 0.005}\right]}$$ (3M)

$$Q1 = \frac{2\pi L\ (T_a - T_b)}{12.64}$$

Heat flow through an insulated wire when critical radius is used is given by

$$Q_2 = \frac{T_a - T_b}{\frac{1}{2\pi L}\left[\frac{\ln\left[\frac{r_c}{r_1}\right]}{K_1} + \frac{1}{h_b r_c}\right]} \qquad \left[r_2 \to r_c\right]$$

$$= \frac{2\pi L\ (T_a - T_b)}{\frac{\ln\left[\frac{4.4\times10^{-3}}{0.003}\right]}{0.11} + \frac{1}{25\times4.4\times10^{-3}}}$$

$$Q_2 = \frac{2\pi L\ (T_a - T_b)}{12.572}$$ (2M)

$\therefore$ Percentage of increase in heat flow by using Critical radius = $\frac{Q_2 - Q_1}{Q_1} \times 100$

$$= \frac{\frac{1}{12.57} - \frac{1}{12.64} \times 100}{\frac{1}{12.64}}$$ (2M)

$$= 0.55\%$$

6

A current of 200 A is passed through a stainless steel wire (K = 19 W/mK) 3 mm in diameter. The resistivity of the steel may be taken as 70 μΩ cm and the length of the wire is submerged in a liquid at 110°C with heat transfer co-efficient h = 4 kW/m^{2}C. Calculate the centre temperature of the wire. (13 M) **– (May 2013)** BTL5

Answer: Page 1.200-Dr.S.Senthil

The maximum temperature in the wire occurs at the centre.

$$T_{max} = T_c = T_w + \frac{qr^2}{4K} \text{........(A) [From Equation No.12]}$$

$$\text{Resistance of wire } R = \frac{\text{Resistivity } \times \text{ Length}}{\text{Area}}$$

$$= \frac{70 \times 10^{-6} \times 10^{-2} \times 1}{\pi/4\left(3 \times 10^{-3}\right)^2}$$

$$\boxed{R = 0.099\ \Omega}$$

(3M)

We know that

$Q = I^2R$

$= (200)^2 \times (0.099)$

$\boxed{Q = 3960\text{ W}}$ (3M)

Heat generated $q = \frac{Q}{V} = \frac{3960}{\pi/4\, d^2 \times L}$

$$q = \frac{3960}{\pi/4\left(3 \times 10^{-3}\right)^2 \times 1}$$

$\boxed{q = 560 \times 10^6\text{ W/m}^3}$ (3M)

Substituting q value in Equation (A)

$$T_{max} = T_c = 383 + \frac{560 \times 106 \times (1.5 \times 10^{-3})^2}{4 \times 19}$$

$$\boxed{T_c = 399.5\text{ K}}$$

(4M)

7

A sphere of 100 mm diameter, having thermal conductivity of 0.18 W/mK. The outer surface temperature is 8°C and 250 W/m^2 of energy is released due to heat source. Calculate

1. Heat generated

2. Temperature at the centre of the sphere.(13M) -BTL5

Answer: Page 1.202-Dr.S.Senthil

Heat generated $q = \frac{Q}{V}$

$$\Rightarrow q/A = \frac{Q/A}{V} \qquad \left[\text{Here Q/A = 250 W/m}^2\right]$$

$$\Rightarrow q/A = \frac{Q/A}{V} \qquad \left[\text{Here Q/A = 250 W/m}^2\right]$$

$$\Rightarrow q/A = \frac{250}{4/3\pi r^3}$$

$$\Rightarrow \frac{q}{4\pi r^2} = \frac{250}{4/3\pi r^3}$$

$$\Rightarrow q = \frac{250 \times 4 \times \pi \times (0.050)^2}{4/3\pi \times (0.50)^3}$$

$$\Rightarrow \boxed{q = 15,000\ W/m^3}$$

(8M)

Temperature at the centre of the sphere

$$T_c = T_w + \frac{qr^2}{6K} \qquad \text{[From Equation No.16]}$$

$$= 281 + \frac{15000 \times (0.050)^2}{6 \times 0.18}$$

$$\boxed{T_c = 315.7\ K}$$

(5M)

8 **One end of the long solid rod of 50 mm diameter is inserted into a furnace with the other end is projecting the atmosphere at 25°C. Once the steady state is reached, the temperature of the rod is measured at two points 20 cm apart are found to be 150°C and 100°C. The convective heat transfer co-efficient between the rod and the surrounding air is 30 W/m^{2}K. Calculate the thermal conductivity of the rod material.**(13M) -BTL5

Answer: Page 1.222-Dr.S.Senthil

Since the rod is long, it is treated as long fin. So, temperature distribution

$$\frac{T - T_\infty}{T_b - T_\infty} = e^{-mx}$$

(2M)

$$\Rightarrow \frac{373 - 298}{423 - 298} = e^{-m\times(0.20)}$$

$$\Rightarrow 0.6 = e^{-m\times(0.20)}$$

$$\Rightarrow \text{In}\ (0.6) = -m \times (0.20)$$

$$\Rightarrow -0.51 = -m \times (0.20)$$

$$\boxed{m = 2.55\ m^{-1}}$$

(4M)

We know that,

	$m = \sqrt{\frac{hP}{KA}}$ [From HMT data book (CPK) Page No.41] $2.55 = \sqrt{\frac{hP}{KA}}$ ....(A) h – heat transfer co-efficient = 30 W/m^{2}K P – Perimeter = πd = π× 0.050 $\boxed{P = 0.157\ m}$ $A - \text{Area} = \frac{\pi}{4} d^2$ $= \frac{\pi}{4}(0.050)^2$ $\boxed{A = 1.96 \times 10^{-3} m^2}$ (4M) $(A) \Rightarrow 2.55 = \sqrt{\frac{30 \times 0.157}{K \times 1.96 \times 10^{-3}}}$ $\Rightarrow 6.50 = \frac{30 \times 0.157}{K \times 1.96 \times 10^{-3}}$ $\boxed{K = 369.7\ W/mK}$ (3M)
9	**An aluminium alloy fin of 7 mm thick and 50 mm long protrudes from a wall, which is maintained at 120°C. The ambient air temperature is 22°C. The heat transfer coefficient and conductivity of the fin material are 140 W/m^{2}K and 55 W/mK respectively. Determine** **1. Temperature at the end of the fin.** **2. Temperature at the middle of the fin.** **3. Total heat dissipated by the fin.**(13M) **-**BTL5 **Answer: Page 1.230-Dr.S.Senthil** $\frac{T - T_\infty}{T_b - T_\infty} = \frac{\cos\ h\ m\ [L\ \text{-}x]}{\cos\ h\ (mL)}$.......(A) **(i) Temperature at the end of the fin, Put x = L**

(A) $\Rightarrow \quad \frac{T - T_\infty}{T_b - T_\infty} = \frac{\cos h\ m\ [L\text{-}L]}{\cos h\ (mL)}$

$$\Rightarrow \quad \frac{T - T_\infty}{T_b - T_\infty} = \frac{1}{\cos h\ (mL)} \qquad ...(1)$$

where

$$m = \sqrt{\frac{hP}{KA}} \qquad \text{(2M)}$$

P = Perimeter = $2 \times L$ (Approx)

= $2 \times$ 0.050

$\boxed{P = 0.1\ m}$

A – Area = Length × thickness = 0.050 × 0.007

$\boxed{A = 3.5 \times 10^{-4} m^2}$

$$\Rightarrow\ m = \sqrt{\frac{hP}{KA}}$$

$$= \sqrt{\frac{140 \times 0.1}{55 \times 3.5 \times 10^{-4}}} \qquad \text{(3M)}$$

$\boxed{m = 26.96}$

(1) $\Rightarrow \quad \frac{T - T_\infty}{T_b - T_\infty} = \frac{1}{\cos h\ (26.9\ \times\ 0.050)}$

$$\Rightarrow \quad \frac{T - T_\infty}{T_b - T_\infty} = \frac{1}{2.05}$$

$$\Rightarrow \quad \frac{T - 295}{393 - 295} = \frac{1}{2.05}$$

$$\Rightarrow \quad T - 295 = 47.8$$

$$\Rightarrow \quad \boxed{T = 342.8\ K}$$

$\boxed{\text{Temperature at the end of the fin } T_{x=L} = 342.8\ K}$ (3M)

(ii) Temperature of the middle of the fin,

Put x = L/2 in Equation (A)

	(A) $\Rightarrow \frac{T - T_\infty}{T_b - T_\infty} = \frac{\cos\ hm\ [L-L/2]}{\cos h\ (mL)}$ $\Rightarrow \frac{T - T_\infty}{T_b - T_\infty} = \frac{\cos\ h\ 26.9 \left[0.050 - \frac{0.050}{2}\right]}{\cos\ h\ \left[26.9 \times (0.050)\right]}$ $\Rightarrow \frac{T- 295}{393 - 295} = \frac{1.234}{2.049}$ $\Rightarrow \frac{T - 295}{393 -295} = 0.6025$ $\boxed{T = 354.04\ K}$ Temperature at the middle of the fin $\boxed{T_{x=L/2} = 354.04\ K}$ (2M) **(iii) Total heat dissipated** $\Rightarrow Q = (hPKA)^{1/2} (T_b - T_\infty) \tan\ h\ (mL)$ $\Rightarrow [140 \times 0.1 \times 55 \times 3.5 \times 10^{-4}]^{1/2} \times (393 - 295)$ $\times \tan\ h\ (26.9 \times 0.050)$ $\boxed{Q = 44.4\ W}$ (3 M)
10	**Ten thin brass fins (K = 100 W/mK), 0.75 mm thick are placed axially on a 1 m long and 60 mm diameter engine cylinder which is surrounded by 35°C. The fins are extended 1.5 cm from the cylinder surface and the heat transfer co-efficient between cylinder and atmospheric air is 15 W/m²K. Calculate the rate of heat transfer and the temperature at the end of fins when the cylinder surface is at 160°C.**(13M)**(May 2019, Dec 2015)-**BTL5 **Answer: Page 1.236-Dr.S.Senthil** Heat transferred Q = $(hPKA)^{1/2}$ $(T_b - T_\infty)$ tan h (mL)….(A) Where P – Perimeter = 2 × Length of the cylinder $\boxed{P = 2m}$ A = Area = length of the cylinder × thickness $\boxed{A = 0.75 \times 10^{-3} m^2}$

$m = \sqrt{\frac{hP}{KA}}$

$= \sqrt{\frac{15 \times 2}{100 \times 0.75 \times 10^{-3}}}$ (2M)

$\boxed{m = 20}$

$\Rightarrow$ Q = $(hPKA)^{1/2}(T_b - T_\infty)\tan h\ (mL)$

$\Rightarrow [15 \times 2 \times 100 \times 0.75 \times 10^{-3}]^{1/2} \times (433 - 300)$

$\times \tan h\ (20 \times 1.5 \times 10^{-2}\ )$

Q = $1.5 \times 133 \times 0.29$

$\boxed{Q = 58.1\ W}$ (2M)

Heat transferred per fin = 58.1 W

The heat transfer for 10 fins = 58.1 × 10

$\boxed{Q_1 = 581\ W}$ ....(B)

Heat transfer from unfinned surface due to convection is

$Q_2 = h\ A\ \Delta T$

$= h \times (\pi dL - 10 \times t \times L)\ (T_b - T_\infty)$

[$\because$ Area of unfinned surface = Area of cylinder - Area of fin] (2M)

$= 15 \times [\pi \times 0.060 \times 1] - [10 \times 0.75 \times 10^{-3} \times 1.5 \times 10^{-2}]$

[433 - 300]

$\boxed{Q_2 = 375.8\ W}$ ....(C)

So, Total heat transfer Q = $Q_1 + Q_2$

Q = 581 + 375.8

$\boxed{\text{Total heat transfer } Q = 956.8\ W}$ (2M)

Temperature distribution [short fin, end insulated]

$\frac{T - T_\infty}{T_b - T_\infty} = \frac{\cos h\ m\ [L\text{-}x]}{\cos h\ (mL)}$

Temperature at the end of fin, so put x = L

$$\Rightarrow \frac{T\text{-}T_\infty}{T_b - T_\infty} = \frac{1}{\cos h\,(20\times 1.5\times 10^{-2})}$$

$$= \frac{1}{0.95}$$

$$\Rightarrow T - T_\infty = \frac{T_b - T_\infty}{0.95}$$ (5M)

$$\Rightarrow T = T_\infty + \frac{T_b - T_\infty}{0.95}$$

$$= 300 + \frac{433 - 300}{0.95}$$

$$\boxed{T = 440\text{ K}}$$

11 **An aluminium cube 6 cm on a side is originally at a temperature of 500°C. It is suddenly immersed in a liquid at 10°C for which h is 120 W/m^{2}K. Estimate the time required for the cube to reach a temperature of 250°C. For aluminium ρ = 2700 kg/m^3, C_ρ= 900 J/kg K, K = 204 W/mK.**(13M) **(Nov 2018, Dec 2016, May 2013)-**BTL5

Answer: Page 1.290-Dr.S.Senthil

For Cube,

Characteristic length $L_c = \frac{L}{6}$

$$= \frac{0.06}{6}$$

$$\boxed{L_c = 0.01\,\text{m}}$$ (2M)

We know

Biot number $B_i = \frac{hL_c}{K}$

$$= \frac{120\times 0.01}{204}$$

B_i = $5.88\times 10^{-3} < 0.1$ (3M)

Biot number value is less than 0.1. So this is lumped heat analysis type problem

For lumped parameter system,

$$\frac{T - T_\infty}{T_0 - T_\infty} = e^{\left[\frac{-hA}{C_\rho \times V \times \rho}\times t\right]} \qquad ....(1)$$ (3M)

[From HMT data book Page No.48]

We know,

Characteristics length $L_c = \frac{V}{A}$

$$(1) \Rightarrow \frac{T-T_\infty}{T_0 - T_\infty} = e^{\left[\frac{-h}{C_\rho \times L_c \times \rho}\times t\right]}$$

$$\Rightarrow \frac{523 - 283}{773 - 283} = e^{\left[\frac{-120}{900\times 0.01\times 2700}\times t\right]}$$ (3M)

$$\Rightarrow \ln (0.489) = \frac{-120}{900\times 0.01\times 2700}\times t$$

$$\Rightarrow \boxed{t = 144.86 \text{ s}}$$

Time required for the cube to reach 250°C is 144.86 s. (2M)

12

A steel ball (specific heat = 0.46 kJ/kgK. and thermal conductivity = 35 W/mK) having 5 cm diameter and initially at a uniform temperature of 450°C is suddenly placed in a control environment in which the temperature is maintained at 100°C. Calculate the time required for the balls to attained a temperature of 150°C. Take h = 10W/m^2K. (May 2010)(13M) -BTL5

Answer: Page 1.296-Dr.S.Senthil

Density of steel is 7833 kg/m^3

$$\boxed{\rho = 7833 \text{ kg/m}^3}$$

For sphere,

Characteristic Length $L_c = \frac{R}{3}$

$$= \frac{0.025}{3}$$

$$\boxed{L_c = 8.33\times 10^{-3} \text{ m}}$$ (2M)

We know,

Biot number $B_i = \frac{hL_c}{K}$

$$= \frac{10\times 8.3\times 10^{-3}}{35}$$

$B_i = 2.38 \times 10^{-3} < 0.1$ (2M)

Biot number value is less than 0.1. So this is lumped heat analysis type problem.

For lumped parameter system,

$$\frac{T - T_\infty}{T_0 - T_\infty} = e^{\left[\frac{-hA}{C_\rho \times V\times \rho}\times t\right]} \quad \text{……….(1)}$$ (2M)

[From HMT data book Page No.48]

We know,

Characteristics length $L_c = \frac{V}{A}$

$$(1) \Rightarrow \frac{T\text{-}T_\infty}{T_0 - T_\infty} = e^{\left[\frac{-h}{C_\rho \times L_c \times \rho} \times t\right]}$$

$$\Rightarrow \frac{423 - 373}{723 - 373} = e^{\left[\frac{-10}{460 \times 8.33 \times 10^{-3} \times 7833} \times t\right]}$$ (5M)

$$\Rightarrow \ln \frac{423 - 373}{723 - 373} = \frac{-10}{460 \times 8.33 \times 10^{-3} \times 7833} \times t$$

$$\Rightarrow \boxed{t = 5840.54 \text{ s}}$$

Time required for the ball to reach 150°C is 5840.54 s. (2M)

13

A large steel plate 5 cm thick is initially at a uniform temperature of 400°C. It is suddenly exposed on both sides to a surrounding at 60°C with convective heat transfer co-efficient of 285 W/m^{2}K. Calculate the centre line temperature and the temperature inside the plate 1.25 cm from themed plane after 3 minutes. (Apr '13)(13M) -BTL5

Answer: Page 1.362-Dr.S.Senthil

For Plate :

Characteristic Length $L_c = \frac{L}{2}$

$$= \frac{0.05}{2}$$ (2M)

$$\boxed{L_c = 0.025 \text{ m}}$$

We know,

Biot number $B_i = \frac{hL_c}{K}$

$$= \frac{285 \times 0.025}{42.5}$$

$$\Rightarrow \boxed{B_i = 0.1675}$$ (2M)

0.1 < B$_i$< 100, So this is infinite solid type problem.

Infinite Solids

Case (i)

[To calculate centre line temperature (or) Mid plane temperature for infinite plate, refer HMT data book Page No.59 Heisler chart].

$$\text{X axis} \rightarrow \text{Fourier number} = \frac{\alpha t}{L_c^{\,2}}$$

$$= \frac{1.19 \times 10^{-5} \times 180}{(0.025)^2}$$ (3M)

$$\boxed{\text{X axis} \rightarrow \text{Fourier number} = 3.42}$$

$$\text{Curve} = \frac{hL_c}{K}$$

$$= \frac{285 \times 0.025}{42.5} = 0.167$$

$$\boxed{\text{Curve} = \frac{hL_c}{K} = 0.167}$$

X axis value is 3.42, curve value is 0.167, corresponding Y axis value is 0.64

$$\text{Y axis} = \frac{T_0 - T_\infty}{T_i - T_\infty} = 0.64$$

$$\frac{T_0 - T_\infty}{T_i - T_\infty} = 0.64$$

$$\Rightarrow \frac{T_0 - T_\infty}{T_i - T_\infty} = 0.64$$

$$\Rightarrow \quad \frac{T_0 - 333}{673 - 333} = 0.64$$

$$\Rightarrow \quad \boxed{T_0 = 550.6 \text{ K}}$$

$$\boxed{\text{Center line temperature } T_0 = 550.6 \text{ K}}$$ (2M)

Case (ii)

Temperature (T_x) at a distance of 0.0125 m from mid plane

[Refer HMT data book Page No.60, Heisler chart]

$$\text{X axis} \rightarrow \text{Biot number } B_i = \frac{hL_c}{K} = 0.167$$

$$\text{Curve} \rightarrow \frac{x}{L_c} = \frac{0.0125}{0.025} = 0.5$$

X axis value is 0.167, curve value is 0.5, corresponding Y axis value is 0.97.

$$\frac{T_x - T_\infty}{T_0 - T_\infty} = 0.97$$ (2M)

Y axis = $\frac{T_x - T_\infty}{T_0 - T_\infty} = 0.97$

$\Rightarrow \quad \frac{T_x - T_\infty}{T_0 - T_\infty} = 0.97$

$\Rightarrow \quad \frac{T_x - 333}{550.6 - 333} = 0.97$

$\Rightarrow \quad \boxed{T_x = 544\ K}$

Temperature inside the plate 1.25 cm from the mid plane is 544 K. (2M)

14

A steel pipe of 120 mm inner diameter, 140 mm outer diameter with thermal conductivity 55 W/mK is covered with two layers of insulation each having a thickness of 55 mm. The thermal conductivity of the first insulation material is 0.05 W/mK and that of the second is 0.11 W/mK. The temperature of the inside tube surface is 240°C and that of the outside surface of the insulation is 60°C.Calculate the loss of heat per meter length of pipe and the interface temperature between the two layers of insulation. (May '12) (13 M) BTL4

Answer: Page 1.126-Dr.S.Senthil

Heat flow through composite cylinder is given by

$$Q = \frac{\Delta T_{overall}}{R}$$ (2M)

Where

ΔT = T_a– T_b(or) T1-T4 (2M)

R= $1/2\pi L \left(\frac{ln\frac{r_2}{r_1}}{K_1} + \frac{ln\frac{r_3}{r_2}}{K_2} + \frac{ln\frac{r_4}{r_3}}{K_3} \right)$ (2M)

Q/L = $\frac{\text{T1}-\text{T4}}{1/2\pi L \left(\frac{ln\frac{r_2}{r_1}}{K_1} + \frac{ln\frac{r_3}{r_2}}{K_2} + \frac{ln\frac{r_4}{r_3}}{K_3} \right)}$ =75.83 W/m (5M)

Q/L = $\frac{\text{T1}-\text{T2}}{1/2\pi L \left(\frac{ln\frac{r_2}{r_1}}{K_1} \right)}$==➔ T_2=512.7 K (1M)

	Q/L =$\frac{T2-T3}{1/2\pi L\left(\frac{ln\frac{r_3}{r_2}}{K_2}\right)}$==➔ T_3=372.7 K (1M)
15	**(i) An electric current is passed through a plane wall of thickness 150 mm which generates heat at the rate of 50000 W/m3. The convective heat transfer coefficient between wall and ambient air is 65 W/m2K, ambient air temperature is 28°C and the thermal conductivity of the wall material is 22 W/mK. Calculate (i) Surface temperature (ii) Maximum temperature in the wall.** (6M) BTL4 **Answer: Page 1.187-Dr.S.Senthil** T_w=$T_\infty + \frac{qL}{2h}$ = 358.6 K (3M) T_{max}=$T_w + \frac{qL^2}{8k}$ = 364.9 K (3M) **(ii) A copper wire of 40 mm diameter carries 250A and has a resistance of 0.25 x 10^{-4} ohm cm/length surface temperature of copper wire is 250°C and the ambient air temperature is 10°C. If the thermal conductivity of the copper wire is 175 W/mK, Calculate (i) Heat transfer co-efficient between wire surface and ambient air, (ii) Maximum temperature in the wire.** (6M) BTL4 **Answer: Page 1.196-Dr.S.Senthil** **Q=$I^2R = 1.562\ W/cm$ = 156 W/m , $\dot{q} = \frac{Q}{V} = 124140\ \frac{W}{m^3}$**(1M) T_{max}=$T_w + \frac{qr^2}{4k}$= 523.07 K (3M) Surface temperature, T_w=$T_\infty + \frac{r\dot{q}}{2h}$= 5.17 W/$m^2K$(3M)
	Part-C
1	**A wall is constructed of several layers. The first layer consists of masonry brick 20 cm. thick of thermal conductivity 0.66 W/mK, the second layer consists of 3 cm thick mortar of thermal conductivity 0.6 W/mK, the third layer consists of 8 cm thick lime stone of thermal conductivity 0.58 W/mK and the outer layer consists of 1.2 cm thick plaster of thermal conductivity 0.6 W/mK. The heat transfer coefficient on the interior and exterior of the wall**

are 5.6 W/m²K and 11 W/m²K respectively. Interior room temperature is 22°C and outside air temperature is -5°C.Calculate

- **a) Overall heat transfer coefficient**
- **b) Overall thermal resistance**
- **c) The rate of heat transfer**
- **d) The temperature at the junction between the mortar and the limestone. (May '13)**(15 M) -BTL5

Answer: Refer Class Notes

Heat flow through composite wall is given by $Q = \frac{\Delta T_{overall}}{R}$ [From equation (13)] (or) [HMT Data book page No. 34], Where, Δ T = T_a– T_b

$$R = \frac{1}{h_a A} + \frac{L_1}{K_1 A} + \frac{L_2}{K_2 A} + \frac{L_3}{K_3 A} + \frac{L_4}{K_4 A} + \frac{1}{h_b A}$$

$$\Rightarrow Q = \frac{T_a - T_b}{\frac{1}{h_a A} + \frac{L_1}{K_1 A} + \frac{L_2}{K_2 A} + \frac{L_3}{K_3 A} + \frac{L_4}{K_4 A} + \frac{1}{h_b A}} \qquad \text{(3M)}$$

$$\Rightarrow Q/A = \frac{295 - 268}{\frac{1}{5.6} + \frac{0.20}{0.66} + \frac{0.03}{0.6} + \frac{0.08}{0.58} + \frac{0.012}{0.6} + \frac{1}{11}}$$

$$\boxed{\text{Heat transfer per unit area Q/A} = 34.56 \text{ W/m}^2}$$

We know

Heat transfer Q = UA (T_a – T_b) [From equation (14)]

Where U – overall heat transfer co-efficient

$$\Rightarrow U = \frac{Q}{A \times (T_a - T_b)}$$

$$\Rightarrow U = \frac{34.56}{295 - 268} \qquad \text{(3M)}$$

$$\boxed{\text{Overall heat transfer co-efficient U} = 1.28 \text{ W/m}^2 K}$$

We know

Overall Thermal resistance (R)

$$R = \frac{1}{h_a A} + \frac{L_1}{K_1 A} + \frac{L_2}{K_2 A} + \frac{L_3}{K_3 A} + \frac{L_4}{K_4 A} + \frac{1}{h_b A} \qquad \text{(1M)}$$

For unit Area

$$R = \frac{1}{h_a} + \frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3} + \frac{L_4}{K_4} + \frac{1}{h_b}$$

$$= \frac{1}{56} + \frac{0.20}{0.66} + \frac{0.03}{0.6} + \frac{0.08}{0.58} + \frac{0.012}{0.6} + \frac{1}{11}$$

(2M)

$$\boxed{R = 0.78\ K/W}$$

Interface temperature between mortar and the limestone T_3

Interface temperatures relation

$$\Rightarrow Q = \frac{T_a - T_1}{R_a} = \frac{T_1 - T_2}{R_1} = \frac{T_2 - T_3}{R_2} = \frac{T_3 - T_4}{R_3} = \frac{T_4 - T_5}{R_4} = \frac{T_5 - T_b}{R_b}$$

$$\Rightarrow Q = \frac{T_a - T_1}{R_a}$$

$$Q = \frac{295\text{-}T_1}{1/h_a A} \qquad \left[\because R_a = \frac{1}{h_a A}\right]$$

$$\Rightarrow Q/A = \frac{295 - T_1}{1/h_a}$$

(3M)

$$\Rightarrow 34.56 = \frac{295 - T_1}{1/5.6}$$

$$\Rightarrow \boxed{T_1 = 288.8\ K}$$

$$\Rightarrow Q = \frac{T_1 - T_2}{R_1}$$

$$Q = \frac{288.8 - T_2}{\frac{L_1}{K_1 A}} \qquad \left[\because R_1 = \frac{L_1}{k_1 A}\right]$$

$$\Rightarrow Q/A = \frac{288.8 - T_2}{\frac{L_1}{K_1}}$$

$$\Rightarrow 34.56 = \frac{288.8 - T_2}{\frac{0.20}{0.66}}$$

$$\Rightarrow \boxed{T_2 = 278.3\text{ K}}$$

$$\Rightarrow Q = \frac{\mathrm{T}_2 - T_3}{R_2}$$

$$Q = \frac{278.3 - T_3}{\frac{L_2}{K_2 A}} \qquad \left[\because \mathrm{R}_2 = \frac{L_2}{K_2 A}\right]$$

$$\Rightarrow Q/A = \frac{278.3 - T_3}{\frac{L_2}{K_2}}$$

$$\Rightarrow 34.56 = \frac{278.3 - T_3}{\frac{0.03}{0.6}}$$

$$\Rightarrow \boxed{T_3 = 276.5\text{ K}}$$

(3M)

Temperature between Mortar and limestone (T_3 is 276.5 K)

2

A composite slab is made of three layers 15 cm, 10 cm and 12 cm thickness respectively. The first layer is made of material with K = 1.45 W/mK, for 60% of the area and the rest of material with K = 2.5 W/mK. The second layer is made of material with K = 12.5 W/mK for 50% of area and rest of material with K = 18.5 W/mK. The third layer is made of single material of K = 0.76 W/mK. The composite slab is exposed on one side to warn at 26°C and cold air at -20°C. The inside heat transfer co-efficient is 15 W/m^{2}K. The outside heat transfer co-efficient is 20 W/m^{2}K determine heat flow rate and interface temperatures. (Dec '14)(15 M)-BTL5

Answer: Refer Class Notes

Heat flow $Q = \frac{\Delta T_{overall}}{R}$

Where

Δ T = T_a– T_b

$$R = \frac{1}{A}\left[\frac{1}{h_a} + \frac{L_1}{K_1} + \frac{L_2}{K_2} + \frac{L_3}{K_3} + \frac{1}{h_b}\right]$$

$$= \frac{1}{A_a h_a} + \frac{L_1}{A_1 K_1} + \frac{L_2}{A_2 K_2} + \frac{L_3}{A_3 K_3} + \frac{1}{A_b h_b} \text{ (2M)}$$

$$\mathrm{R} = \mathrm{R}_a + R_1 + R_2 + R_3 + R_b$$

$$\Rightarrow Q = \frac{\mathrm{T_a} - T_b}{\mathrm{R_a} + R_1 + R_2 + R_3 + R_b} \text{....}(A)$$

Where

$$R_a = \frac{1}{A_a h_a} = \frac{1}{1 \times 15}$$

$$\boxed{R_a = 0.066\ K/W}$$

$$R_1 = \frac{R_{1a} \times R_{1b}}{R_{1a} + R_{1b}} \qquad \text{.....(1)}$$

$$\mathrm{R_{1a}} = \frac{L_1}{K_{1a} \times A_{1a}} = \frac{0.15}{1.45 \times 0.6}$$

$$\boxed{R_{1a} = 0.1724\ \mathrm{K/W}}$$

$$R_{1b} = \frac{L_1}{K_{1b} \times A_{1b}} = \frac{0.15}{2.5 \times 0.4}$$ (2M)

$$\boxed{R_{1b} = 0.15\ \mathrm{K/W}}$$

Substitute R_{1a} and R_{1b} value in (1)

$$(1) \Rightarrow R_1 = \frac{0.1724 \times 0.15}{0.1724 + 0.15}$$

$$\boxed{R_1 = 0.08\ K/W}$$

Similarly,

$$R_2 = \frac{R_{2a} \times R_{2b}}{R_{2a} + R_{2b}} \qquad \text{.....(2)}$$

$$\mathrm{R_{2a}} = \frac{L_2}{K_{2a} \times A_{2a}} = \frac{0.1}{12.5 \times 0.5}$$

$$\boxed{R_{2a} = 0.016\ \mathrm{K/W}}$$

$$\mathrm{R_{2b}} = \frac{L_2}{K_{2b} \times A_{2b}} = \frac{0.1}{18.5 \times 0.5}$$

$$\boxed{R_{2b} = 0.0108\ \mathrm{K/W}}$$

$$(2) \Rightarrow R_2 = \frac{0.016 \times 0.0108}{0.016 + 0.0108}$$

$$\boxed{R_2 = 0.0064\ K/W}$$

$$\mathrm{R}_3 = \frac{L_3}{A_3 K_3} = \frac{0.12}{1\times 0.76} \qquad \left[\because \mathrm{A}_3 = 1m^2\right]$$

$$\boxed{R_3 = 0.15789 \text{ K/W}}$$

$$\mathrm{R}_\mathrm{b} = \frac{1}{A_a h_b} = \frac{1}{1\times 20} \qquad \left[\because \mathrm{A}_\mathrm{b} = 1m^2\right]$$

$$\boxed{R_b = 0.05 \text{ K/W}}$$

$$(A) \Rightarrow Q = \frac{299-253}{0.066+0.08+0.0064+0.15789+0.05} \qquad (4M)$$

$$\boxed{Q = 127.67 \text{ W}}$$

(ii) Interface températures (T_1, T_2, T_3 and T_4)

We know

$$\Rightarrow Q = \frac{T_a - T_b}{R} = \frac{T_a - T_1}{R_a} = \frac{T_1 - T_2}{R_1} = \frac{T_2 - T_3}{R_2} \qquad (1M)$$

$$= \frac{T_3 - T_4}{R_3} = \frac{\mathrm{T}_4 - T_b}{R_b} \quad .....(\mathrm{B})$$

$$(\mathrm{B}) \Rightarrow Q = \frac{T_a - T_1}{R_a}$$

$$= \frac{299 - T_1}{0.066}$$

$$127.67 = \frac{299 - T_1}{0.066}$$

$$\boxed{T_1 = 290.57K}$$

$$(\mathrm{B}) \Rightarrow Q = \frac{T_1 - T_2}{R_1}$$

$$127.67 = \frac{290.57 - T_2}{0.08}$$

$$\boxed{T_2 = 280.35\ K}$$

$$(\mathrm{B}) \Rightarrow Q = \frac{T_2 - T_3}{R_2}$$

$$127.67 = \frac{280.35 - T_3}{0.0064}$$

$$\boxed{T_3 = 279.532\ K}$$

$$(B) \Rightarrow Q = \frac{T_3 - T_4}{R_3}$$

$$127.67 = \frac{279.532 - T_4}{0.15789}$$ (6M)

$$\boxed{T_4 = 259.374\ K}$$

3

A 12 cm diameter long bar initially at a uniform temperature of 40° C is placed in a medium at 650°C with a convective co-efficient of 22 W/m^{2}K. Determine the time required for the center to reach 255°C. For the material of the bar, K = 20 W/mK, Density = 580 kg/m^3, specific heat = 1050 J/kg K. (15 M)-BTL5

Answer: Refer Class Notes

For cylinder,

Characteristic Length $L_c = \frac{R}{2}$

$$= \frac{0.06}{2}$$ (3M)

$$\boxed{L_c = 0.03\ m}$$

We know,

Biot number $B_i = \frac{hL_c}{K}$

$$= \frac{22 \times 0.03}{20}$$

$B_i = 0.033 < 0.1$ (3M)

Biot number value is less than 0.1. So this is lumped heat analysis type problem.

For lumped parameter system, (2M)

$$\frac{T - T_\infty}{T_0 - T_\infty} = e^{\left[\frac{-hA}{C_\rho \times V \times \rho} \times t\right]}$$ ……….(1) (3M)

[From HMT data book Page No.48]

We know,

Characteristics length $L_c = \frac{V}{A}$

$$(1) \Rightarrow \frac{T\text{-}T_\infty}{T_0 - T_\infty} = e^{\left[\frac{-h}{C_\rho \times L_c \times \rho} \times t\right]}$$

$$\Rightarrow \frac{528 - 923}{313 - 923} = e^{\left[\frac{-22 \times t}{1050 \times 0.03 \times 580}\right]}$$ (4M)

$$\Rightarrow \boxed{t = 360.8\ s}$$

4

Alloy steel ball of 2 mm diameter heated to 800°C is quenched in a bath at 100°C. The material properties of the ball are K = 205 kJ/m hr K, ρ = 7860 kg/m³, C_ρ = 0.45 kJ/kg K, h = 150 KJ/ hr m² K. Determine (i) Temperature of ball after 10 second and (ii) Time for ball to cool to 400°C. (15 M)**-** BTL5

Answer: Refer Class Notes

Case (i) Temperature of ball after 10 sec.

For sphere,

Characteristic Length $L_c = \frac{R}{3}$

$$= \frac{0.006}{3}$$

(3M)

$$\boxed{L_c = 0.002 \text{ m}}$$

We know,

Biot number $B_i = \frac{hL_c}{K}$

$$= \frac{41.667 \times 0.002}{56.94}$$

$B_i = 1.46 \times 10^{-3} < 0.1$ (3M)

Biot number value is less than 0.1. So this is lumped heat analysis type problem.

For lumped parameter system,(2M)

$$\frac{T - T_\infty}{T_0 - T_\infty} = e^{\left[\frac{-hA}{C_\rho \times V \times \rho} \times t\right]} \quad \text{..........(1)}$$

[From HMT data book Page No.48]

We know,

Characteristics length $L_c = \frac{V}{A}$

$$(1) \Rightarrow \frac{T\text{-}T_\infty}{T_0 - T_\infty} = e^{\left[\frac{-h}{C_\rho \times L_c \times \rho} \times t\right]} \quad \text{..........(2)}$$

$$\Rightarrow \frac{T - 373}{1073 - 373} = e^{\left[\frac{-41.667}{450 \times 0.002 \times 7860} \times 10\right]}$$ (3M)

$$\Rightarrow \boxed{T = 1032.95 \text{ K}}$$

Case (ii) Time for ball to cool to 400°C

$$\therefore T = 400°C + 273 = 673\ K$$

$$(2) \Rightarrow \frac{T-T_\infty}{T_0 - T_\infty} = e^{\left[\frac{-h}{C_\rho \times L_c \times \rho}\times t\right]} \qquad ....(2)$$

$$\Rightarrow \frac{673\ -\ 373}{1073\ -\ 373} = e^{\left[\frac{-41.667}{450\times 0.002\times 7860}\times t\right]}$$

(4M)

$$\Rightarrow \ln\left[\frac{673\ -\ 373}{1073\ -\ 373}\right] = \frac{-41.667}{450\times 0.002\times 7860}\times t$$

$$\Rightarrow \boxed{t = 143.849\ s}$$

5 **A long steel cylinder 12 cm diameter and initially at 20°C is placed into furnace at 820°C with h = 140 W/m^{2}K. Calculate the time required for the axis temperature to reach 800°C. Also calculate the corresponding temperature at a radius of 5.4 cm at that time. Physical properties of steel are K = 21 W/mK, α = 6.11 × 10^{-6} m^2/s.** (15 M)-BTL5

Answer: Refer Class Notes

For Cylinder,

Characteristic Length $L_c = \frac{R}{2} = \frac{0.06}{2}$ (1M)

$$\boxed{L_c = 0.03\ m}$$

We know,

Biot number $B_i = \frac{hL_c}{K}$

$$= \frac{140\times 0.03}{21}$$

$$\Rightarrow \boxed{B_i = 0.2}$$

0.1 < B_i<100, So this is infinite solid type problem.(2M)

Infinite Solids

Case (i)

$$\left.\begin{array}{l}\text{Axis temperature}\\ \qquad\text{(or)}\\ \text{Centre line temperature}\end{array}\right\} T_0 = 800°C$$

T_o = 800°C + 273 = 1073 K

Time (t) ?

[Refer HMT data book Page No.61. Heisler's chart]

$$\text{Curve} = \frac{hR}{K}$$

$$= \frac{140\times\ 0.06}{21} = 0.4$$

$$\text{Y axis} = \frac{T_0 - T_\infty}{T_i - T_\infty}$$

$$= \frac{1073\text{ - }1093}{293\text{ - }1093}$$

$$\boxed{\text{Y axis} = 0.025}$$

Curve value is 0.4, Y axis 0.025, corresponding X axis value is 5.

$$\frac{T_0 - T_\infty}{T_i - T_\infty} = 0.025$$

$$\Rightarrow \quad \text{X axis} = \frac{\alpha t}{R^2} = 5$$

$$\Rightarrow \quad t = \frac{5\times(0.06)^2}{(6.11\times10^{-6})}$$ (6M)

$$\boxed{t = 2945.9\ s}$$

Case (ii)

Intermediate radius r – 5.4 cm = 0.054 m

[Refer HMT data book Page No.62]

$$\text{Curve} = \frac{r}{R} = \frac{0.054}{0.06} = 0.9$$

$$\text{X axis} = \frac{hR}{K}$$

$$= \frac{140\ \times\ 0.06}{21} = 0.4$$

Curve value is 0.9, X axis value is 0.4, and corresponding Y axis value is 0.84.

$$\Rightarrow \quad \text{Y axis} = \frac{T_r - T_\infty}{T_0 - T_\infty} = 0.84$$

	$\Rightarrow \quad \frac{T_r - T_\infty}{T_0 - T_\infty} = 0.84$ $\Rightarrow \quad \frac{T_r - 1093}{1073 - 1093} = 0.84$ (6M) $\Rightarrow \quad \boxed{T_r = 1076.2\ K}$ 1. Time required for the axis temperature to reach 800°C is 2945.9 s. 2. Temperature (T_r) at a radius of 5.4 cm is 1076.2 K

UNIT II CONVECTION

Free and Forced Convection - Hydrodynamic and Thermal Boundary Layer. Free and Forced Convection during external flow over Plates and Cylinders and Internal flow through tubes.

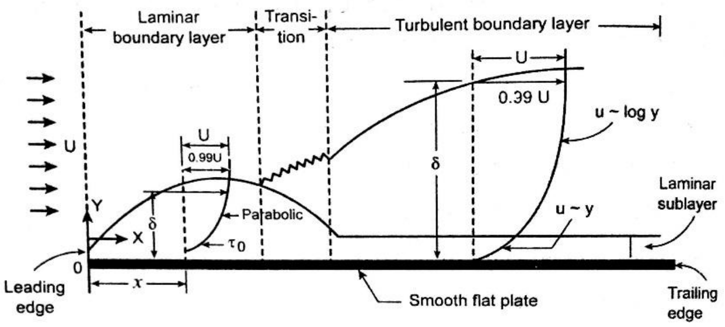
PART * A

Q.No.	Questions
1.	**Define Reynolds number (Re).** BTL1 It is defined as the ratio of inertia force to viscous force. $\text{Re} = \frac{\text{Inertia force}}{\text{Viscous force}}$
2	**Define Prandtl number (Pr).** BTL1 It is the ratio of the momentum diffusivity of the thermal diffusivity. $\text{Pr} = \frac{\text{Momentum diffusivity}}{\text{Thermal diffusivity}}$
3	**Define Nusselt number (Nu).** BTL1 It is defined as the ratio of the heat flow by convection process under an unit temperature gradient to the heat flow rate by conduction under an unit temperature gradient through a stationary thickness (L) of metre. Nusselt number (Nu) = $\frac{Q_{\text{conv}}}{Q_{\text{cond}}}$.
4	**What is Grashoff number?** BTL1 It is defined as the ratio of product of inertia force and buoyancy force to the square of viscous force. $\text{Gr} = \frac{\text{Inertia force} \times \text{Buyoyancy force}}{(\text{Viscous force})^2}$
5	**ExplainNewtonion and non – Newtonion fluids?** BTL2 The fluids which obey the Newton's Law of viscosity are called Newtonion fluids and those which do not obey are called non – newtonion fluids.
6	**What is meant by laminar flow and turbulent flow?** BTL2 **Laminar flow:** Laminar flow is sometimes called stream line flow. In this type of flow, the fluid moves in layers and each fluid particle follows a smooth continuous path. The fluid particles in each layer remain in an orderly sequence without mixing with each other. **Turbulent flow:** In addition to the laminar type of flow, a distinct irregular flow is frequency observed in nature. This type of flow is called turbulent flow. The path of any individual particle is zig – zag and irregular. Fig. shows the instantaneous velocity in laminar and turbulent flow.
7	**State Newton's law of convection.** BTL2 Heat transfer from the moving fluid to solid surface is given by the equationQ = h A $(T_w - T_\infty)$ **,**This equation is referred to as Newton's law of cooling. Where , h – Local heat transfer coefficient in

	W/m^2K, A – Surface area in m^2,T_w – Surface (or) Wall temperature in K, T_∞ - Temperature of fluid in K.
8	**Define free or natural convection.**(**AUMay2004,Dec2004,June 2006, May 2004**)BTL2 If the fluid motion is produced due to change in density resulting from temperature gradients, the mode of heat transfer is said to be free or natural convection.
9	**Define forced convection.(AU May 2004, Dec 2004, June 2006, May 2004)** BTL2 If the fluid motion is artificially created by means of an external force like a blower or fan, that type of heat transfer is known as forced convection.
10	**Define boundary layer thickness.** BTL2 The thickness of the boundary layer has been defined as the distance from the surface at which the local velocity or temperature reaches 99% of the external velocity or temperature.
11	**Give the form of equation used to calculate heat transfer for flow through cylindrical pipes.** BTL3 Nu = 0.023 $(Re)^{0.8}$ $(Pr)^n$, n = 0.4 for heating of fluids, n = 0.3 for cooling of fluids
12	**Name the dimensionless parameters used in forced convection.** BTL2 1. Reynolds number (Re) 2. Nusselt number (Nu) 3. Prandtl number (Pr)
13	**Define hydrodynamic boundary layer.** BTL2 In hydrodynamic boundary layer, velocity of the fluid is less than 99% of free stream velocity.
14	**Explain thermal boundary layer.** BTL2 In thermal boundary layer, temperature of the fluid is less than 99% of free stream velocity.
15	**Define Stanton number (St).** BTL1 It is the ratio of Nusselt number to the product of Reynolds number and Prandtl number. $St = \frac{Nu}{Re \times Pr}$
16	**Indicate the significance of boundary layer.** BTL2 In boundary layer concept the flow field over a body is divided into two regions: (i) A thin region near the body called the boundary layer where the velocity and the temperature gradients are large. (ii) The region outside the boundary layer where the velocity and the temperature gradients are very nearly equal to their free stream values.
17	**An electrically heated plate dissipates heat by convection at a rate of 8000 W/m^2 in to the ambient air at 25ºC. If the surface of the hot plate is at 125ºC, calculate the heat transfer coefficient for convection between the plate and air. (Nov 2018, Dec 2016, May 2013)**BTL 4. Heat Transfer Q=hA(Tw-Tα), 8000= h x 1 (398-298) = 80 W/m^2K.

<table>
<tr><td>18</td><td>

Sketch the boundary development of a plate.BTL 1



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<tr><td>19</td><td>

Define displacement thickness.BTL 2

The displacement thickness is the distance, measured perpendicular to the boundary, by which the free stream is displaced on account of formation of boundary layer.

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<tr><td>20</td><td>

Explainmomentum thickness? (Dec 2019, May 2017, Dec 2016, May 2014)BTL 2

The momentum thickness is defined as the distance through which the total loss of momentum per second be equal to if it were passing a stationary plate.

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<tr><td>21</td><td>

Define energy thickness. BTL 1

The energy thickness can be defined as the distance, measured perpendicular to the boundary of the solid body, by which the boundary should be displaced to compensate for the reduction in kinetic energy of the flowing fluid on account of boundary layer formation.

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Part-B

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<tr><td>1</td><td>

Air at 20°C, at a pressure of 1 bar is flowing over a flat plate at a velocity of 3 m/s. if the plate maintained at 60°C, calculate the heat transfer per unit width of the plate. Assuming the length of the plate along the flow of air is 2m. (13 M)-BTL5

Answer: Page 2.26-Dr.S.Senthil

Film temperature $T_f = \frac{T_w + T_\infty}{2}$

$= \frac{60+20}{2}$

$T_f = 40°C$

Properties of air at 40°C:

Density ρ = 1.129 Kg/m^3

Thermal conductivity K = $26.56 \times 10^{-3} W/mK$,

Kinematic viscosity v = $16.96 \times 10^{-6} m^2/s$.

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Prandtl number Pr = 0.699

We know,

Reynolds number $Re = \frac{UL}{v}$

$$= \frac{3 \times 2}{16.96 \times 10^{-6}}$$
$$= 35.377 \times 10^{4}$$

$$Re = 35.377 \times 10^{4} < 5 \times 10^{5}$$ (4 M)

Reynolds number value is less than 5×10^{5}, so this is laminar flow.

For flat plate, Laminar flow,

Local Nusselt Number $Nu_x = 0.332\ (Re)^{0.5}\ (Pr)^{0.333}$

$$Nu_x = 0.332\ (35.377 \times 10^{4})^{0.5} \times (0.699)^{0.333}$$
$$Nu_x = 175.27$$

We know that,

Local Nusselt Number $Nu_x = \frac{h_s \times L}{K}$

$$\Rightarrow 175.27 = \frac{h_s \times 2}{26.56 \times 10^{-3}}$$

Local heat transfer coefficient $h_x = 2.327\ W/m^2K$ (4 M)

We know, Average heat transfer coefficient $h = 2 \times h_x$

$h = 2 \times 2.327 \Rightarrow h = 4.65\ W/m^2K$

Heat transfer $Q = h\ A\ (T_w - T_\infty)$

$$= 4.65 \times 2\ (60 - 20)$$
$$[\therefore \text{Area} = \text{width} \times \text{length} = 1 \times 2 = 2]$$
$$Q = 372 \text{ Watts.}$$

(5 M)

2 **Air at 20°C at atmospheric pressure flows over a flat plate at a velocity of 3 m/s. if the plate is 1 m wide and 80°C, calculate the following at x = 300 mm. 1. Hydrodynamic boundary layer thickness, 2. Thermal boundary layer thickness, 3. Local friction coefficient,4. Average friction coefficient, 5. Local heat transfer coefficient, 6. Average heat transfer coefficient,7. Heat transfer.(13 M)**BTL5

Answer: Page 2.30-Dr.S.Senthil

Film temperature $T_f = \frac{T_w + T_\infty}{2}$

$= \frac{80+20}{2}$

$T_f = 50°C$

Properties of air at 50°C

Density ρ= 1.093 kg/m^3

Kinematic viscosity v = $17.95 \times 10^{-6} m^2/s$

Prandtl number Pr =0.698

Thermal conductivity K = $28.26 \times 10^{-3} W/mK$

We know, Reynolds number Re = $\frac{UL}{v}$

$$= \frac{3 \times 0.3}{17.95 \times 10^{-6}}$$

$$Re = 5.01 \times 10^4 < 5 \times 10^5$$ **(4 M)**

Since Re < 5 × 10^5, flow is laminar

For Flat plate, laminar flow,

1. Hydrodynamic boundary layer thickness:

$$\delta_{hx} = 5 \times x \times (Re)^{-0.5}$$

$$= 5 \times 0.3 \times (5.01 \times 10^4)^{-0.5}$$

$$\delta_{hx} = 6.7 \times 10^{-3} m$$ **(1 M)**

2. Thermal boundary layer thickness:

$$\delta_{TX} = \delta_{hx} (Pr)^{-0.333}$$

$$\Rightarrow \delta_{TX} = \left(6.7 \times 10^{-3}\right)(0.698)^{-0.333}$$

$$\delta_{TX} = 7.5 \times 10^{-3} m$$ **(1 M)**

3. Local Friction coefficient:

$$C_{fx} = 0.664 (Re)^{-0.5}$$

$$= 0.664\ (5.01 \times 10^4)^{-0.5}$$

$$C_{fx} = 2.96 \times 10^{-3}$$ **(1 M)**

4. Average friction coefficient:

$$\overline{C_{fL}} = 1.328\ (Re)^{-0.5}$$
$$= 1.328\ (5.01\times10^{4})^{-0.5}$$
$$= 5.9\times10^{-3}$$
$$\overline{C_{fL}} = 5.9\times10^{-3}$$ **(1 M)**

5. Local heat transfer coefficient (h_x):

Local Nusselt Number

$Nu_x = 0.332\ (Re)^{0.5}\ (Pr)^{0.333}$

$$= 0.332\ (5.01\times10^{4})\ (0.698)^{0.333}$$
$$Nu_x = 65.9$$

We know

Local Nusselt Number

$$Nu_x = \frac{h_x \times L}{K}$$
$$65.9 = \frac{h_x \times 0.3}{23.26\times10^{-3}} \quad [\because\ x = L = 0.3m]$$
$$\Rightarrow\ h_x = 6.20\ W/m^2K$$ **(1 M)**

$$\text{Local heat transfer coefficient } h_x = 6.20\ W/m^2K$$

6. Average heat transfer coefficient (h):

$$h = 2\times h_x$$
$$= 2\times 6.20$$
$$h = 12.41\ W/m^2K$$ **(2 M)**

7. Heat transfer:

We know that,

$$Q = h\ A(T_w - T_\infty)$$
$$= 12.41\times(1\times0.3)\ (80\text{-}20)$$
$$Q = 23.38\ \text{Watts}$$ **(2 M)**

3 **Air at 30°C, Flows over a flat plate at a velocity of 4 m/s. The plate measures 50 × 30 cm and is maintained at a uniform temperature of 90°C. Compare the heat loss from the plate when the air flows (a) Parallel to 50 cm, (b) Parallel to 30 cm, Also calculate the percentage of heat loss. (13 M)**BTL5

Answer: Page 2.55-Dr.S.Senthil

Film temperature $T_f = \frac{T_w + T_\infty}{2}$

$$= \frac{90+30}{2}$$

$T_f = 60°C$

Properties of air at 60°C,

$\rho = 1.060 \text{ Kg/m}^3$

$\nu = 18.97 \times 10^{-6} \text{m}^2/\text{s}$ (2 M)

$\Pr = 0.696$

$K = 28.96 \times 10^{-3} \text{ W/mK}$

Case (i) : When the flow is parallel to 50 cm.

Reynolds number $\text{Re} = \frac{UL}{v}$

$$= \frac{4 \times 0.50}{18.97 \times 10^{-6}}$$

$\text{Re} = 1.05 \times 10^5 < 5 \times 10^5$ (2 M)

Since $\text{Re} < 5 \times 10^5$, flow is laminar

Local nusselt number NUx = $0.332(\text{Re})^{0.5}(\text{Pr})^{0.333}$

$NU_x = 0.332 \left(1.05 \times 10^5\right)^{0.5} \times (0.696)^{0.333}$

Local nusseltnumberNU_x =95.35

We know

$$NU_x = \frac{h_x L}{K}$$

$95.35 = \frac{h_x \times 0.50}{28.96 \times 10^{-3}}$ (3 M)

Local heat transfer coefficient $h_x = 5.52 \text{ W/m}^2\text{K}$

We know

Average heat transfer coefficient $h = 2 \times h_x$ (2 M)

$$\Rightarrow h = 2 \times 5.52$$

$$h = 11.04 \text{ W/m}^2\text{K}$$

$$\text{Heat transfer } Q_1 = h\ A(T_w - T_\infty)$$

$$= 11.04 \times (0.5 \times 0.3) \times (90 - 30)$$

$$Q_1 = 99.36 \text{ W}$$

(1 mark)

Case (ii) : When the flow is parallel to 30 cm side.

Reynolds number Re = $\dfrac{UL}{v}$

$$= \frac{4 \times 0.3}{18.97 \times 10^{-6}}$$

$$\text{Re } = 6.3 \times 10^4 < 5 \times 10^5$$

Since $\text{Re} < 5 \times 10^5$, flow is laminar

For flat plate, laminar flow,

Local Nusselt Number

$$NU_x = 0.332\ (\text{Re})^{0.5} (0.696)^{0.333}$$

$$= 0.332\ (6.32 \times 10^4)^{0.5}\ (0.696)^{0.333}$$

$$NU_x = 74.008$$

We know that, $NU_x = \dfrac{h_x L}{K}$

$$74.008 = \frac{h_x \times 0.30}{28.96 \times 10^{-3}}$$

(1 M)

$$\Rightarrow h_x = 7.141 \text{ W/m}^2\text{K}$$

Local heat transfer coefficient $h_x = 7.141 \text{ W/m}^2\text{K}$

Average heat transfer coefficient h = 2×h_x

$h = 2 \times 7.14$

$h = 14.28\ \text{W/m}^2\text{K}$

We know

Heat transfer $Q_2 = h \times A \times (T_w - T_\infty)$

$= h \times L \times W\ (T_w - T_\infty)$

$= 14.28 \times 0.3 \times 0.5 \times (363 - 303)$

$Q_2 = 128.5\text{W}$ **(1 M)**

Case (iii):

$$\% \text{ heat loss} = \frac{Q_2 - Q_1}{Q_1} \times 100$$

$$= \frac{128.5\text{-}99.36}{99.36} \times 100 \quad \textbf{(1 M)}$$

% heat loss = 29.3%

4

Air at 290°C flows over a flat plate at a velocity of 6 m/s. The plate is 1m long and 0.5 m wide. The pressure of the air is 6 kN/m^2. If the plate is maintained at a temperature of 70°C, estimate the rate of heat removed from the plate. (13 M)(Nov 2018, Dec 2016, May 2013)BTL5

Answer: Page 2.63-Dr.S.Senthil

We know , Film temperature $T_f = \dfrac{T_w + T_\infty}{2}$

$= \dfrac{70 + 290}{2}$

$T_f = 180°\text{C}$

Properties of air at 180°C (At atmospheric pressure)

$\rho = 0.799\ \text{Kg/m}^3$

$\nu = 32.49 \times 10^{-6}\ \text{m}^2/\text{s}$

$\text{Pr} = 0.681$

$K = 37.80 \times 10^{-3}\ \text{W/mK}$

Kinematic viscosity $\nu = \nu_{atm} \times \dfrac{P_{atm}}{P_{given}}$ (2 M)

$$\Rightarrow \nu = 32.49 \times 10^{-6} \frac{1\,\text{bar}}{6 \times 10^{3}\text{N/m}^{2}}$$

$$\left[\because \text{ Atmospheric pressure = 1 bar}\right]$$

$$= 32.49 \times 10^{-6} \times \frac{10^{5}\text{N/m}^{2}}{6 \times 10^{3}\text{N/m}^{3}}$$

$$\left[\because \text{ 1 bar = } 1 \times 10^{5}\text{N/m}^{2}\right]$$

$$\text{Kinematic viscosity v = } 5.145 \times 10^{-4}\text{m}^{2}\text{/s.}$$

We know,

Reynolds number $\text{Re} = \frac{\text{UL}}{\text{v}}$

$$= \frac{6 \times 1}{5.145 \times 10^{-4}}$$

$$\text{Re} = 1.10 \times 10^{4} - 5 \times 10^{5}$$

Since Re< 5×10^{5}, flow is laminar **(4 M)**

For plate, laminar flow,

Local nusselt number

$$\text{NU}_{x} = 0.332\ (\text{Re})^{0.5}(\text{Pr})^{0.333}$$

$$= 0.332\ (1.10 \times 10^{4})^{0.5}\ (0.681)^{0.333}$$

$$\text{NU}_{x} = 30.63$$

We know, $\text{NU}_x = \frac{\text{h}_{x}\text{L}}{\text{K}}$

$$30.63 = \frac{\text{h}_{x} \times 1}{37.80 \times 10^{-3}} \qquad [\because \text{L = 1 m}]$$

Local heat transfer coefficient $\text{h}_{x} = 1.15\ \text{W/m}^{2}\text{K}$ **(2 M)**

We know

Average heat transfer coefficient h = 2×h_x

$$\text{h} = 2 \times 1.15$$

$$\text{h} = 2.31\ \text{W/m}^{2}\text{K}$$

(2 M)

	We know Heat transferred $Q = h\ A\ (T_\infty - T_w)$ $= 2.31 \times (1 \times 0.5) \times (563 - 343)$ $Q = 254.1\ W$ Heat transfer from both side of the plate = 2 × 254.1= 508.2 W. **(3 M)**
5	**Air at 15°C, 30 km/h flows over a cylinder of 400 mm diameter and 1500 mm height with surface temperature of 45°C. Calculate the heat loss.(13 M)(Dec 2019, May 2017, Dec 2016, May 2014)**BTL5 **Answer: Page 2.117-Dr.S.Senthil** We know Film temperature $T_f = \frac{T_w + T_\infty}{2}$ $\boxed{T_f = 30°C}$ Reynolds Number Re = $\frac{UD}{v}$ $= \frac{8.33 \times 0.4}{16 \times 10^{-6}}$ $\boxed{Re_D = 2.08 \times 10^5}$ **(4 M)** We know Nusselt Number Nu = C $(Re)^m$ $(Pr)^{0.333}$ $\Rightarrow$ NU = 0.0266 × $(2.08 \times 10^5)^{0.805}$× $(0.701)^{0.333}$ $\boxed{NU = 451.3}$ We know that, Nusselt Number NU = $\frac{hD}{K}$ $\Rightarrow\ 451.3 = \frac{h \times 0.4}{26.75 \times 10^{-3}}$ $\Rightarrow\ h = 30.18\ W/m^2K$ **(4 M)**

$$\boxed{\text{Heat transfer coefficient h} = 30.18\ \text{W/m}^2\text{K}}$$

$$\text{Heat transfer Q} = \text{hA}\ (T_w - T_\infty)$$

$$= h \times \pi \times D \times L \times (T_w - T_\infty)$$

$$[\because\ A = \pi DL]$$

$$= 30.18 \times \pi \times 0.4 \times 1.5 \times (45\ \text{-}15)$$

$$\boxed{Q = 1706.6\ \text{W}}$$

(5 M)

6 **Air at 30°C, 0.2 m/s flows across a 120W electric bulb at 130°C. Find heat transfer and power lost due to convection if bulb diameter is 70 mm.(13 M)(May 2019, Dec 2015)**BTL5

Answer: Page 2.118-Dr.S.Senthil

1. Film temperature $T_f = \frac{T_w + T_\infty}{2}$

$$= \frac{130 + 30}{2}$$

$T_f = 80°C$

Properties of air at 80°C:

ρ = 1 Kg/m^3

$\nu = 21.09 \times 10^{-6}\ m^2/s$

Pr = 0.692

K = 30.47×10^{-3} W/mK

We know

Reynolds number Re = $\frac{UD}{\nu}$

$$= \frac{0.2 \times 0.070}{21.09 \times 10^{-3}} = 663.82$$

$$Re = 663.82$$

(4 M)

We know

Nusselt Number Nu = 0.37 (Re)$^{0.6}$

= 0.37 (663.82)$^{0.6}$

Nu = 18.25

We know

	Nusselt number $Nu = \frac{hD}{K}$ $\Rightarrow 18.25 = \frac{h \times 0.070}{30.47 \times 10^{-3}}$ $\Rightarrow h = 7.94\ W/m^2K$ **(4 M)** Heat transfer coefficient h = 7.94 W/m^{2}K We know Heat transfer $Q_2 = h\ A\ (T_w - T_\infty)$ $= h \times 4\pi r^2\ [T_w - T_\infty]\ [\because A = 4\pi r^2]$ $= 7.94 \times 4 \times \pi \times \left(\frac{0.070}{2}\right)^2 \times (130 - 30)$ Heat transfer $Q_2 = 12.22\ W$ 2. % of heat lost = $\frac{Q_2}{Q_1} \times 100$ $= \frac{12.22}{120} \times 100$ $= 10.18\%$ **(5 M)**
7	**Air at 40°C flows over a tube with a velocity of 30 m/s. The tube surface temperature is 120°C. Calculate the heat transfer for the following cases. 1. Tube could be square with a side of 6 cm.2. Tube is circular cylinder of diameter 6 cm.(13 M)** BTL 5 **Answer: Page 2.120-Dr.S.Senthil** We know, Film temperature $T_f = \frac{T_w - T_\infty}{2}$ $= \frac{120 + 40}{2}$

$T_f = 80°C$

Properties of air at 80°C:

ρ = 1 Kg/m^3

$\nu = 21.09 \times 10^{-6}$ m^2/s **(2 M)**

Pr = 0.692

K = 30.47 × 10^{-3} W/mK

Case (i): Tube is considered as square of side 6 cm

i.e., L = 6cm = 0.06m

Reynolds number Re = $\frac{UL}{v}$

$$= \frac{30 \times 0.06}{21.09 \times 10^{-6}}$$

$Re = 0.853 \times 10^5$

Nusselt Number Nu = $C \times (Re)^n (Pr)^{0.333}$

For square, n = 0.675

C = 0.092 (4 M)

$\Rightarrow$ Nu = 0.092 $(0.853 \times 10^5)^{0.675} \times (0.692)^{0.333}$

$\Rightarrow$ Nu = 173.3

We know that, NU = $\frac{hL}{K}$

$$173.3 = \frac{h \times 0.06}{30.47 \times 10^{-3}}$$

Heat transfer coefficient h = 88 W/m^{2}K

Case (ii)

Tube diameter D = 6cm = 0.06 m

Reynolds number Re = $\frac{UD}{\nu}$

$$= \frac{30 \times 0.06}{21.09 \times 10^{-6}}$$ (2 M)

$Re = 0.853 \times 10^5$

Nusselt number Nu = C $(Re_D)^m (Pr)^{0.333}$

Re value is 0.853 × 10^5, so corresponding C and m values are 0.0266 and 0.805 respectively.

$$\Rightarrow \text{Nu} = 0.0266 \times (0.853 \times 10^5)^{0.805} \times (0.692)^{0.333}$$

Nu = 219.3 (3 M)

$$\text{We know Nu} = \frac{hD}{K}$$

$$\Rightarrow 219.3 \; \frac{h \times 0.06}{30.47 \times 10^{-3}}$$

$$\Rightarrow h = 111.3 \text{ W/m}^2\text{K}$$

$\Rightarrow$ Heat transfer coefficient h = 111.3 W/m^{2}K **(2 M)**

8

When 0.6 Kg of water per minute is passed through a tube of 2 cm diameter, it is found to be heated from 20°C to 60°C. The heating is achieved by condensing steam on the surface of the tube and subsequently the surface temperature of the tube is maintained at 90°C. Determine the length of the tube required for fully developed flow. (13 M) (Dec 2016) BTL5

Answer: Page 2.131-Dr.S.Senthil

Bulk mean temperature $T_m = \frac{T_{mi} + T_{mo}}{2}$

$$= \frac{20 + 60}{2}$$

$$T_m = 40°C$$

Properties of water at 40°C:

ρ = 995 Kg/m^3

$\nu = 0.657 \times 10^{-6} \text{m}^2/\text{s}$

Pr = 4.340

K = 628×10^{-3} W/mK

$C_P = 4.178$ KJ/KgK = 4178 J/KgK

Mass flow rate m = ρ A U

$$\Rightarrow U = \frac{m}{\rho A}$$

$$= \frac{0.01}{995 \times \frac{\pi}{4}(0.02)^2}$$

Velocity U = 0.031 m/s (4 M)

Let us first determine the type of flow

$$\text{Re} = \frac{UD}{\nu}$$

	$\Rightarrow Re = \frac{0.031\times 0.02}{0.657\times 10^{-6}}$ $Re = 943.6$ (2 M) Since Re < 2300, flow is laminar For laminar flow, Nusselt number NU = 3.66 We know $NU = \frac{hD}{K}$ $\Rightarrow 3.66 = \frac{h\times 0.02}{628\times 10^{-3}}$ $\Rightarrow h = 114.9 W/m^2K$ Heat transfer $Q = mC_P\Delta t$ $= mC_P(T_{mo} - T_{mi})$ $= 0.01\times 4178\times (60\text{-}20)$ Q = 1671.2 W **(2 M)** We know that $Q = h A \Delta T$ $= h\times \pi \times D\times L\times (T_w - T_m)$ $= 1671.2 = 114.9\times \pi \times 0.02\times L\times (90\text{-}40)$ L = 4.62m **(5 M)**
9	**Water at 50°C enters 50 mm diameter and 4 m long tube with a velocity of 0.8 m/s. The tube wall is maintained at a constant temperature of 90°C. Determine the heat transfer coefficient and the total amount of heat transferred if exist water temperature is 70°C.(13 M)** BTL5 **Answer: Page 2.133-Dr.S.Senthil** Bulk mean temperature $T_m = \frac{T_{mi} + T_{mo}}{2}$

$= \frac{50+70}{2}$

$T_m = 60°C$

Properties of water at 60°C:

ρ = 985 Kg/m^3

ν = 0.478 × 10^{-6}m^2 / s

Pr = 3.020

K = 651.3×10^{-3}W/mK

Let us first determine the type of flow:

$$Re = \frac{UD}{\nu}$$

$$= \frac{0.8 \times 0.05}{0.478 \times 10^{-6}}$$

$$Re = 8.36 \times 10^4$$

Since Re > 2300, flow is turbulent **(4 M)**

$$\frac{L}{D} = \frac{4}{0.05} = 80$$

$$\frac{L}{D} = 80 > 60$$

$$Re = 8.36 \times 10^4 > 10{,}000$$

$$Pr = 3.020 \Rightarrow 0.6 < Pr < 160$$

$\frac{L}{D}$ ratio is greater than 60. Re value is greater than 10,000 and Pr value is in between 0.6 and 160 so, (3 M)

Nusselt number NU = 0.023 (Re)$^{0.8}$ (Pr)^n

[Inlet temperature 50°C, Exit temperature 70°C

⇒ Heating Process, So n = 0.4]

$$\Rightarrow Nu = 0.023 \times (8.36 \times 10^4)^{0.8} \times (3.020)^{0.4}$$

$$Nu = 310$$

We know that $Nu = \frac{hD}{K}$

$$310 = \frac{h \times 0.05}{651.3 \times 10^{-3}}$$

Heat transfer coefficient h = 4039.3 W/m²K **(2 M)**

Heat transfer Q = h A ($T_w - T_m$)

$$= h \times \pi \times D \times L \times (T_w - T_m)$$

$$= 4093.3 \times \pi \times 0.05 \times 4 \times (90 - 60)$$

$$Q = 76139 \text{ W}$$

(4 M)

10

Air at 333K, 1.5 bar pressure, flow through 12 cm diameter tube. The surface temperature of the tube is maintained at 400°K and mass flow rate is 75 kg/hr. Calculate the heat transfer rate for 1.5 m length of the tube. (13 M) BTL5

Answer: Page 2.143-Dr.S.Senthil

Properties of air at 60°C

$\rho = 1.060 \text{ Kg/m}^3$

$\nu = 18.97 \times 10^{-6} \text{ m}^2/\text{s}$

Pr = 0.696

K = 28.96×10^{-3} W/mK

(2 M)

Reynolds number $Re = \frac{UD}{\nu}$

We know

Mass flow rate m p Δ U

$$0.020 = 1.060 \times \frac{\pi}{4} \times D^2 \times U$$

$$\Rightarrow 0.020 = 1.060 \times \frac{\pi}{4} \times (0.12)^2 \times U$$

$$\Rightarrow U = 1.668 \text{ m/s}$$

$$(1) \Rightarrow Re = \frac{UD}{\nu}$$

$$= \frac{1.668 \times 0.12}{18.97 \times 10^{-6}}$$

$$Re = 10551.3$$

(2 M)

Since Re > 2300, so flow is turbulent

For turbulent flow, general equation is (Re>10000)

$$Nu = 0.023 \times (Re)^{0.8} \times (0.696)^{0.4}$$

Nu = 32.9 (3 M)

We know $Nu = \frac{hD}{K}$

$\Rightarrow\ 32.9 = \frac{h \times 0.12}{28.96 \times 10^{-3}}$

$\Rightarrow\ h = 7.94\ W/m^2K$

Heat transfer rate $Q = h\ A\ (T_w - T_m)$

$= h \times (\pi \times D \times L) \times (T_w - T_m)$

$= 7.94 \times (\pi \times 0.12 \times 1.5) \times (127 - 60)$

$Q = 300.82\ W$ **(3+3 M)**

A vertical plate of 0.7 m wide and 1.2 m height maintained at a temperature of 90ºC in a room at 30ºC. Calculate the convective heat loss.(13 M) BTL4

Answer: Page 2.168-Dr.S.Senthil

Properties of air at T_f=60ºC(2M)

$Gr = \frac{g\beta L^3 \Delta T}{\vartheta^2} = 8.4\ x\ 10^9$ (2M)

$Gr.Pr$ =5.9 x $10^9 > 10^9$ Turbulent flow (2M)

Nusselt number, Nu = 0.10 $(Gr.Pr)^{0.333}$ =179.3 (2M)

Nu = hl/K ➔ h=4.32 W/m^2K (2M)

Heat loss Q = hA(Tw-Tα)=218.16 W (3M)

Part-C

1 **For a particular engine, the underside of the crank case can be idealized as a flat plat measuring 80 cm × 20 cm. The engine runs at 80 km/hr and the crank case is cooled by air flowing past it at the same speed. Calculate the loss of heat from the crank case surface of temperature 75°C to the ambient air temperature 25°C. Assume the boundary layer becomes turbulent from the loading edge itself.(15 M)(Nov 2018, Dec 2016, May 2013)**BTL5

Answer: Page 2.108-Dr.S.Senthil

1. Heat loss

Film temperature $T_f = \frac{T_w + T_\infty}{2} = \frac{75+25}{2}$

$T_f = 50°C$

Properties of air at 50°C:

ρ = 1.093 Kg/m^3 (2 M)

$\nu = 17.95 \times 10^{-6}\ m^2/s$

$Pr = 0.698$

$K = 28.26 \times 10^{-3}$ W/mK

We know

Reynolds number $Re = \frac{UL}{v}$

$= \frac{22.22 \times 0.8}{17.95 \times 10^{-6}}$ [$\because$ L = 0.8m]

$Re = 9 \times 10^5$

$Re = 9 \times 10^5 > 5 \times 10^5$

Since Re>5×10^5, Flow is turbulent **(2 M)**

Local Nusselt number} $NU_x = 0.0296\ (Re)^{0.8}\ (Pt)^{0.333}$

$NU_x = 1524.6$

We know that, $NU_x = \frac{h_x L}{K}$

$1524.6 = \frac{h_x \times 0.8}{28.26 \times 10^{-3}}$ [$\because$ L = 0.8m]

$h_x = 53.85$ W/m^{2}K **(5 M)**

Local heat transfer coefficient} h_x= 53.85 W/m^{2}K

For turbulent flow, flat plate

Average heat transfer coefficient} h = 1.24 h_x

h = 1.24 × 53.85 **(3 M)**

h = 66.78 W/m^{2}K

We know,

Heat loss $Q = h\ A\ (T_w - T_\infty)$

<table>
<tr><td></td><td>= 66.78 × 0.16 (75 – 25)
Q = 534.2 W (3 M)</td></tr>
<tr><td>2</td><td>Air at 30°C, 6 m/s flows over a rectangular section of size 300 × 800 mm. Calculate the heat leakage per meter length per unit temperature difference.(15 M) BTL5
Answer: Page 2.140-Dr.S.Senthil
:
Properties of air at 30°C
ρ = 1.165 Kg/m^3
$\nu = 16\times10^{-4}\ \text{m}^2/\text{s}$
$\text{Pr} = 0.701$
$\text{K} = 26.75\times10^{-3}\text{W/mK}$
Equivalent diameter for 300 × 800 mm^2 cross section is given by
$$D_e = \frac{4A}{P} = \frac{4\times(0.3\times0.8)}{2\ (0.3+0.8)}$$
Where P - Perimeter = 2 (L+W)
$\Rightarrow\ D_e = 0.436\ \text{m}$ (3 M)
$$\text{Reynolds Number Re} = \frac{UD_e}{\nu}$$
$$= \frac{6\times0.436}{16\times10^{-6}}$$
$\text{Re} = 16.3\times10^4$ (3 M)
Since Re > 2300, flow is turbulent.
For turbulent flow general equation is (Re > 10000)
Nu = 0.023 $(\text{Re})^{0.8}$ $(\text{Pr})^{n}$
Assuming the pipe wall temperature to be higher than a temperature. So heating process ⇒ n = 0.4
$\Rightarrow\ \text{Nu} = 0.023\ (16.3\times10^4)^{0.8}(0.701)^{0.4}$
$\text{Nu} = 294.96$
We know</td></tr>
</table>

Nusselt Number $Nu = \frac{hD_e}{K}$

$$\Rightarrow 294.96 = \frac{h \times 0.436}{26.75 \times 10^{-3}}$$

Heat transfer coefficient ⇒ $h = 18.09\ W/m^2K$ **(5 M)**

Heat leakage per unit per length per unit temperature difference

$Q = h\ P$

$$= 18.09 \times [2 \times (0.3 + 0.8]$$

$Q = 39.79\ W$ **(4 M)**

3

250 Kg/hr of air are cooled from 100°C to 30°C by flowing through a 3.5 cm inner diameter pipe coil bent in to a helix of 0.6 m diameter. Calculate the value of air side heat transfer coefficient if the properties of air at 65°C are K = 0.0298 W/mK ;μ = 0.003 Kg/hr – m ;Pr = 0.7 ;ρ = 1.044 Kg/m^3.(15 M) BTL5

Answer: Page 2.150-Dr.S.Senthil

Reynolds Number $Re = \frac{UD}{\nu}$

Kinematic viscosity $\nu = \frac{\mu}{\rho}$

$$\frac{\frac{0.003}{3600} Kg/s - m}{1.044\ Kg/m^3}$$

$$v = 7.98 \times 10^{-7}\ m^2/s$$ (2 M)

Mass flow rate in = ρ A U

$$0.056 = 1.044 \times \frac{\pi}{4} \times D^2 \times U$$

$$\Rightarrow U = 55.7\ m/s$$

$$(1) \Rightarrow Re = \frac{UD}{\nu}$$

$$= \frac{55.7 \times 0.035}{7.98 \times 10^{-7}}$$

$Re = 2.44 \times 10^6$ **(3 M)**

<table>
<tr><td></td><td>

$Nu = 0.023 \times (Re)^{0.8} \times (Pr)^{0.3}$

This is cooling process, so n = 0.3

$\Rightarrow$ Nu = $0.023 \times (2.44 \times 10^{6})^{0.8} \times (0.7)^{0.3}$ **(4 M)**

Nu = 2661.7

We know that, $Nu = \frac{hD}{K}$

$2661.7 = \frac{h \times 0.035}{0.0298}$

Heat transfer coefficient h = 2266.2 W/m^{2}K **(4 M)**

</td></tr>
<tr><td>4</td><td>

Engine oil flows through a 50 mm diameter tube at an average temperature of 147°C. The flow velocity is 80 cm/s. Calculate the average heat transfer coefficient if the tube wall is maintained at a temperature of 200°C and it is 2 m long. (15 M)BTL5

Answer: Page 2.154-Dr.S.Senthil

Properties of engine oil at 147°C

Reynolds number Re = $\frac{UD}{\nu}$

$= \frac{0.8 \times 0.05}{7 \times 10^{-6}}$

Re = 5714.2 **(5 M)**

Since Re < 2300 flow is turbulent

$\frac{L}{D} = \frac{2}{0.050} = 40$

$10 < \frac{L}{D} < 400$

For turbulent flow, (Re < 10000)

</td></tr>
</table>

	Nusselt number $Nu = 0.036\,(Re)^{0.8}(Pr)^{0.33}\left(\frac{D}{L}\right)^{0.055}$ $Nu = 0.036\ (5714.2)^{0.8} \times (116)^{0.33} \times \left(\frac{0.050}{2}\right)^{0.055}$ $Nu = 142.8$ We know $Nu = \frac{hD}{K}$ $\Rightarrow\ 142.8 = \frac{h \times 0.050}{133.8\ \times 10^{-3}}$ $\Rightarrow\ h = 382.3\ W/m^2K$ **(5+5 M)**
5	**A thin 100 cm long and 10 cm wide horizontal plate is maintained at a uniform temperature of 150°C in a long tank full of water at 75°C. Estimate the rate of heat to be supplied to the plate to maintain constant plate temperature as heat is dissipated from either side of the plate.** (15M) BTL4 **Answer: Page 2.210-Dr.S.Senthil** Properties of air at T_f=112.5ºC(2M) $Gr = \frac{g\beta Lc^3\Delta T}{\vartheta^2} = 1.0853\ x\ 10^9$ (2M) $Gr.Pr$ =1.682 x $10^9 > 10^9$Gr.Pr values lies between 8x10^6<Gr.Pr<10^{11}(2M) For horizontal plate, upper surface heated, Nusselt number, Nu = 0.15 $(Gr.Pr)^{0.333}$ =177.13 (1M) Nu=$h_u l_c$/K ➔ h=2419.7W/m^2K (2M) For horizontal plate, lower surface heated, Nusselt number, Nu = 0.27 $(Gr.Pr)^{0.25}$ =54.68 (1M) Nu=$h_l l_c$/K ➔h=746.94 W/m^2K (2M) Heat loss Q = (h_u+h_l)A(Tw-Tα)=(h_u+h_l)(WxL)(Tw-Tα)=23749.8 W (3M)

UNIT III PHASE CHANGE HEAT TRANSFER AND HEAT EXCHANGERS	
Nusselt's theory of condensation - Regimes of Pool boiling and Flow boiling. Correlations in boiling and condensation. Heat Exchanger Types - Overall Heat Transfer Coefficient – Fouling Factors - Analysis – LMTD method - NTU method.	
PART * A	
Q.No.	**Questions**
1.	**Define boiling.** BTL1 The change of phase from liquid to vapour state is known as boiling.
2	**What is meant by condensation?** BTL2 The change of phase from vapour to liquid state is known as condensation.
3	**Give the applications of boiling and condensation.** BTL2 Boiling and condensation process finds wide applications as mentioned below. 1. Thermal and nuclear power plant. 2. Refrigerating systems 3. Process of heating and cooling Air conditioning systems
4	**Define pool boiling.** BTL2 If heat is added to a liquid from a submerged solid surface, the boiling process referred to as pool boiling. In this case the liquid above the hot surface is essentially stagnant and its motion near the surface is due to free convection and mixing induced by bubble growth and detachment.
5	**What are the modes of condensation?** BTL2 There are two modes of condensation 1. Film wise condensation 2. Drop wise condensation
6	**What is meant by Film wise condensation?[(Dec 2016, May 2015)**BTL2 The liquid condensate wets the solid surface, spreads out and forms a continuous film over the entire surface is known as film wise condensation.
7	**Write short note on drop wise condensation. [April 2000 MU Oct 2000 MU]** BTL2 In drop wise condensation the vapour condenses into small liquid droplets of various sizes which fall down the surface in a random fashion.
8	**What is heat exchanger?** BTL2

	A heat exchanger is defined as an equipment which transfers the heat from a hot fluid to a cold fluid.
9	**Give classifications of heat exchanger.**BTL2 The types of heat exchangers are as follows 1. Direct contact heat exchangers 2. Indirect contact heat exchangers 3. Surface heat exchangers 4. Parallel flow heat exchangers 5. Counter flow heat exchangers 6. Cross flow heat exchangers 7. Shell and tube heat exchangers 8. Compact heat exchangers.
10	**What is meant by Direct heat exchanger (or) open heat exchanger?** BTL2 In direct contact heat exchanger, the heat exchange takes place by direct mixing of hot and cold fluids.
11	**What is meant by Indirect contact heat exchanger?** BTL2 In this type of heat exchangers, the transfer of heat between two fluids could be carried out by transmission through a wall which separates the two fluids.
12	**What is meant by Regenerators?(Dec 2019, May 2017, Dec 2016, May 2014)** BTL2 In this type of heat exchangers, hot and cold fluids flow alternately through the same space.Examples: IC engines, gas turbines.
13	**Define recuperators (or) surface heat exchangers.**BTL2 This is the most common type of heat exchangers in which the hot and cold fluid do not come into direct contact with each other but are separated by a tube wall or a surface.
14	**What is meant by parallel flow heat exchanger?** BTL2 In this type of heat exchanger, hot and cold fluids move in the same direction.
15	**What is meant by counter flow heat exchanger?** BTL2 In this type of heat exchanger hot and cold fluids move in parallel but opposite directions.
16	**What is meant by cross flow heat exchanger?** BTL2 In this type of heat exchanger, hot and cold fluids move at right angles to each other.
17	**What is shell and tube heat exchanger?** BTL2 In this type of heat exchanger, one of the fluids move through a bundle of tubes enclosed by a shell. The other fluid is forced through the shell and it moves over the outside surface of the

	tubes.
18	**Define compact heat exchangers. (Dec 2016, May 2015)** BTL2 There are many special purpose heat exchangers called compact heat exchangers. They are generally employed when convective heat transfer coefficient associated with one of the fluids is much smaller than that associated with the other fluid.
19	**What is meant by LMTD?** BTL2 We know that the temperature difference between the hot and cold fluids in the heat exchanger varies from point in addition various modes of heat transfer are involved. Therefore based on concept of appropriate mean temperature difference, also called logarithmic mean temperature difference, also called logarithmic mean temperature difference, the total heat transfer rate in the heat exchanger is expressed as Q = U A (ΔT)m , Where , U – Overall heat transfer coefficient W/m^2K A – Area m^2 , $(\Delta T)_m$ – Logarithmic mean temperature difference
20	**What is meant by Fouling factor?** BTL2 We know the surfaces of a heat exchangers do not remain clean after it has been in use for some time. The surfaces become fouled with scaling or deposits. The effect of these deposits the value of overall heat transfer coefficient. This effect is taken care of by introducing an additional thermal resistance called the fouling resistance.
Part- B	
1	**Water is to be boiled at atmospheric pressure in a polished copper pan by means of an electric heater. The diameter of the pan is 0.38 m and is kept at 115°C. Calculate the following, 1. Power required to boil the water, 2. Rate of evaporation, 3. Critical heat flux. (13 M)**BTL4 **Answer: Page 3.7-Dr.S.Senthil** We know saturation temperature of water is 100°C i.e. $\boxed{T_{sat} = 100°C}$ Properties of water at 100°C (From HMT data book Page No.13)

Density ρ_1 = 961 kg/m^3

Kinematic viscosity $\nu = 0.293 \times 10^{-6}\ \text{m}^2/\text{s}$

Prandtl number $P_r = 1.740$

Specific heat cpl = 4.216 kj/kg K = 4216/Kg K

Dynamic viscosity $\mu_1 = \rho_1 \times \nu$

$$= 961 \times 0.293 \times 10^{-6}$$

$$\mu_1 = 281.57 \times 10^{-6} \text{Ns/m}^2$$

From steam table R.S. Khurmi Steam table Page No.4 (1 M)

At 100°C, Enthalpy of evaporation hfg = 2256.9 kj/kg, hfg = 2256.9 × 10^3 j/kg

Specific volume of vapour, vg = 1.673 m^3/kg

$$\rho v = \frac{1}{vg}$$

Density of vapour, $\frac{1}{1.673}$

$$\boxed{\rho_v = 0.597\ \text{kg}/\text{m}^3}$$

$\Delta T =$ Excess temperature = $T_w - T_{sat} = 115^\circ - 100 = 15^\circ C$

$\Delta T = 15^\circ C < 50^\circ C$. So this process is nucleate pool boiling.

1. Power required to boil the water.

For nucleate boiling

$$\text{Heat flux } \frac{Q}{a} = \mu l \times hfg \left|\frac{g \times (\rho_1 - \rho_v)}{\sigma}\right| \times \left|\frac{Cpl \times \Delta T}{Csf \times hfgP_r^{1.7}}\right|^3$$

$$(1) \Rightarrow \frac{Q}{A} = 281.57 \times 10^{-6} \times 2256.9 \times 10^3$$

$$\left|\frac{9.81\times961-597}{58.8\times10^{-3}}\right|^{0.5}$$

$$\left|\frac{4216\times\Delta T}{.013\times2256.9\times10^{3}\times(1.74)^{1.7}}\right|^{3}$$

Heat flux $\frac{Q}{A}=151.1\times10^{3}\ \text{W/m}^{2}$

Heat transfer Q = $151.1\times10^{3}\times A$

$=151.1\times10^{3}\times\frac{\pi}{4}d^{2}$

$=\ 151.1\times10^{3}\times\frac{\pi}{4}(0.38)^{2}$

$Q=17.1\times10^{3}\ W$

Q = 17.1×10^{3} = p

$$\boxed{\text{power} = 17.1\times10^{3}\ W}$$ (4 M)

2. Rate of evaporation (m)

We know heat transferred

Q = m ×hfg

$$m=\frac{Q}{hfg}=\frac{17.1\times10^{3}}{2256.9\times10^{3}}$$ (4 M)

$$\boxed{m=.0075\ kg/s}$$

3. Critical heat flux

We know for nucleate pool boiling. Critical heat flux

$$\left|\frac{Q}{A}=0.18\ hfg\times\rho\nu\ \left|\frac{\sigma\times g\times(\rho l\ \text{-}\ \rho\nu)}{\rho_{v}^{2}}\right|0.25\right.$$

From HMT data book Page No.142

$$0.18\times2256.9\times10^{3}\times0.597$$

$$\left|\frac{58.8\times10^{-3}\times9.81\times961-.597}{.597^{2}}\right|^{0.25}$$

$$\frac{Q}{A}=1.52\times10^{6}\ \text{w/m}^{2}$$

(4 M)

$$\boxed{\text{Critical Heat flux q = }\frac{Q}{A}1.52\times10^{6}\,\text{w/m}^{2}}$$

2

Water is boiled at the rate of 24 kg/h in a polished copper pan, 300 mm in diameter, at atmospheric pressure. Assuming nucleate boiling conditions calculate the temperature of the bottom surface of the pan. (13 M) (Dec 2016) BTL4

Answer: Page 3.11-Dr.S.Senthil

We know saturation temperature of water is 100°C

i.e. T_{sat} = 100°C

Properties of water at 100°C

From HMT data book Page No.13

Density ρl = 961 kg/m^3

Kinematic viscosity v = $0.293\times10^{-6}\ m^2/s$

Prandtl number $P_r - 1.740$

Specific heat Cpl = 4.216 kj/kg K = 4216 j/kg K

Dynamic viscosity $\mu l = \rho l \times v$

$= 961\times0.293\times10^{-6}$

$$\boxed{\mu L = 281.57\times10^{-6}\ \text{Ns/m}^2}$$

From steam table (R.S. Khumi Steam table Page No.4)

At 100°C

Enthalpy of evaporation hfg = 2256.9 kj/kg

$$\boxed{\text{hfg} = 2256.9\times10^{3}\ \text{j/kg}}$$

Specific volume of vapour, Vg = 1.673 m^3/kg

$$\rho v = \frac{1}{vg}$$

Density of vapour, $\frac{1}{1.673}$ (3 M)

$$\boxed{\rho v = 0.597\ \text{kg/m}^3}$$

For nucleate boiling

$$\text{Heat flux } \frac{Q}{A} = \mu l \times hfg \left|\frac{g \times (\rho_l - \rho_v)}{\sigma}\right| \times \left|\frac{Cpl \times \Delta T}{Csf \times hfgP_r^{1.7}}\right|^3$$

We know transferred Q = m × hfg

Heat transferred Q = m × hfg.

$$\frac{Q}{A} = \frac{mhg}{A}$$

$$\frac{Q}{A} = \frac{6.6 \times 10^{-3} \times 2256.9 \times 10^3}{\frac{\pi}{4} d^2}$$

$$= \frac{6.6 \times 10^{-3} \times 2256.9 \times 10^3}{\frac{\pi}{4} (.3)^2}$$

(5 M)

$$\boxed{\frac{Q}{A} = 210 \times 10^3 \, w/m^2}$$

$\sigma =$ surface tension for liquid vapour interface

At 100°C (From HMT data book Page No.147)

$$\boxed{\sigma = 58.8 \times 10^{-3} N/m}$$

For water – copper – Csf = Surface fluid constant = 013

$\boxed{C_{sf} = .013}$ (From HMT data book Page No.145)

Substitute, μl, h_{fg}, ρl, ρv, σ, Cpl, hfg, $\frac{Q}{A}$ and P_r values in Equation (1)

	$(1) \Rightarrow 210\times10^{3} = 281.57\times10^{-6}\times2256.9\times10^{3}$ $\left\lvert\frac{9.81\times961-597}{58.8\times10^{-3}}\right\rvert^{0.5}$ $\left\lvert\frac{4216\times\Delta T}{.013\times2256.9\times10^{3}\times(1.74)^{1.7}}\right\rvert^{3}$ $\Rightarrow \left\lvert\frac{4216\times\Delta T}{75229.7}\right\rvert = 0.825$ $\Rightarrow \Delta T(.56)^{3} = .825$ $\Rightarrow \Delta T\times.056 = 0.937$ $\Delta T - 16.7$ (5 M) We know that Excess temperature $\Delta T = T_w - T_{sat}$ $16.7 = T_w - 100°C.$ $\boxed{T_w = 116.7°C}$
3	**Water is boiling on a horizontal tube whose wall temperature is maintained ct 15°C above the saturation temperature of water. Calculate the nucleate boiling heat transfer coefficient. Assume the water to be at a pressure of 20 atm. And also find the change in value of heat transfer coefficient when, The temperature difference is increased to 30°C at a pressure of 10 atm, The pressure is raised to 20 atm at Δ T = 15°C (13 M) (Jun '12)** BTL4 **Answer: Page 3.17-Dr.S.Senthil** We know that for horizontal surface, heat transfer coefficient $h = 5.56\ (\Delta T)^{3}$ From HMT data book Page No.128 $h = 5.56\ (T_w - T_{sat})^{3}$ $= 5.56\ (115 - 100)^{3}$ $\boxed{h = 18765\ w/m^{2}K}$ (2 M) Heat transfer coefficient other than atmospheric pressure $h_p = hp^{0.4}$ From HMT data book Page No.144 $= 18765 \times 10^{0.4}$ $\boxed{\text{Heat transfer coefficient } h_p = 47.13\times10^{3}\ W/m^{2}K}$ (2 M)

	Case (i) P = 100 bar ΔT = 30°C From HMT data book Page No.144 Heat transfer coefficient $h = 5.56\ (\Delta T)^3 = 5.56(30)^3$ $\boxed{h = 150 \times 10^3 W/m^2K}$ (2 M) Heat transfer coefficient other than atmospheric pressure $h_p = hp^{0.4}$ $= 150 \times 10^3 (10)^{0.4}$ $\boxed{h_p = 377 \times 10^3 W/m^2K}$ (3 M) **Case (ii)** P = 20 bar; ΔT = 15°C Heat transfer coefficient $h = 5.56\ (\Delta T)^3 = 5.56\ (15)^3$ $\boxed{h = 18765\ W/m^2K}$ Heat transfer coefficient other than atmospheric pressure $h_p = hp^{0.4}$ $= 18765\ (20)^{0.4}$ $\boxed{h_p = 62.19 \times 10^3\ W/m^2K}$ (4 M)
4	**Dry saturated steam at a pressure of 3 bar, condenses on the surface of a vertical tube of height 1m. The tube surface temperature is kept at 110°C. Calculate the following, 1. Thickness of the condensate film, 2. Local heat transfer coefficient at a distance of 0.25m. (13 M)**BTL4 **Answer: Page 3.22-Dr.S.Senthil** Properties of steam at 3 bar From steam table R.S. Khurmi steam table Page No.10) $T_{sat} = 133.5°C$ $h_{fg} = 2163.2\ kj/kg = 2163.2 \times 10^3\ j/kg$

We know that $Tf = \frac{T_w + T_{sat}}{2}$

$$\text{Film temperature} = \frac{110+133.5}{2}$$

$$Tf = 121.75°C$$

Properties of saturated water at 121.75°C

From HMT data book Page No.13

$$\rho = 945 \text{ kg/m}^3$$
$$\nu = 0.247 \times 10^{-6} m^2/s$$
$$k = 685 \times 10^{-3} W/mk$$
$$\mu = \rho \times \nu = 945 \times 0.247 \times 10^{-6}$$

(4 M)

For vertical surfaces,

$$\delta x = \left(\frac{4\mu K \times x \times (T_{sat} - T_w)}{g \times h_{fg} \times \rho^2} \right)^{0.25}$$

$$\boxed{\mu = 2.33 \times 10^{-4} Ns/m^2}$$

(2 M)

From HMT data book Page No.150

$$\left(\frac{4 \times 2.33 \times 10^{-4} \times 685 \times 10^{-3} \times 0.25 \times 133.5 - 110}{9.81 \times 2163.2 \times 10^3 \times 945^2} \right)$$

$$\boxed{\text{Thickness } \delta x = 1.18 \times 10^{-4} m}$$

(2 M)

Local heat transfer coefficient $h_x = \frac{k}{\delta_x}$

From HMT data book Page No.150

$$h_x = \frac{635 \times 10^{-3}}{1.18 \times 10^{-4}}$$

$$\boxed{h_x = 5775.2 \text{ W/m}^2K}$$

(5 M)

5 **A vertical tube of 65 mm outside diameter and 1.5 m long is exposed to steam at atmospheric pressure. The outer surface of the tube is maintained at a temperature of 60°C by circulating cold water through the tube. Calculate the following, 1. The rate of heat transfer to the coolant, 2. The rate of condensation of steam.(13M)** BTL4

Answer: Page 3.34-Dr.S.Senthil

Enthalpy of evaporation

$$h_{fg} = 2256.9 \text{ kj/kg} = 2256.9 \times 10^3 \text{ j/kg}$$

We know

$$\text{Film temperature } T_f = \frac{T_w + T_{sat}}{2}$$

$$= \frac{60 + 100}{2}$$

$$\boxed{T_f = 80°C}$$

Properties of saturated water at 80°C

From HMT data book Page No.13

$$\rho \text{ - } 974 \text{ kg/m}^3$$

$$\nu = 0.364 \times 10^{-6} \text{ m}^2/\text{s}$$

$$k = 668.7 \times 10^{-3} \text{W/mK} \qquad \text{(4 M)}$$

$$\mu = \rho \times \nu = 974 \times 0.364 \times 10^{-6}$$

$$\boxed{\mu = 354.53 \times 10^{-6} \text{ Ns/m}^2}$$

Assuming that the condensate film is laminar

For laminar flow, vertical surface heat transfer coefficient

$$h = 0943 \left(\frac{K^3 \rho^2 h_{fg}}{\mu L (T_{sat} - T_w)} \right)^{0.25} \qquad \text{(2 M)}$$

From HMT data book Page No.150

The factor 0.943 may be replaced by 1.13 for more accurate result as suggested by Mc Adams

$$1.13 \left(\frac{\left(668.7 \times 10^{-3}\right)^3 \times (974)^2 \times 9.81 \times 2256.9 \times 10^3}{354.53 \times 10^{-6} \times 1.5 \times 100 - 60} \right)^{0.25} \qquad \text{(2 M)}$$

$$h = 4684 \text{ W/m}^2\text{k.}$$

$$Q = hA\Delta T$$
$$= hA(T_{sat} - T_w)$$
$$= h \times \pi \times D \times L \times (T_{sat} - T_w)$$
$$= 4.684 \times \pi \times .065 \times 1.5 \times 100\text{-}60$$

$$\boxed{Q = 57.389\ W}$$

ii) The rate of condensation of steam m

We know Heat transfer Q = m hfg

$$m = \frac{Q}{h_{fg}}$$

$$m = \frac{57,389}{2256.9 \times 10^3}$$

$$\boxed{m = 0.0254\ kg/s}$$

Let us check the assumption of laminar film condensation. We know

$$\text{Reynolds Number } R_e = \frac{4m}{p\mu}$$ P = Perimeter = πD = π× 0.0065 = 0.204 m

Where

$$R_e = \frac{4 \times .0254}{0.204 \times 354.53 \times 10^{-6}}$$ (5 M)

$$R_e = 1406.3 < 1800$$

So our assumption laminar flow is correct.

6

A vertical flat plate in the form of fin is 500m in height and is exposed to steam at atmospheric pressure. If surface of the plate is maintained at 60°C. calculate the following.1. The film thickness at the trailing edge,2. Overall heat transfer coefficient, 3. Heat transfer rate, 4. The condensate mass flow rate.Assume laminar flow conditions and unit width of the plate. (13 M)(Dec 2019, May 2017, Dec 2016, May 2014)BTL4

Answer: Page 3.37-Dr.S.Senthil

$$\text{Film temperature } T_f = \frac{T_w + T_{sat}}{2}$$

$$= \frac{60 + 100}{2}$$

$$\boxed{T_f = 80°C}$$

Properties of saturated water at 80°C

(From HMT data book Page No.13)

ρ - 974 kg/m^3

$v = 0.364 \times 10^{-6}\ m^2/s$

$k = 668.7 \times 10^{-3} W/mk$

$\mu = p \times v = 974 \times 0.364 \times 10^{-6}$

$$\boxed{\mu = 354.53 \times 10^{-6} Ns/m^2}$$ (3 M)

1. Film thickness δ_x

We know for vertical plate

Film thickness

$$\delta x = \left(\frac{4 \mu K \times x \times (T_{sat} - T_w)}{g \times h_{fg} \times \rho^2} \right)^{0.25}$$

Where, X = L = 0.5 m

$$\delta_x = \frac{4 \times 354.53 \times 10^{-6} \times 668.7 \times 10^{-3} \times 0.5 \times 100 - 60}{9.81 \times 2256.9 \times 10^3 \times 974^2}$$ (3 M)

$$\delta_x = 1.73 \times 10^{-4} m$$

2. Average heat transfer coefficient (h)

For vertical surface Laminar flow

$$h = 0.943 \left[\frac{k_3 \times \rho^2 \times g \times h_{fg}}{\mu \times L \times T_{sat} - T_w} \right]^{0.25}$$

The factor 0.943 may be replace by 1.13 for more accurate result as suggested by Mc Adams

$$1.13 \left(\frac{(668.7 \times 10^{-3})^3 \times (974)^2 \times 9.81 \times 2256.9 \times 10^3}{354.53 \times 10^{-6} \times 1.5 \times 100 - 60} \right)^{0.25}$$ (3 M)

$$h = 6164.3\ W/m^2k.$$

3. Heat transfer rate Q

We know

$$Q = hA(T_{sat} - T_w)$$
$$= h \times L \times W \times (T_{sat} - T_w)$$
$$= 6164.3 \times 0.5 \times 1 \times 100\text{-}60$$
$$\boxed{Q = 123286 \text{ W}}$$

(2 M)

4. Condensate mass flow rate m

We know

$$Q = m \times h_{fg}$$
$$m = \frac{Q}{h_{fg}}$$
$$m = \frac{1.23.286}{2256.9 \times 10^3}$$
$$\boxed{m = 0.054 \text{ kg/s}}$$

(2 M)

7 **A horizontal tube of outer diameter 2.2 cm is exposed to dry steam at 100°C. The pipe surface is maintained at 62°C by circulating water through it. Calculate the rate of formation of condensate per meter length of the pipe.(13 M)** BTL4

Answer: Page 3.54-Dr.S.Senthil

$$T_f = \frac{T_w + T_{sat}}{2}$$

$$\text{Film temperature} = \frac{62+100}{2}$$
$$T_f = 81°\text{C} = 80°\text{C}$$

Properties of saturated water at 80°C

From HMT data book Page No.13

$$\rho - 974 \text{ kg/m}^3$$
$$\nu = .364 \times 10^{-6} \text{ m}^2/\text{s}$$
$$k = 668.7 \times 10^{-3} \text{ W/mk}$$
$$\mu = \rho \times \nu = 974 \times .364 \times 10^{-6}$$
$$\boxed{\mu = 354.53 \times 10^{-6} \text{ Ns/m}^2}$$

(3 M)

For horizontal tubes heat transfer coefficient.

	$h = 0.728\left[\frac{K^3\rho^2 g\ h^{fg}}{\mu\ D(T_{sat}-T_w)}\right]^{0.25}$ From HMT data book Page No.150 $h = 0.728\left[\frac{(668.7\times10^{-3})^3\times(974)^2\times9.81\times2256.9\times10^3}{354.53\times10^{-6}\times2.2\times10^{-2}\times(100-62)}\right]^{0.25}$ (4 M) $\boxed{h = 8783.4\ W/m^2K}$ We know Heat transfer Q $hA\ (T_{sat}-T_w)$ $h\times\pi DL\times(T_{sat}-T_w)$ $=8783.4\times\pi\times2.2\times10^{-2}\times1\ (100 - 62)$ (3 M) $\because$ L = 1m $\boxed{Q = 23.068.5\ W}$ We know , Q = mhfg $m=\frac{Q}{hfg}$ $m=\frac{23.0685}{2256.9\times10^3}=0.010\ kg/s$ (3 M) $\boxed{m = 0.010\ kg/s}$
8	**In a counter flow double pipe heat exchanger, oil is cooled from 85°C to 55°C by water entering at 25°C. The mass flow rate of oil is 9,800 kg/h and specific heat of oil is 2000 j/kg K. the mass flow rate of water is 8,000 kg/h and specific heat of water is 4180 j/kg K. Determine the heat exchanger area and heat transfer rate for an overall heat transfer coefficient of 280 W/m^2 K. (13 M)(Dec 2016)** BTL4. **Answer: Page 3.37-Dr.S.Senthil** Heat lost by oil Hot fluid = Heat gained by water cold fluid $Qh = Q_c$

$$m_h C_{ph}(T_1 - T_2) = m_c C_{pc}(t_2 - t_1)$$

$$2.72 \times 2000 \text{ (85-55)} = 2.22 \times 4180 \times (t_2 - 25)$$

$$163.2 \times 10^3 = 9279.6 \ t_2 - 231.9 \times 10^3$$ (4 M)

$$t_2 = 42.5°C$$

$$\boxed{\text{Exit temperature of water } t_2 = 42.5°C}$$

Heat transfer Q $= m_c C_{pc}(t_2 - t_1)$ (or) $m_h C_{ph}(T_1 - T_2)$

$$Q = 2.22 \times 4180 \times (42.5 - 25)$$ (4 M)

$$Q = 162 \times 10^3 \text{ W}$$

$Q = UA \ (\Delta T)_m$........1

From HMT data book Page No.154

For counter flow

$$(\Delta T)_m = \frac{(T_1 - t_1) \text{ - } (T_2 - t_2)}{\ln\left[\dfrac{T_1 - t_1}{T_2 - t_2}\right]}$$

From HMT data book Page No.154

(2 M)

$$(\Delta T)_m = \frac{(85 - 42.5) \text{ - } (55 - 25)}{\ln\left[\dfrac{85 - 42.5}{55 - 25}\right]}$$

$$\boxed{(\Delta T)_m = 35.8°C}$$

Substitute $(\Delta T)_m$ U and Q values in Equation (1)

$$(1) \Rightarrow Q = UA \ (\Delta T)_m$$

$$\Rightarrow 162 \times 10^3 = 280 \times A \times 35.8$$ (3 M)

$$\boxed{\Rightarrow A = 16.16 \text{ m}^2}$$

9 **Water flows at the rate of 65 kg/min through a double pipe counter flow heat exchanger. Water is heated from 50°C to 75°C by an oil flowing through the tube. The specific heat of the oil is 1.780 kj/kg K. The oil enters at 115°C and leaves at 70°C. The overall heat transfer coefficient is 340 W/m^2 K. Calculate the following, 1. Heat exchanger area, 2. Rate of heat transfer (13 M)**BTL4

Answer: Page 3.86-Dr.S.Senthil

<table>
<tr><td></td><td>

Heat transfer $Q = m_c C_{pc}(t_2 - t_1)$ (or)

$m_h C_{ph}(T_1 - T_2)$

$Q = m_c C_{pc}(t_2 - t_1)$

$Q = 1.08 \times 4186 \times (75 - 50)$ (4 M)

$\because$ Specific heat of water $C_{ph} - 4186$ j/kg K

$\boxed{Q = 113 \times 10^3 \text{ W}}$

We know

Heat transfer Q = U × A $(\Delta T)_m$ (3 M)

From HMT data book Page No., 154

Where

$(\Delta T)_m$ – Logarithmic Mean Temperature Difference. LMTD

For Counter flow

$$(\Delta T)_m = \frac{(T_1 - t_1) - (T_2 - t_2)}{\ln\left[\dfrac{T_1 - t_1}{T_2 - t_2}\right]}$$

From HMT data book Page No.154 (3 M)

$$(\Delta T)_m = \frac{(115 - 75) - (70 - 50)}{\ln\left[\dfrac{115 - 75}{70 - 50}\right]}$$

$\boxed{(\Delta T)_m = 28.8°C}$

Substitute $(\Delta T)_m$ Q and U values in Equation (1)

$(1) \Rightarrow Q = UA\ (\Delta T)_m$

$\Rightarrow 113 \times 10^3 = 340 \times A \times 28.8$ (3 M)

$\boxed{\Rightarrow A = 11.54 \text{ m}^2}$

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<tr><td>10</td><td>

In a double pipe heat exchanger hot fluid with a specific heat of 2300 J/kg K enters at 380°C and leaves at 300°C. cold fluid enters at 25°C and leaves at 210°C. Calculate the heat exchanger area required for

1. Parallel flow **2. Counter flow**

Take overall heat transfer coefficient is 750 w/m^2 K and mass flow rate of hot fluid is 1 kg/s. (13 M) BTL4

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</table>

Answer: Page 3.89-Dr.S.Senthil

Case (i)

For parallel flow

$$(\Delta T)_m = \frac{(T_1 - t_1) - (T_2 - t_2)}{\ln\left[\frac{T_1 - t_1}{T_2 - t_2}\right]}$$

From HMT data book Page No.154

$$(\Delta T)_m = \frac{(380 - 25) - (300 - 210)}{\ln\left[\frac{380 - 25}{300 - 210}\right]}$$

$$\boxed{(\Delta T)_m = 193.1°C}$$

Heat transfer Q = $m_c C_{pc}(t_2 - t_1)$ (or)

$m_h C_{ph}(T_1 - T_2)$

$$Q = m_c C_{pc}(t_2 - t_1)$$

$$= 1 \times 2300 \times 380 - 300$$

$$Q = 184 \times 10^3 \text{ W}$$

From HMT data book Page No.154

We know that

$$Q = U \times A \ (\Delta T)_m$$

Heat transfer $184 \times 10^3 = 750 \times A \times 193.1$

Area for parallel flow A = 1.27 m^2 (3+3 M)

Case (ii)

For counter flow

$$(\Delta T)_m = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln\left[\frac{T_1 - t_2}{T_2 - t_1}\right]}$$

From HMT data book Page No.154

(5 M)

$$(\Delta T)_m = \frac{(380 - 210) - (300 - 25)}{\ln\left[\frac{380 - 210}{300 - 25}\right]}$$

$$(\Delta T)_m = 218.3°C$$

We know that,

Heat transfer Q = UA $(\Delta T)_m$

$$\Rightarrow 184 \times 10^3 = 750 \times A \times 218.3$$

Area for counter flow A = 1.12 m^2

(2 M)

Part –C

1 **A nickel wire carrying electric current of 1.5 mm diameter and 50 cm long, is submerged in a water bath which is open to atmospheric pressure. Calculate the voltage at the burn out point, if at this point the wire carries a current of 200A. (15 M)(Dec 2016)** BTL4

Answer: Page 3.9-Dr.S.Senthil

$$hfg - 2256.9 \text{ kj/kg}$$

$$hfg = 2256.9 \times 10^3 \text{ j/kg}$$

$$v_g = 1.673 m^3 / kg$$

$$\rho v = \frac{1}{\nu_g} = \frac{1}{1.673} = 0.597 \text{ kg/m}^3$$

σ = Surface tension for liquid – vapour interface

At 100°C

$\sigma = 58.8 \times 10^{-3}$ N/m (From HMT data book Page No.147)

For nucleate pool boiling critical heat flux (AT burn out)

$$\frac{Q}{A} = 0.18 \times h_{fg} \times \rho v \left[\frac{\sigma \times g \times (\rho l - \rho v)^{0.25}}{\rho v^2}\right] ----1$$

(5 M)

(From HMT data book Page No.142)

Substitute h_{fg}, ρl, ρv, σ values in Equation (1)

$$(1) \Rightarrow \frac{Q}{A} = 0.18 \times 2256.9 \times 10^3 \times 0.597$$

$$\left[\frac{58.8 \times 10^{-3} \times 9.81\,(961 - .597)}{.597^2}\right]^{0.25}$$ (5 M)

$$\boxed{\frac{Q}{A} = 1.52 \times 10^6 \text{ W/m}^2}$$

We know , Heat transferred Q = V × I

$$\frac{Q}{A} = \frac{V \times I}{A}$$

$$1.52 \times 10^6 = \frac{V \times 200}{\pi dL} \qquad \because A = \pi dL$$ (5 M)

$$1.52 \times 10^6 = \frac{V \times 200}{\pi \times 1.5 \times 10^{-3} \times .50}$$

$$\boxed{V = 17.9 \text{ volts}}$$

2

A heating element cladded with metal is 8 mm diameter and of emissivity is 0.92. The element is horizontally immersed in a water bath. The surface temperature of the metal is 260°C under steady state boiling conditions. Calculate the power dissipation per unit length for the heater. (15 M)(Dec 2016) BTL4

Answer: Refer class notes

Excess temperature, $\Delta T = T_w - T_{sat}$

$$\Delta T = 260 - 100$$

$$\boxed{\Delta T = 160°C > 50°C}$$

So this is film pool boiling

Film temperature $T_f = \frac{T_w + T_{sat}}{2}$

$$= \frac{260 + 100}{2}$$

$$\boxed{Tf = 180°C}$$

Properties of water vapour at 180°C

(From HMT data book Page No.30)

$\rho v = 5.16\ kg/m^3$

$K_v = 32.68\times10^{-3}\ w/mK$

Cpv = 2.709 kj/kgK =2709 j/kg K

$\mu v = 15.10\times10^{-6}\ Ns/m^2$

(5 M)

Properties of saturated water at 100°C

$\rho l = 961\ kg/m^3$ (From HMT data book Page No.13)
From steam table At 100°C. (R.S. Khurmi Steam table Page No.4)

$$\boxed{h_{fg} = 2256.9\times10^3\,j/kg}$$

(3 M)

In film pool boiling heat is transferred due to both convection and radiation.

Heat transfer coefficient $h = h_{conv} + \frac{3}{4}h_{rad} ---1$

$$h_{conv} = 0.62\left[\frac{K_v^3\times\rho_v\times(\rho_v-\rho_v)\times g\times\left(h_{fg}+0.4\left(C_{pv}\Delta T\right)\right)}{\mu_v D\Delta T}\right]^{0.25}$$

From HMT data book Page No.143

$$h_{conv} = 0.62\left[\frac{\begin{array}{c}(32.68\times10^{-3})\times5.16\times961-5.16\times9.81\\ \times2256.9\times10^{3}+0.4\times2709\times160)f\end{array}}{15.10\times10^{-6}\times8\times10^{-3}\times160}\right]$$

(3 M)

$$h_{conv} = 0.62\left[\frac{4.10\times10^6}{1.93\times10^{-5}}\right]^{0.25}$$

$$\boxed{h_{conv} = 421.02\ W/m^2K........2}$$

$$h_{rad} = \sigma\in\left\{\frac{T_w^{\Delta}-T_{sat}^4}{T_w-T_{sat}}\right\}$$

From HMT data book Page No.143

$$h_{rad} = 5.67\times10^{-8}\times0.92\times\left[\frac{(260+273)^4-(100+273)^4}{260+273-100+273}\right]$$

(2 M)

	Stefan boltzmann constant $\sigma = 5.67\times10^{-8}\ \text{W/m}^2\text{K}^4$ $h_{rad} = 20W/m^2K............3$ Substitute (2) (3) in (1) $1 \Rightarrow h = 421.02 + \frac{3}{4}(20)$ $\boxed{h = 436.02\ \text{W/m}^2\text{K}}$ Heat transferred Q = hA $(T_w - T_{sat})$ $= h\times\pi\times D\times L\ (T_w - T_{sat})$ $= 4366.02\times\pi\times8\times10^{-3}\times1\times260-100$ (3 M) Q = 1753.34 W/m ∵ L = 1m Or Power dissipation = 1753.34 W/m. (2 M)
3	**Steam at 0.080 bar is arranged to condense over a 50 cm square vertical plate. The surface temperature is maintained at 20°C. Calculate the following.** **a. Film thickness at a distance of 25 cm from the top of the plate.** **b. Local heat transfer coefficient at a distance of 25 cm from the top of the plate.** **c. Average heat transfer coefficient.** **d. Total heat transfer** **e. Total steam condensation rate.** **f. What would be the heat transfer coefficient if the plate is inclined at 30°C with horizontal plane.(15 M)**-BTL4 **Answer: Refer class notes** Film temperature $T_f = \frac{T_w + T_{sat}}{2}$ $= \frac{20+41.53}{2}$ $\boxed{T_f = 30.76°C}$ Properties of saturated water at 30.76°C = 30°C From HMT data book Page No.13

$$\rho - 997 \text{ kg/m}^3$$

$$\nu = 0.83 \times 10^{-6} \text{ m}^2/\text{s}$$

$$\text{k} = 612 \times 10^{-3} \text{W/mK}$$ (2 M)

$$\mu = \text{p} \times \text{v} = 997 \times 0.83 \times 10^{-6}$$

$$\mu = 827.51 \times 10^{-6} \text{Ns/m}^2$$

a. Film thickness

We know for vertical surfaces

$$\delta\text{x} = \left(\frac{4\mu\text{K} \times \text{x} \times (\text{T}_{\text{sat}} - \text{T}_{\text{w}})}{\text{g} \times \text{h}_{\text{fg}} \times \rho^2} \right)^{0.25}$$

(From HMT data book Page No.150) (2 M)

$$\delta_{\text{x}} = \frac{4 \times 827.51 \times 10^{-6} \times 612 \times 10^{-3} \times .25 \times (41.53 - 20)100}{9.81 \times 2403.2 \times 10^3 \times 997^2}$$

$$\delta_{\text{x}} = 1.40 \times 10^4 \text{m}$$

b. Local heat transfer coefficient h$_x$ Assuming Laminar flow

$$\text{h}_{\text{x}} = \frac{\text{k}}{\delta\text{x}}$$

$$\text{h}_{\text{x}} = \frac{612 \times 10^{-3}}{1.46 \times 10^{-4}}$$ (3 M)

$$\boxed{\text{hx} = 4{,}191 \text{ W/m}^2\text{K}}$$

c. Average heat transfer coefficient h

(Assuming laminar flow)

$$\text{h} = 0.943 \left[\frac{\text{k}^3 \times \rho^2 \times \text{g} \times \text{h}_{\text{fg}}}{\mu \times \text{L} \times \text{T}_{\text{sat}} - \text{T}_{\text{w}}} \right]^{0.25}$$ (3 M)

The factor 0.943 may be replaced by 1.13 for more accurate result as suggested by Mcadams

$$\text{h} = 0.943 \left[\frac{\text{k}^3 \rho^2 \text{g h}_{\text{fg}}}{\mu \times \text{L} \times \text{T}_{\text{sat}} - \text{T}_{\text{w}}} \right]^{0.25}$$

Where L = 50 cm = .5 m

$$h = 1.13\left|\frac{(612\times10^{-3})^{3}\times(997)^{2}\times9.81\times2403.2\times10^{3}}{827.51\times10^{-6}\times.5\times41.53-20}\right|^{0.25}$$ (2 M)

$$h = 5599.6\ \text{W/m}^2\text{k}$$

d. Heat transfer (Q), We know , Q = $hA(T_{sat} – T_w)$

$$h\times A\times(T_{sat}-T_w)$$
$$= 5599.6\times0.25\times(41.53-20$$ (3 M)
$$Q = 30.139.8\ \text{W}$$

4

The outer surface of a cylindrical vertical drum having 25 cm diameter is exposed to saturated steam at 1.7 bar for condensation. The surface temperature of the drum is maintained at 85°C. Calculate the following, Length of the drum, Thickness of condensate layer to condense 65 kg/h steam. (15 M)(Dec 2015)-BTL4

Answer: Page 3.44-Dr.S.Senthil

Film temperature $T_f = \frac{T_w + T_{sat}}{2}$

$$= \frac{85+115.2}{2}$$

$$\boxed{T_f = 100.1°C}$$

Properties of saturated water at 100°C

From HMT data book Page No.13

ρ - 961 kg/m^3

ν - 0.293×10^{-6} m^2/s

$k = 680.4\times10^{-3}$ W/mK

$\mu = \rho\times\nu = 961\times0.293\times10^{-6}$

$$\boxed{\mu = 281.57\times10^{-6}\ \text{Ns/m}^2}$$

For vertical surfaces (Assuming Laminar flow)

Average heat transfer coefficient

$$h = 0.943\left(\frac{k^3\rho^2 g\times h_{fg}}{\mu L(T_{sat}-T_w)}\right)^{0.25}$$ (5 M)

From HMT data book Page No.150

$$h-1.13\left(\frac{k^3\rho^2 g\times h_{fg}}{\mu L(T_{sat}-T_w)}\right)^{0.25}$$

$$h=1.13\left(\frac{(680.4\times10^{-3})^3(961)^2\times9.81\times2215.8\times10^3}{281.57\times10^{-6}\times l\times(115.2-85)}\right)^{0.25}$$ (2 M)

$$\boxed{h=\ 5900L^{-0.25}........1}$$

Heat transfer Q

$m\times h_{fg}$

$=\ 0.0180\ kg/s\ \times 2215.8\times 103\ j/kg$

$= 39.8\times 103\ j/s$

$\boxed{Q = 39.8\times 103\ W}$

We know that ,

$$Q=hA(T_{sat}-T_w)$$

$$39.8\times10^3=h\times\pi DL\times(T_{sat}-T_w)$$ (3 M)

$$39.8\times10^3=h\times\pi\times.25\times L\ (115.2-85)$$

Substitute h value

$39.8\times10^3=(5900L^{-0.25})\times\pi\times.25\times L\times(115.2-85)$

$0.278=L^{0.75}\times(115.8-85)$

$L=0.18m$

$\boxed{\text{Length of the drum L = 0.18 m}}$

2. Film thickness

$$\delta x=\left(\frac{4\mu Kx(T_{sat}-T_w)}{g\times h_{fg}\times\rho^2}\right)^{0.25}$$

$\boxed{x=L=0.18\ m}$

Let us check the assumption of laminar flow

We know that , Reynolds Number $R_e=\dfrac{4m}{p\mu}$

Where , P = Perimeter = $\pi D=\pi\times.25=0.785$

$$R_e = \frac{4 \times .0180}{0.785 \times 281.57 \times 10^{-6}}$$ (5 M)

$$R_e = 325.7 < 1800$$

So our assumption laminar flow is correct.

5

In a refrigerating plant water is cooled from 20°C to 7°C by brine solution entering at -2°C and leaving at 3°C. The design heat load is 5500 W and the overall heat transfer coefficient is 800 W/m² K. What area required when using a shell and tube heat exchanger with the water making one shell pass and the brine making two tube passes.(15 M)-BTL4

Answer: Page 3.112, Dr.S.Senthil

Shell and tube heat exchanger – one shell pass and two tube passes

For shell and tube heat exchanger or cross heat exchanger.

$Q = F\ U\ A\ (\Delta T)_m$ (Counter flow)

(From HMT data book Page No.154) (3 M)

For counter flow

$$(\Delta T)_m = \frac{\left[(T_1 - t_2) - (T_2 - t_1)\right]}{\ln\left[\dfrac{T_1 - t_2}{T_2 - t_1}\right]}$$

$$= \frac{(20\text{-}3)\text{-}(7+2)}{\ln\left[\dfrac{20\text{-}3}{7\text{+}2}\right]}$$ (5 M)

$$\boxed{(\Delta T)_m = 12.57°C}$$

To find correction factor F refer HMT data book Page No.161

One shell pass and two tube passes

From graph

$$X_{axis}\ \text{Value P} = \frac{t_2 - t_1}{T_1 - t_1} = \frac{3+2}{20+2} = \frac{5}{22}$$

$$P = 0.22$$ (5 M)

$$\text{Curve value = R=} \frac{T_1 - T_2}{t_2 - t_1} = \frac{20-7}{3+2} = \frac{13}{5}$$

$$R = 2.6$$

	X_{axis} value is 0.22 curve value is 2.6 corresponding Y_{axis} value is 0.94 Substitute $(\Delta T)_m$ Q, U and F value is Equation (1) $1 \Rightarrow Q = F\ U\ A\ (\Delta T)_m$ $5500 = 0.94 \times 800 \times A \times 12.57$ (2 M) $\boxed{A = 0.58\ m^2}$

UNIT IV RADIATION

Black Body Radiation – Grey body radiation - Shape Factor – Electrical Analogy – Radiation Shields. Radiation through gases.

PART * A

Q.No.	Questions
1	**Define Radiation.** BTL1 The heat transfer from one body to another without any transmitting medium is known as radiation. It is an electromagnetic wave phenomenon.
2	**Define emissive power [E].(Nov 2018, Dec 2016, May 2013)**BTL1 The emissive power is defined as the total amount of radiation emitted by a body per unit time and unit area. It is expressed in W/m^2.
3	**Define monochromatic emissive power. [$E_{b\lambda}$]** BTL1 The energy emitted by the surface at a given length per unit time per unit area in all directions is known as monochromatic emissive power.
4	**What is meant by absorptivity?** BTL2 Absorptivity is defined as the ratio between radiation absorbed and incident radiation. Absorptivity $\alpha = \dfrac{\text{Radiation absorbed}}{\text{Incident radiation}}$
5	**What is meant by reflectivity?** BTL2 Reflectivity is defined as the ratio of radiation reflected to the incident radiation. Reflectivity $\rho = \dfrac{\text{Radiation reflected}}{\text{Incident radiation}}$
6	**What is meant by Transmissivity?** BTL2 Transmissivity is defined as the ratio of radiation transmitted to the incident radiation. Transmissivity $\tau = \dfrac{\text{Radiation transmitted}}{\text{Incident radiation}}$
7	**What is black body? [April.97, April 99]** BTL2 Black body is an ideal surface having the following properties. 1. A black body absorbs all incident radiation, regardless of wave length and direction.

	2. For a prescribed temperature and wave length, no surface can emit more energy than black body.
8	**State Planck's distribution law. (Dec 2019, May 2017, Dec 2016, May 2014)**BTL2 The relationship between the monochromatic emissive power of a black body and wave length of a radiation at a particular temperature is given by the following expression, by Planck. $E_{b\lambda} = \dfrac{C_1\lambda^{-5}}{e^{\left(\frac{C_2}{\lambda T}\right)}-1}$ Where $E_{b\lambda}$ = Monochromatic emissive power W/m^2 λ = Wave length – m $c_1 = 0.374 \times 10^{-15}$ W m^2 $c_2 = 14.4 \times 10^{-3}$mK
9	**State Wien's displacement law.** BTL2 The Wien's law gives the relationship between temperature and wave length corresponding to the maximum spectral emissive power of the black body at that temperature. $\lambda_{mas}\ T = c_3$ Where $c_3 = 2.9 \times 10^{-3}$ [Radiation constant] $\Rightarrow \lambda_{mas}\ T = 2.9 \times 10^{-3}$ mK
10	**State Stefan – Boltzmann law. [April 2002]** BTL2 The emissive power of a black body is proportional to the fourth power of absolute temperature. $E_b \quad \infty \quad T^4$ $E_b = \sigma T^4$ Where E_b = Emissive power, w/m^2 σ = Stefan. Boltzmann constant = 5.67×10^{-8} W/m^2 K^4 T = Temperature, K
11	**Define Emissivity. [Oct. 2000, April 2002]** BTL1 It is defined as the ability of the surface of a body to radiate heat. It is also defined as the ratio of emissive power of any body to the emissive power of a black body of equal temperature.

	Emissivity $\varepsilon = \frac{E}{E_b}$
12	**What is meant by gray body? [April, 2000, 2002]** BTL2 If a body absorbs a definite percentage of incident radiation irrespective of their wave length, the body is known as gray body. The emissive power of a gray body is always less than that of the black body.
13	**State Kirchoff's law of radiation. [April 2001]** BTL2 This law states that the ratio of total emissive power to the absorbtivity is constant for all surfaces which are in thermal equilibrium with the surroundings. This can be written as $\frac{E_1}{\alpha_1} = \frac{E_2}{\alpha_2} = \frac{E_3}{\alpha_3}$, It also states that the emissivity of the body is always equal to its absorptivity when the body remains in thermal equilibrium with its surroundings. $\alpha_1 = E_1$; $\alpha_2 = E_2$ and so on.
14	**Define intensity of radiation (I_b). [Nov. 96, Oct. 98, 99]** BTL1 It is defined as the rate of energy leaving a space in a given direction per unit solid angle per unit area of the emitting surface normal to the mean direction in space. $I_n = \frac{E_b}{\pi}$
15	**State Lambert's cosine law.** BTL1 It states that the total emissive power E_b from a radiating plane surface in any direction proportional to the cosine of the angle of emission $E_b \infty \cos\theta$
16	**What is the purpose of radiation shield? [Apr. 2012,Apr.2013]** BTL2 Radiation shields constructed from low emissivity (high reflective) materials. It is used to reduce the net radiation transfer between two surfaces.
17	**Define irradiation (G) [Nov. 17]** BTL1 It is defined as the total radiation incident upon a surface per unit time per unit area. It is expressed in W/m^2.
18	**What is radiosity (J)? [April 2016]** BTL2 It is used to indicate the total radiation leaving a surface per unit time per unit area. It is

	expressed in W/m^2.
19	**What is meant by shape factor? (Dec 2016, May 2015)**BTL2 The shape factor is defined as the fraction of the radiative energy that is diffused from on surface element and strikes the other surface directly with no intervening reflections. It is represented by F_{ij}. Other names for radiation shape factor are view factor, angle factor and configuration factor.
20	**What are the assumptions made to calculate radiation exchange between the surfaces?** BTL2 1. All surfaces are considered to be either black or gray 2. Radiation and reflection process are assumed to be diffuse. 3. The absorptivity of a surface is taken equal to its emissivity and independent of temperature of the source of the incident radiation.
Part*B	
	A black body at 3000 K emits radiation. Calculate the following: **i) Monochromatic emissive power at 7 μm wave length.** **ii) Wave length at which emission is maximum.** **iii) Maximum emissive power.** **iv) Total emissive power,** **Calculate the total emissive of the furnace if it is assumed as a real surface having emissivity equal to 0.85. (Nov 2018, Dec 2016, May 2013)(13 M)**BTL4 **Answer: Page 4.9-Dr.S.Senthil** **1. Monochromatic Emissive Power :** From Planck's distribution law, we know $E_{b\lambda} = \frac{C_1\lambda^{-5}}{e^{\left(\frac{C_2}{\lambda T}\right)}-1}$ [From HMT data book, Page No.71] Where $c_1 = 0.374 \times 10^{-15}$ W m^2 $c_2 = 14.4 \times 10^{-3}$mK $\lambda = 1 \times 10^{-6}$ m [Given]

$$\Rightarrow \quad E_{b\lambda} = \frac{0.374\times10^{-15}[1\times10^{-6}]^{-5}}{\left[\frac{144\times10^{-3}}{1\times10^{-6}\times3000}\right]_{-1}}$$ (3 M)

$$E_{b\lambda} = 3.10\times10^{12}\ \text{W/m}^2$$

2. Maximum wave length (λ_{max})

From Wien's law, we know

$$\lambda_{max}T = 2.9\times10^{-3}\ \text{mK}$$

$$\Rightarrow \quad \lambda_{max} = \frac{2.9\times10^{-3}}{3000}$$ (3 M)

$$\lambda_{max} = 0.966 \times 10^{-6}\text{m}$$

3. Maximum emissive power ($E_{b\lambda}$) max:

Maximum emissive power

$(E_{b\lambda})_{max} = 1.307 \times 10^{-5}\ T^5$

$= 1.307 \times 10^{-5}\times (3000)^5$

$(E_{b\lambda})_{max} = 3.17 \times 10^{12}$ W/m^2 (2 M)

4. Total emissive power (E_b):

From Stefan – Boltzmann law, we know that

$E_b = \sigma T^4$

[From HMT data book Page No.71]

Where σ = Stefan – Boltzmann constant

$= 5.67 \times 10^{-8}$ W/m^{2}K^4

$\Rightarrow E_b = (5.67 \times 10^{-8})\ (3000)^4$

$E_b = 4.59 \times 10^6$ W/m^2 (2 M)

5. Total emissive power of a real surface:

$(E_b)_{real} = \varepsilon\sigma\ T^4$

Where ε = Emissivity = 0.85

$(E_b)_{real} = 0.85\times5.67\times10^{-8}\times(3000)^4$

$$(E_b)_{real} = 3.90\times10^6\ \text{W/m}^2$$ (3 M)

1

A black body of 1200 cm² emits radiation at 1000 K. Calculate the following:

1. **Total rate of energy emission**
2. **Intensity of normal radiation**
3. **Wave length of maximum monochromatic emissive power.**
4. **Intensity of radiation along a direction at 60° to the normal. (13 M)**BTL4

Answer: Page 4.13-Dr.S.Senthil

1. Energy emission $E_b = \sigma T^4$

[From HMT data book, Page No.71]

$\Rightarrow E_b = 5.67 \times 10^{-8} \times (1000)^4$

$$E_b = 5.67 \times 10^3 \text{ W/m}^2$$

Here Area $= 1200 \times 10^{-4}$ m²,

$\Rightarrow E_b = 5.67 \times 10^3 \times 1200 \times 10^{-4}$

$$E_b = 6804 \text{ W}$$ (3 M)

2. Intensity of normal radiation

$$I_n = \frac{E_b}{\pi}$$

$$= \frac{56.7 \times 10^3 \text{ W/m}^2}{\pi}$$ (5 M)

$$I_n = 18{,}048 \text{ W/m}^2$$

3. From Wien's law, we know that

$\lambda_{max} T = 2.9 \times 10^{-3}$ mK

$$\Rightarrow \lambda_{max} = \frac{2.9 \times 10^{-3}}{3000}$$

$$\lambda_{max} = 2.9 \times 10^{-6} \text{ m}$$ (5 M)

$$\lambda_{max} = 2.9\ \mu \qquad [\because 1\mu = 10^{-6} \text{ m}]$$

2

Assuming sun to be black body emitting radiation at 6000 K at a mean distance of 12 × 10¹⁰ m from the earth. The diameter of the sun is 1.5 × 10⁹ m and that of the earth is 13.2 × 10⁶ m. Calculation the following. (i) Total energy emitted by the sun, (ii) The emission received per m² just outside the earth's atmosphere, (iii) The total energy received by the earth if no radiation is blocked by the earth's atmosphere, (iv) The energy received by a

2 × 2 m solar collector whose normal is inclined at 45° to the sun. The energy loss through the atmosphere is 50% and the diffuse radiation is 20% of direct radiation.(13 M) (Dec 2019, May 2017, Dec 2016, May 2014)BTL4

Answer: Page 4.15-Dr.S.Senthil

1. Energy emitted by sun E_b = σ T^4

$$\Rightarrow \quad E_b = 5.67\times10^{-8}\times(6000)^4$$

$$[\because \ \sigma = \text{Stefan - Boltzmann constant} = 5.67\times10^{-8}\ \text{W}/\text{m}^2\ \text{K}^4]$$

$$E_b = 73.4 \times 10^6\ \text{W/m}^2$$

Area of sun $A_1 = 4\pi\ R_1^2$

$$= 4\pi \times \left(\frac{1.5\ \times10^9}{2}\right)^2$$

$$\boxed{A_1 = 7\times10^{18}\text{m}^2}$$

$\Rightarrow$ Energy emitted by the sun

$$E_b = 73.4\times10^6\times7\times10^{18}$$ (3 M)

$$\boxed{E_b = 5.14\times10^{26}\ \text{W}}$$

2. The emission received per m^2 just outside the earth's atmosphere:

The distance between earth and sun

$R = 12 \times 10^{10}$ m

$$\text{Area, } A = 4\pi\ R^2$$

$$= 4\times\pi\times(12\times10^{10})^2$$

$$\boxed{A = 1.80\times10^{23}\ \text{m}^2}$$

$\Rightarrow$ The radiation received outside the earth atmosphere per m^2 (3 M)

$$= \frac{E_b}{A}$$

$$= \frac{5.14\times10^{26}}{1.80\times10^{23}}$$

$$= 2855.5\ \text{W/m}^2$$

3. Energy received by the earth:

	Earth area = $\frac{\pi}{4}(D_2)^2$ $= \frac{\pi}{4}\times[13.2\times10^6]^2$ $\boxed{\text{Earth area} = 1.36 \times 10^4 m^2}$ Energy received by the earth $= 2855.5\times1.36\times10^4$ $= 3.88\times10^{17}$ W (3 M) **4. The energy received by a 2 × 2 m solar collector;** Energy loss through the atmosphere is 50%. So energy reaching the earth. $= 100 - 50 = 50\%$ $= 0.50$ Energy received by the earth $= 0.50\times2855.5$ $= 1427.7 \text{ W/m}^2$ ......(1) Diffuse radiation is 20% $\Rightarrow 0.20\times1427.7 = 285.5 \text{ W/m}^2$ $\boxed{\text{Diffuse radiation} = 285.5 \text{ W/m}^2}$ ....(2) (2 M) Total radiation reaching the collection $= 142.7 + 285.5$ $= 1713.2 \text{ W/m}^2$ Plate area $= A\times\cos\ \theta$ $= 2\times2\times\cos 45°$ $= 2.82 \text{ m}^2$ Energy received by the collector $= 2.82\times1713.2$ $= 4831.2$ W (2 M)
3	**A large enclosure is maintained at a uniform temperature of 3000 K. Calculate the following, (i) Emissive power, (ii) The wave length λ_1 below which 20 percent of the emission is concentrated and the wave length λ_2 above which 20 percent of the emission is**

concentrated, (iii) The maximum wave length, (iv) Spectral emissive power, (v) The irradiation incident.(13 M)BTL4

Answer: Page 4.22-Dr.S.Senthil

1. Emissive power $E_b = \sigma\ T^4$

$$= 5.67 \times 10^{-8} \times (3000)^4$$

$$\boxed{E_b = \ 4.59 \times 10^6 \ \text{W/m}^2} \qquad \text{(3 M)}$$

2. The wave length λ_1 corresponds to the upper limit, containing 20% of emitted radiation.

$$\Rightarrow \quad \frac{E_{b(0\text{-}\lambda_1 T)}}{\sigma\ T^4} = 0.20 \text{, corresponding}$$

$\lambda_1 T = 2666\ \mu K$

[From HMT data book, Page No.72]

$$\Rightarrow \quad \lambda_1 T = 2666\ \mu K$$

$$\Rightarrow \quad \lambda_1 \ = \ \frac{2666}{3000}$$

$$\Rightarrow \quad \boxed{\lambda_1 = 0.88}$$

The wave length λ_2 corresponds to the lower limit, containing 20% of emitted radiation.

$$\Rightarrow \quad \frac{E_{b(0\text{-}\lambda_1 T)}}{\sigma T^4} = (1 - 0.20)$$

$$\Rightarrow \quad \frac{E_{b(0\text{-}\lambda_1 T)}}{\sigma T^4} = 0.80, \text{ corresponding}$$

$$\lambda_2 T = 6888\ \mu K \qquad \text{(3 M)}$$

$$\Rightarrow \quad \lambda_2 \ = \ \frac{6888}{3000}$$

$$\boxed{\lambda_2 = 2.2\ \mu}$$

3. Maximum wave length (λ_{max}):

$\lambda_{max}\ T = 2.9 \times 10^{-3}$mK

$$\lambda_{max} = \frac{2.9\times10^{-3}}{3000}$$

$$= 9.6\times10^{-7}\text{m}$$ (2 M)

$$\boxed{\lambda_{max} = 0.96\times10^{-6}\text{m}}$$

4. Spectral Emissive Power:

From Planck's distribution law, we know

$$E_{b\lambda} = \frac{C_1\lambda_{max}^{-5}}{e^{\left(\frac{C_2}{\lambda T}\right)}-1}$$ [From HMT data book, Page No.71]

where $C_1 = 0.374\times10^{-15}\text{W m}^2$

$C_2 = 14.4\times10^{-3}\text{ mK}$

$$\Rightarrow \quad E_{b\lambda} = \frac{\left(0.374\times10^{-15}\right)\times\left(0.96\times10^{-6}\right)^{-5}}{e^{\left(\frac{14.4\times10^{-3}}{0.96\times10^{-6}\times3000}\right)}-1}$$ (3 M)

$$\Rightarrow \quad E_{b\lambda} = 3.1 \times 10^{12}\text{ W/m}^2$$

5. Irradiation:

The irradiation incident on a small object placed within the enclosure may be treated as equal to emission from a black body at the enclosure surface temperature.

So, G = E_b= $4.59\times10^6\text{ W/m}^2$. (2 M)

4

A furnace wall emits radiation at 2000 K. Treating it as black body radiation, calculate, (i) Monochromatic radiant flux density at 1μm wave length, (ii) Wave length at which emission is maximum and the corresponding emissive power., (iii) Total emissive power (13 M)BTL4

Answer: Page 4.26-Dr.S.Senthil

1. Monochromatic emissive power ($E_{b\lambda}$):

$$E_{b\lambda} = \frac{c_1\lambda^{-5}}{e^{\left(\frac{C_2}{\lambda T}\right)}-1}$$ [From HMT data book, Page No.71]

where $C_1 = 0.374 \times 10^{-15} W\ m^2$

$C_2 = 14.4 \times 10^{-3}\ mK$

$\lambda\ = 1\ \mu m = 1 \times 10^{-6}\ m$ [Given] (4 M)

$$\Rightarrow \quad E_{b\lambda} = \frac{0.374 \times 10^{-15} \times (1 \times 10^{-6})^{-5}}{e^{\left(\frac{14.4 \times 10^{-3}}{1 \times 10^{-6} \times 2000}\right)} - 1}$$

$$\boxed{E_{b\lambda} = 2.79 \times 10^{11} W/m^2}$$

2. Maximum Wave Length (λ_{max}):

From Wien's Law, we know that

$\lambda_{max}\ T = 2.9 \times 10^{-3} mK$

[From HMT data book, Page No.71]

$$\lambda_{max} = \frac{2.9 \times 10^{-3}}{T}$$

$$= \frac{2.9 \times 10^{-3}}{2000} = 1.45 \times 10^{-6} m$$

$$\boxed{\lambda_{max} = 1.45 \mu}$$

Corresponding emissive power

$$E_{b\lambda} = \frac{c_1 \lambda_{max}^{-5}}{e^{\left(\frac{C_2}{\lambda_{max} T}\right)} - 1}$$

$$= \frac{0.374 \times 10^{-15} \times \left[1.45 \times 10^{-6}\right]^{-5}}{e^{\left(\frac{14.4 \times 10^{-3}}{1.45 \times 10^{-6} \times 2000}\right)} - 1}$$ (4 M)

$$= 4.09 \times 10^{11} W/m^2$$

3. Total emissive power (E_b):

From Stefan – Boltzmann law, we know

$E_b = \sigma T^4$

Where σ - Stefan – Boltzmann constant

$$= 5.67 \times 10^{-8}\ \text{W/m}^2\ \text{K}^4$$

$$E_b = 5.67 \times 10^{-8} \times (2000)^4$$ (5 M)

$$\boxed{E_b = 907.2 \times 10^3\ \text{W/m}^2}$$

5

The temperature of a black surface 0.25 m^2 of area is 650°C. Calculate, (i) 1. The total rate of energy emission, (ii) 2. The intensity of normal radiation, (iii) The wavelength of maximum monochromatic emissive power. (13 M)BTL4

Answer: Page 4.28-Dr.S.Senthil

1. We know

Emissive power $E_b = \sigma T^4$

$$= 5.67 \times 10^{-8} \times (923)^4$$

$$\boxed{E_b = 41151.8\ \text{W/m}^2}$$

Here Area = 0.25 m^2

$$\Rightarrow \quad E_b = 41151.8\ \text{W/m}^2 \times 0.25\ \text{m}^2$$

$$\boxed{E_b = 10.28 \times 10^3\ \text{Watts}}$$ (5 M)

2. We know

$$\text{Intensity} = I_n = \frac{E_b}{\pi}$$

$$= \frac{10.28 \times 10^3}{\pi}$$ (3 M)

$$I_n = 3274.7\ \text{W}$$

3. From Wien's law,

$$\lambda_{max}\ T = 2.9 \times 10^{-3}\text{m}$$

$$\lambda_{max} = \frac{2.9 \times 10^{-3}}{923}$$ (5 M)

$$\boxed{\lambda_{max} = 3.13 \times 10^{-6}\text{m}}$$

6

Calculate the heat exchange by radiation between the surfaces of two long cylinders having radii 120mm and 60mm respectively. The axis of the cylinder are parallel to each other. The inner cylinder is maintained at a temperature of 130°C and emissivity of 0.6. Outer cylinder is maintained at a temperature of 30°C and emissivity of 0.5.(13 M)BTL4

	Answer: Page 4.52-Dr.S.Senthil $Q = \bar{\varepsilon}\ \sigma A\left[T_1^4 - T_2^4\right]$ .....(1) [From equation No.27] where $\bar{\varepsilon} = \dfrac{1}{\dfrac{1}{\varepsilon_1} + \dfrac{A_1}{A_2}\left(\dfrac{1}{\varepsilon_2} - 1\right)}$ $\bar{\varepsilon} = \dfrac{1}{\dfrac{1}{0.6} + \dfrac{\pi D_1 L_2}{\pi D_2 L_2}\left(\dfrac{1}{0.5} - 1\right)}$ $[\because A = \pi DL]$ $= \dfrac{1}{\dfrac{1}{0.6} + \dfrac{0.12}{0.24}\left(\dfrac{1}{0.5} - 1\right)}$ $[\because\ L_1 = L_2 = 1]$ $\boxed{\bar{\varepsilon} = 0.46}$ $(1)\ \Rightarrow$ $Q_{12} = 0.46 \times 5.67 \times 10^{-8} \times \pi \times D_1 \times L \times \left[(403)^4 - (303)^4\right]$ $= 0.46 \times 5.67 \times 10^{-8} \times \pi \times 0.12 \times 1 \times \left[(403)^4 - (303)^4\right]$ (13 M) $\boxed{Q_{12} = 176.47\ \text{W}}$
7	**Emissivities of two large parallel plates maintained at 800°C and 300°C are 0.5 respectively. Find net radiant hat exchange per square metre for these plates. Find the percentage reduction in heat transfer when a polished aluminium radiation shield of emissivity 0.06 is placed between them. Also find the temperature of the shield. (13 M) (Jun '12)** BTL4 **Answer: Page 4.60-Dr. S. Senthil** Heat exchange between two large parallel plates without radiation shield is given by $Q_{12} = \bar{\varepsilon}\ \sigma A\left[T_1^4 - T_2^4\right]$

$$(1) \Rightarrow \; Q_{12} = 0.230 \times \sigma \times A \times [T_1^4 - T_2^4]$$

$$= 0.230 \times 5.67 \times 10^{-8} \times A \times \left[(1073)^4 - (573)^4\right]$$

$$\frac{Q_{12}}{A} = 15{,}879.9 \text{ W/m}^2$$ (3 M)

Heat transfer square metre without radiation shield

$$\boxed{\frac{Q_{12}}{A} = 15.87 \text{ k W/m}^2} \quad ......(1)$$

Heat exchange between plate 1 and radiation shield 3 is given by

$$(1) \Rightarrow \quad Q_{13} = \bar{\varepsilon}\sigma A \; [T_1^4 - T_2^4]$$

$$\bar{\varepsilon} = \frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_3} - 1}$$

$$\Rightarrow \qquad Q_{13} = \frac{\sigma \times A \; [T_1^4 - T_3^4]}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_3} - 1} .....(A)$$

Heat exchange between radiation shield 3 and plate 2 is given by

$$Q_{32} = \bar{\varepsilon}\sigma A \; [T_3^4 - T_2^4]$$

Where $\bar{\varepsilon} = \dfrac{1}{\frac{1}{\varepsilon_3} + \frac{1}{\varepsilon_2} - 1}$

$$\Rightarrow \qquad Q_{32} = \frac{\sigma \times A\left[T_3^4 - T_2^4\right]}{\frac{1}{\varepsilon_3} + \frac{1}{\varepsilon_2} - 1} .....(B)$$

We know $Q_{13} = Q_{32}$

$$\Rightarrow \quad T_3^4 = 0.926 \left[(1073)^4 - 0.926 \times (T_3)^4\right] + (573)^4$$

$$(T_3)^4 + 0.926 \; (T_3^4) = 1.33 \times 10^{12}$$

$$(1.926)\; (T_3)^4 = 1.33 \times 10^{12}$$

$$(T_3)^4 = 6.90 \times 10^{11}$$ (5 M)

$$\boxed{T_3 = 911.5 \text{ K}}$$

$$\boxed{\text{Radiation shield temperature } T_3 = 911.5 \text{ K}}$$

Substituting T_3 value in equation (A) (or) equation (B), Heat transfer with radiation shield

$$\Rightarrow \qquad Q_{13} = \frac{5.67\times10^{-8}\times A\times\left[(1073)^4-(911.5)^4\right]}{\frac{1}{0.3}+\frac{1}{0.06}-1}$$

$$\frac{Q_{13}}{A} = 1895.76\ \text{W/m}^2$$

Heat transfer with radiation shield

$$\Rightarrow \qquad \boxed{\frac{Q_{13}}{A} = 1.89\text{kW}/\text{m}^2} ......(2)$$

Reduction in heat loss due to radiation shield

$$= \frac{Q_{\text{without shield}} - Q_{\text{with shield}}}{Q_{\text{without shield}}} = \frac{Q_{12}-Q_{13}}{Q_{12}}$$

$$= \frac{15.87 - 1.89}{15.87}$$

$$= 0.88 = 88\%$$

(5 M)

8

Find the relative heat transfer between two large plane at temperature 1000 K and 500 K when they are 1. Black bodies 2. Gray bodies with emissivities of each surface is 0.7. (13 M)BTL4

Answer: Page 4.15-Dr.S.Senthil

Case 1: Heat exchange between two large parallel plate is given by

$$Q = \bar{\varepsilon}\ A\ \ \sigma\left[T_1^{\ 4} - T_2^{\ 4}\right]$$

For black bodies, $\bar{\varepsilon} = 1$

$$Q = A\ \ \sigma\left[T_1^{\ 4} - T_2^{\ 4}\right]$$

$$\frac{Q}{A} = 5.67\times10^{-8}\left[(1000)^4-(500)^4\right]$$

$$\boxed{\frac{Q}{A} = 53.15\times10^3\,\text{W}/\text{m}^2}$$

(5 M)

Case 2: $Q = \bar{\varepsilon}\ A\ \ \sigma\left[T_1^{\ 4} - T_2^{\ 4}\right]$

$$\bar{\varepsilon} = \frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

$$\bar{\varepsilon} = \frac{1}{\frac{1}{0.7} + \frac{1}{0.7} - 1}$$

$$\boxed{\bar{\varepsilon} = 0.538}$$

(8 M)

$$\Rightarrow Q = 0.538 \times A \times 5.67 \times 10^{-8}\left[(1000)^4 - (500)^4\right]$$

$$\boxed{\frac{Q}{A} = 28.6 \times 10^3 \ \text{W/m}^2}$$

9

Two parallel plates of size 3 m × 2 m are placed parallel to each other at a distance of 1 m. One plate is maintained at a temperature of 550°C and the other at 250°C and the emissivities are 0.35 and 0.55 respectively. The plates are located in a large room whose walls are at 35°C. If the plates located exchange heat with each other and with the room, calculate. (i) Heat lost by the plates, (ii) Heat received by the room. (13 M)BTL4

Answer: Page 4.121Dr.S.Senthil

Area $A_1 = 3 \times 2 = 6 \text{ m}^2$

$$\boxed{A_1 = A_2 = 6\text{m}^2}$$

Since the room is large $\boxed{A_3 = \infty}$

From electrical network diagram.

$$\frac{1-\varepsilon_1}{\varepsilon_1 A_1} = \frac{1-0.35}{0.35 \times 6} = 0.309$$

$$\frac{1-\varepsilon_2}{\varepsilon_2 A_2} = \frac{1-0.55}{0.55 \times 6} = 0.136$$

(2 M)

$$\frac{1-\varepsilon_3}{\varepsilon_3 A_3} = 0 \qquad [\because A_3 = \infty]$$

Apply $\frac{1-\varepsilon_3}{\varepsilon_3 A_3} = 0$, $\frac{1\text{-}\varepsilon_1}{\varepsilon_1 A_1} = 0.309$, $\frac{1-\varepsilon_2}{\varepsilon_2 A_2} = 0.136$ values in electrical network diagram.

To find shape factor F_{12} refer HMT data book, Page No.78.

$$X = \frac{b}{c} = \frac{3}{1} = 3$$

(3 M)

$$Y = \frac{a}{c} = \frac{2}{1} = 2$$

X value is 3, Y value is 2, corresponding shape factor
[From table]

F_{12} = 0.47

$$\boxed{F_{12} = 0.47}$$

We know that,

$F_{11} + F_{12} + F_{13} = 1$

But, $F_{11} = 0$

$$\Rightarrow \quad F_{13} = 1 - F_{12}$$

$$\Rightarrow \quad F_{13} = 1 - 0.47$$

(2 M)

$$\boxed{F_{13} = 0.53}$$

Similarly, $F_{21} + F_{22} + F_{23} = 1$

We know $F_{22} = 0$

$$\Rightarrow \quad F_{23} = 1 - F_{21}$$

$$\Rightarrow \quad F_{23} = 1 - F_{12}$$

(2 M)

$$F_{13} = 1 - 0.47$$

$$\boxed{F_{23} = 0.53}$$

From electrical network diagram,

$$\frac{1}{A_1F_{13}} = \frac{1}{6 \times 0.53} = 0.314 \qquad ....(1)$$

$$\frac{1}{A_2F_{23}} = \frac{1}{6 \times 0.53} = 0.314 \qquad ....(2)$$

(2 M)

$$\frac{1}{A_1F_{12}} = \frac{1}{6 \times 0.47} = 0.354 \qquad ....(3)$$

From Stefan – Boltzmann law, we know

$$E_b = \sigma\ T^4$$

$$E_{b1} = \sigma T_1^{\ 4}$$

$$= 5.67 \times 10^{-8} \left[823\right]^4$$

$$\boxed{E_{b1} = 26.01 \times 10^3 W/m^2} \qquad .....(4)$$

$$E_{b2} = \sigma\ T_2^{\ 4}$$

$$= 5.67 \times 10^{-8} \left[823\right]^4$$

$$\boxed{E_{b2} = 4.24 \times 10^3 W/m^2} \qquad .....(5)$$

$$E_{b3} = \sigma T_3^{\ 4}$$

$$= 5.67 \times 10^{-8} \left[308\right]^4$$

$$\boxed{E_{b3} = J_3 = 510.25\ W/m^2} \qquad .....(6)$$

At Node J_1:

$$\frac{E_{b1} - J_1}{0.309} + \frac{J_2 - J_1}{\frac{1}{A_1F_{12}}} + \frac{E_{b3} - J_1}{\frac{1}{A_1F_{13}}} = 0$$

[From diagram]

At node j_2

$$\frac{J_1 - J_2}{\frac{1}{A_1F_{12}}} + \frac{E_{b3} - J_2}{\frac{1}{A_2F_{23}}} + \frac{E_{b2} - J_2}{0.136} = 0$$

$$\Rightarrow \qquad -9.24J_1 + 2.82J_2 = -85.79 \times 10^3 \quad .....(7)$$

$$\Rightarrow \qquad 2.82J_1 - 13.3J_2 = -32.8 \times 10^3 \quad .....(8)$$

(2 M)

$$\boxed{\begin{aligned} J_2 &= 4.73 \times 10^3 W/m^2 \\ J_1 &= 10.73 \times 10^3 W/m^2 \end{aligned}}$$

10 **A furnace of 25 m² area and 12 m² volume is maintained at a temperature of 925°C over is entire volume. The total pressure of the combustion gases is 3 atm, the partial pressure of water vapour is 0.1 atm and that of CO_2 is 0.25 atm.Calculate the emissivity of the gaseous mixture. (13 M)**BTL4

Answer: Page 4.161-Dr.S.Senthil

$$L_m = 3.6 \times \frac{V}{A}$$

$$= 3.6 \times \frac{12}{25}$$

$$\boxed{L_m = 1.72 \text{ m}}$$

To find emissivity of CO_2

$$P_{CO_2} \times L_m = 0.25 \times 1.72$$

$$\boxed{P_{CO_2} \times L_m = 0.43 \text{ m-atm.}}$$

From HMT data book, Page No.90, we can find emissivity of CO_2.

$$\boxed{\varepsilon_{CO_2} \times C_{CO_2} = 0.18}$$

From graph, Emissivity of CO_2 = 0.15 , $\boxed{\varepsilon_{CO_2} = 0.15}$ (3 M)

To find correction factor for CO_2: Total pressure P = 3 atm.

$$P_{CO_2}\ L_m = 0.43 \text{ m-atm}$$

From HMT data book, Page No.91, we can find correction factor for CO_2.

From graph, we find $C_{CO_2} = 1.2$

$$\boxed{C_{CO_2} = 1.2}$$

$$\therefore\ \varepsilon_{CO_2} \times C_{CO_2} = 0.15 \times 1.72 \qquad .....(1)$$ (3 M)

To find emissivity of H_2O:

$P_{H_2O} \times L_m = 0.1 \times 1.72,$ $\boxed{P_{H_2O} \times L_m = 0.172}$

From HMT data book, Page No.92, we can find emissivity of H_2O.

From graph, Emissivity of H_2O = 0.15

$$\boxed{\varepsilon_{H_2O} = 0.15}$$ (3 M)

To find correction factor for H_2O:

	$\frac{P_{H_2O}+P}{2}=\frac{0.1+3}{2}=1.55\ \frac{P_{H_2O}+P}{2}=1.55, P_{H_2O}\ L_m=0.172.$ From HMT data book, Page No.94, we can find correction factor for H_2O. $\boxed{P_{CO_2}\ L_m+P_{H_2O}\ L_m=0.602}$ From graph, we find $C_{H_2O}=1.58$ $\boxed{C_{H_2O}=1.58}$ $\Rightarrow\ \varepsilon_{H_2O}\times C_{H_2O}=0.15\times1.58$ $\boxed{\varepsilon_{H_2O}\times C_{H_2O}=0.237}$ ....(2) Correction Factor for mixture of CO_2 and H_2O: $\frac{P_{H_2O}}{P_{H_2O}+P_{CO_2}}=\frac{0.1}{0.1+0.25}=0.285$ $\boxed{\frac{P_{H_2O}}{P_{H_2O}+P_{CO_2}}=0.285}$ $P_{CO_2}\times L_m+P_{H_2O}\times L_m=0.25\times1.72+0.1\times1.72$ (3 M) = 0.602. From HMT data book, Page No.95 we can find correction factor for mixture of CO_2 and H^2O. From graph, we find Δε = 0.045. $\boxed{\Delta\varepsilon=0.045}$ ....(3) Total emissivity of the gaseous mixture is $\varepsilon_{mix}=\varepsilon_{CO_2}\ C_{CO_2}+\varepsilon_{H_2O}\ C_{H_2O}-\Delta\varepsilon$ $\varepsilon_{mix}=0.18+0.237-0.045$ [From equation (1), (2) and (3)] (1 M) $\boxed{\varepsilon_{mix}=0.372}$
Part*C	
1	**The sun emits maximum radiation at λ = 0.52μ. Assuming the sun to be a black body,**

calculate the surface temperature of the sun. Also calculate the monochromatic emissive power of the sun's surface. (Dec 2016, May 2015)(15 M)BTL4

Answer: Page 4.25-Dr.S.Senthil

1. From Wien's law, we know

$$\lambda_{max}\ T = 2.9\times10^{-3}\text{mK}$$

[From HMT data book, Page No.71]

$$\Rightarrow \qquad T = \frac{2.9\times10^{-3}}{0.52\times10^{-6}}$$

(5 M)

$$\boxed{T = 5576\ K}$$

2. Monochromatic emissive power ($E_{b\lambda}$):

From Planck's law, we know

$$E_{b\lambda} = \frac{c_1\lambda^{-5}}{e^{\left(\frac{C_2}{\lambda T}\right)}-1}$$

[From HMT data book, Page No.71]

$$\text{where} \qquad C_1 = 0.374\times10^{-15}\,W\ m^2$$

$$C_2 = 14.4\times10^{-3}\ mK$$

$$\lambda\ = 0.52\times10^{-6}\ m$$

(5 M)

$$\Rightarrow \qquad E_{b\lambda} = \frac{0.374\times10^{-15}\times(0.52\times10^{-6})^{-5}}{e^{\left(\frac{14.4\times10^{-3}}{0.52\times10^{-6}\times5576}\right)}-1}$$

$$\boxed{E_{b\lambda} = 6.9\times10^{13}\,W/m^2}$$

(5 M)

2 **Two concentric spheres 30 cm and 40 cm in diameter with the space between them evacuated are used to store liquid air at - 130°C in a room at 25°C. The surfaces of the spheres are flushed with aluminium of emissivity ε = 0.05. Calculate the rate of evaporation of liquid air if the latent heat of vaporization of liquid air is 220 kJ/kg.(15 M)(Dec 2019, May 2017, Dec 2016, May 2014)**BTL4

Answer: Page 4.56-Dr.S.Senthil

Solution: This is heat exchange between large concentric sphere problems.

	Heat transfer $Q_{12} = \bar{\varepsilon}\ \sigma A_1\ [T_1^4 - T_2^4]$ ......(1) (5 M) Where $\bar{\varepsilon} = \dfrac{1}{\dfrac{1}{\varepsilon_1} + \dfrac{A_1}{A_2}\left(\dfrac{1}{\varepsilon_2} - 1\right)}$ $\bar{\varepsilon} = \dfrac{1}{\dfrac{1}{0.05} + \dfrac{4\pi r_1^2}{4\pi r_2^2}\left(\dfrac{1}{0.05} - 1\right)}$ $[\because\ \varepsilon_1 = \ \varepsilon_2 = 0.05; A = 4\pi r^2]$ (5 M) $= \dfrac{1}{\dfrac{1}{0.05} + \dfrac{(0.15)^2}{(0.20)^2}\left(\dfrac{1}{0.05} - 1\right)}$ $\boxed{\bar{\varepsilon} = 0.032}$ (5 M)
3	**Emissivities of two large parallel plates maintained at T₁ K and T₂ K are 0.6 and 0.6 respectively. Heat transfer is reduced 75 times when a polished aluminium radiation shields of emissivity 0.04 are placed in between them. Calculate the number of shields required.(15 M)**BTL4 **Answer: Page 4.75-Dr.S.Senthil** $Q_{in} = \dfrac{A\sigma\ [T_1^4 - T_2^4]}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_2}\left(\dfrac{2n}{\varepsilon_s}\right) - (n-1)}$ ....(1) Heat transfer without shield, i.e., n=0 (5 M) $(1) \Rightarrow \quad Q_{12} = \dfrac{A\sigma[T_1^4 - T_2^4]}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_2} - 1}$ ....(2) Heat transfer is reduced 75 times $\Rightarrow \quad \dfrac{Q_{\text{without shield}}}{Q_{\text{with shield}}} = 75$ (5 M) $\Rightarrow \quad \dfrac{Q_{12}}{Q_{13}} = 75$

$$\frac{(2)}{(1)} \Rightarrow \frac{\dfrac{A\sigma\,[T_1^4 - T_2^4]}{\dfrac{1}{\varepsilon_1}+\dfrac{1}{\varepsilon_2}-1}}{\dfrac{A\sigma\,[T_1^4 - T_2^4]}{\dfrac{1}{\varepsilon_1}+\dfrac{1}{\varepsilon_2}\dfrac{2n}{\varepsilon_s}-(n+1)}} = 75$$

$$\Rightarrow \quad \frac{\dfrac{1}{\varepsilon_1}+\dfrac{1}{\varepsilon_2}\dfrac{2n}{\varepsilon_s}-(n+1)}{\dfrac{1}{\varepsilon_1}+\dfrac{1}{\varepsilon_2}-1} = 75$$

$$\Rightarrow \quad \frac{\dfrac{1}{0.6}+\dfrac{1}{0.6}\;\dfrac{2n}{0.04}-(n+1)}{\dfrac{1}{0.6}+\dfrac{1}{0.6}-1} = 75$$

$$\Rightarrow \quad \frac{3.33+50n-(n-1)}{2.33} = 75$$

$$\Rightarrow \quad 50n\ n\text{-}1 = 171.67$$

$$49n - 1 = 171.67$$

(5 M)

$$49n = 172.67$$

$$n = 3.52 \approx 4$$

$$\boxed{n = 4}$$

The inner sphere of liquid oxygen container is 40 cm diameter and outer sphere is 50 cm diameter. Both have emissivities 0.05. Determine the rate at which the liquid oxygen would evaporate at -183°C when the outer sphere at 20°C. Latent heat of oxygen is 210 kJ/kg.(15 M) May 2BTL4

Answer: Page 4.90-Dr.S.Senthil

This is heat exchange between two large concentric spheres problem.

4 Heat transfer $Q = \bar{\varepsilon}\ \sigma A_1\left[T_1^4 - T_2^4\right]$ ......(1)

[From equation No.27]

$$\text{where } \bar{\varepsilon} = \frac{1}{\dfrac{1}{\varepsilon_1}+\dfrac{A_1}{A_2}\left(\dfrac{1}{\varepsilon_2}-1\right)}$$

(5 M)

	$$= \frac{1}{\frac{1}{0.05} + \frac{4\pi r_1^2}{4\pi r_2^2}\left(\frac{1}{0.05} - 1\right)} \qquad [\because\ A = 4\pi r^2]$$ $$= \frac{1}{\frac{1}{0.05} + \frac{r_1^2}{r_2^2}\left(\frac{1}{0.05} - 1\right)}$$ (5 M) $$= \frac{1}{\frac{1}{0.05} + \frac{(0.20)^2}{(0.25)^2}\left(\frac{1}{0.05} - 1\right)}$$ $$\boxed{\bar{\varepsilon} = 0.031}$$ $$(1) \Rightarrow Q_{12} = 0.031 \times 5.67 \times 10^{-8} \times 4 \times \pi\left[(90)^4 - (293)^4\right]$$ $$\boxed{Q_{12} = 6.45\ \text{W}}$$ [Negative sign indicates heat is transferred from outer surface to inner surface.] Rate of evaporation = $\frac{\text{Heat transfer}}{\text{Latent heat}}$ $$= \frac{6.45\ \text{W}}{210 \times 10^3\ \text{J/kg}}$$ $$= \frac{6.45\ \text{J/s}}{210 \times 10^3 \text{J/kg}}$$ $$\boxed{\text{Rate of evaporation} = 3.07 \times\ 10^{-5} \text{kg/s}}$$ (5 M)
5	**Emissivities of two large parallel plates maintained at 800°C and 300°C are 0.3 and 0.5 respectively. Find the net radiant heat exchange per square meter of the plates. If a polished aluminium shield (ε = 0.05) is placed between them. Find the percentage of reduction in heat transfer. (15 M) (May 17)** BTL4 **Answer: Page 4.92-Dr.S.Senthil** **Case 1 : Heat transfer without radiation shield:** Heat exchange between two large parallel plats without radiation shield is given by $$Q_{12} = \bar{\varepsilon}\ \sigma A\left[T_1^4 - T_2^4\right]$$ $$\bar{\varepsilon} = \frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

$$= \frac{1}{\frac{1}{0.3}+\frac{1}{0.5}-1}$$

$$\boxed{\bar{\varepsilon} = 0.230}$$

$$\Rightarrow \ Q_{12} = 0.230 \times 5.67 \times 10^{-8} \times A \times \left[(1073)^4 - (573)^4\right]$$

$$\boxed{\text{Heat transfer}\Big\} \frac{Q_{12}}{A} = 15.8 \times 10^3 \ \ W/m^2}$$

Case 2: Heat transfer with radiation shield:

Heat exchange between plate 1 and radiation shield 3 is given by

$$Q_{13} = \bar{\varepsilon}\sigma A \ [T_1^4 - T_2^4]$$

$$\text{where} \qquad \bar{\varepsilon} = \frac{1}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_3}-1}$$

(5 M)

$$\Rightarrow \qquad Q_{13} = \frac{\sigma A \ [T_1^4 - T_3^4]}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_3}-1} \text{.....(A)}$$

Heat exchange between radiation shield 3 and plate 2 is given by

$$Q_{32} = \bar{\varepsilon}\sigma A \ [T_3^4 - T_2^4]$$

$$\text{Where} \qquad \bar{\varepsilon} = \frac{1}{\frac{1}{\varepsilon_3}+\frac{1}{\varepsilon_2}-1}$$

$$\Rightarrow \qquad Q_{32} = \frac{\sigma A\left[T_3^4 - T_2^4\right]}{\frac{1}{\varepsilon_3}+\frac{1}{\varepsilon_2}-1} \text{.....(B)}$$

We know $Q_{13} = Q_{32}$

$$\Rightarrow \qquad = \frac{\sigma A\,[T_1^4 - T_3^4]}{\dfrac{1}{\varepsilon_1}+\dfrac{1}{\varepsilon_3}-1} = \frac{\sigma A\,[T_3^4 - T_2^4]}{\dfrac{1}{\varepsilon_3}+\dfrac{1}{\varepsilon_2}-1}$$

$$\Rightarrow \qquad = \frac{(1073)^4\text{-}\,(T_3^4)}{\dfrac{1}{0.3}+\dfrac{1}{0.05}-1} = \frac{(T_3^4)-(573)^4]}{\dfrac{1}{0.3}+\dfrac{1}{0.05}-1}$$

(5 M)

$$\Rightarrow \qquad \frac{(1073)^4-(T_3^4)}{22.3} = \frac{(T_3^4)-(573)^4}{21}$$

$$\Rightarrow \qquad 2.78\times10^{13} - 21T_3^4 = 22.3T_3^4 - 2.4\times10^{13}$$

$$\Rightarrow \qquad 3.02\times10^{13} = 43.3T_3^4$$

$$\text{Shield temperature} \Rightarrow \boxed{T_3 = 913.8\ \text{K}}$$

Substitute T_3 value in equation (A) or (B).

Substituting T_3 value in equation (A) (or) equation (B),

$$\left.\begin{array}{r}\text{Heat transfer with}\\ \text{radiation shield}\end{array}\right\} Q_{13} = \frac{5.67\times10^{-8}\times A\times\left[(1073)^4-(913.8)^4\right]}{\dfrac{1}{0.3}+\dfrac{1}{0.05}-1}$$

$$\boxed{\frac{Q_{13}}{A} = 1594.6\ \text{W}/\text{m}^2} \qquad ......(2)$$

$$\left.\begin{array}{l}\text{Reduction in heat loss}\\ \text{due to radiation shield}\end{array}\right\} = \frac{Q_{\text{without shield}} - Q_{\text{with shield}}}{Q_{\text{without shield}}}$$

$$= \frac{Q_{12}-Q_{13}}{Q_{12}}$$

(5 M)

$$= \frac{15.8\times10^3\text{- }1594.6}{15.8\times10^3}$$

$$= 0.899 = 89.9\%$$

UNIT V MASS TRANSFER

Basic Concepts – Diffusion Mass Transfer – Fick‟s Law of Diffusion – Steady state Molecular Diffusion – Convective Mass Transfer – Momentum, Heat and Mass Transfer Analogy –Convective Mass Transfer Correlations.

PART * A

Q.No.	Questions
1	**What is mass transfer?** BTL2 The process of transfer of mass as a result of the species concentration difference in a mixture is known as mass transfer.
2	**Give the examples of mass transfer.** BTL3 Some examples of mass transfer. 1. Humidification of air in cooling tower 2. Evaporation of petrol in the carburetor of an IC engine. **3.** The transfer of water vapour into dry air.
3	**What are the modes of mass transfer?** BTL2 There are basically two modes of mass transfer, 1. Diffusion mass transfer 2. Convective mass transfer
4	**What is molecular diffusion? (Jun ’13)** BTL2 The transport of water on a microscopic level as a result of diffusion from a region of higher concentration to a region of lower concentration in a mixture of liquids or gases is known as molecular diffusion.
5	**What is Eddy diffusion?** BTL2 When one of the diffusion fluids is in turbulent motion, eddy diffusion takes place.
6	**What is convective mass transfer?** BTL2 Convective mass transfer is a process of mass transfer that will occur between surface and a fluid medium when they are at different concentration.
7	**State Fick’s law of diffusion. (AU June 06, May’05).**BTL2 The diffusion rate is given by the Fick’s law, which states that molar flux of an element per unit area is directly proportional to concentration gradient.

	$\frac{m_a}{A} = -D_{ab}\frac{dC_a}{dx}$ where, $\frac{ma}{A}$ – Molar flux, $\frac{kg\text{ -mole}}{s\text{-}m^2}$ D_{ab} Diffusion coefficient of species a and b, m^2/s $\frac{dC_a}{dx}$ – concentration gradient, kg/m^3
8	**What is free convective mass transfer?** BTL2 If the fluid motion is produced due to change in density resulting from concentration gradients, the mode of mass transfer is said to be free or natural convective mass transfer. Example : Evaporation of alcohol.
9	**Define forced convective mass transfer.** BTL1 If the fluid motion is artificially created by means of an external force like a blower or fan, that type of mass transfer is known as convective mass transfer. Example: The evaluation if water from an ocean when air blows over it.
10	**Define Schmidt Number.** BTL1 It is defined as the ratio of the molecular diffusivity of momentum to the molecular diffusivity of mass. $Sc = \frac{\text{Molecular diffusivity of momentum}}{\text{Molecular diffusivity of mass}}$
11	**Define Scherwood Number.** BTL1 It is defined as the ratio of concentration gradients at the boundary. $Sc = \frac{h_m x}{D_{ab}}$ hm – Mass transfer coefficient, m/s D_{ab} – Diffusion coefficient, m^2/s x – Length, m
12	**Give two examples of convective mass transfer.** BTL3. Evaporation of alcohol, Evaporation of water from an ocean when air blows over it.
13	**Define Mass concentration and molar concentration.** BTL 1

Mass Concentration = Mass of component/Unit volume of mixture

Molar Concentration = Number of moles of component/ Unit volume of mixture.

14 **Define mass fraction and molar fraction.** BTL 1

Mass fraction=Mass concentration of a species/ Total mass density

Molar fraction = Mole concentration of a species/ Total molar concentration.

Part * B

1 **Explain steady diffusion through a plane membrane.(13 M)(Dec 2016)** BTL2

Answer: Page::5.4-Dr.S.Senthil

Consider a plane membrane of thickness L, containing fluid ‘a’. The concentrations of the fluid at the opposite wall faces are C_{a1} and C_{a2} respectively.

$$\frac{d2C_a}{dx^2} = 0$$

Integrating above equation (3 M)

$$\frac{dC_a}{dx} = C_1$$

$$\Rightarrow \text{ Ca} = C_1 x + C_2 \text{..........(2)}$$

Apply boundary condition

At, x = L

$C_{a1} = C_2$

$C_{a2} = C_1 L + C_2$

$C_{a2} = C_1 L + C_{a1}$

$$\Rightarrow C_1 = \left[\frac{C_{a2} - C_{a1}}{L}\right]$$

Substituting C_1, C_2 values in equation (2) (3 M)

$$(2) \Rightarrow C_{a1} = \frac{C_{a2} - C_{a1}}{L} x + C_{a1}$$

From Fick’s law we know

Molar flux, $\frac{m_a}{A} = -D_{ab} \frac{dC_a}{DX}$ (3 M)

$$\Rightarrow \frac{M_a}{A} = -D_{ab}\frac{d}{dx}\left[\left[\frac{C_{a2}-C_{a1}}{L}\right]x + C_{a1}\right]$$

where, $\frac{m_a}{A}$ – Molar Flux - $\frac{\text{kg-mole}}{\text{s-m}^2}$

D_{ab} – diffusion coefficient - $\left[\frac{m^2}{S^2}\right]$

C_{a1} – Concentrations at inner side - $\frac{\text{kg-mole}}{m^3}$

L – Thickness, For cylinders.

$$L = r_2 - r_1$$

$$A \frac{2\pi L(r_2 - r_1)}{\ln\left[\frac{r_2}{r_1}\right]} \text{ (2 M)}$$

$A = 4\pi r_1 r_2$

where,

for sphere, L = $r_2 - r_1$, r_1 = Inner radius - m (2 M)

r_2 = Outer radius - m

L = Length - m

2 **Helium diffuses through a plane membrane of 2 mm thick. At the inner side the concentration of helium is 0.25 kg mole/m^3. At the outer side the concentration of helium is 0.007 kg mole/m^3. What is the diffusion flux of helium through the membrane. Assume diffusion coefficient of helium with respect to plastic is 1 × 10^{-9} m^2/s. (Nov 2018, Dec 2016, May 2013)(8 M)**BTL4

Answer: Page: 5.13-Dr.S.Senthil

We know, for plane membrane

$$\frac{m_o}{A} = \frac{D_{ab}}{L}\left[C_{a1} - C_{a2}\right] \quad \text{[From equation 3]} \text{ (4 M)}$$

$$\text{Molar flux, } \frac{m_a}{A} = \frac{1\times10^{-9}}{.002}[.025 - .007]$$

$$\frac{m_a}{A} = 9\times10^{-9}\frac{\text{kg}-\text{mole}}{\text{s}-\text{m}^2} \text{ (4 M)}$$

3 **Gaseous hydrogen is stored in a rectangular container. The walls of the container are of steel having 25 mm thickness. At the inner surface of the container, the molar concentration of hydrogen in the steel is 1.2 kg mole/m^3 while at the outer surface of the container the molar concentration is zero, calculate the molar diffusion flux for hydrogen through the steel. Take**

	diffusion coefficient for hydrogen in steel is 0.24 × 10^{-12} m^2/s. (5 M)BTL4 **Answer: Page: 5.18-Dr.S.Senthil** $\frac{m_a}{A} = \frac{D_{ab}}{L}\left[C_{a1} - C_{a2}\right]$ $\text{Molar Flux,} = \frac{0.24\times10^{-12}}{25}[1.2-0]$ (5 M) $\frac{m_a}{A} = 1.15\times10\text{-}11\ \frac{\text{kg-mole}}{\text{s-m}^2}$
4	**Oxygen at 25°C and pressure of 2 bar is flowing through a rubber pipe of inside diameter 25 mm and wall thickness 2.5 mm. The diffusivity of O2 through rubber is 0.21 × 10^{-9} m^2/s and the solubility of O2 in rubber is 3.12 × 10^{-3}** $\frac{\text{kg}-\text{mole}}{\text{m}^3-\text{bar}}$**. Find the loss of O_2 by diffusion per metre length of pipe. (13 M)**BTL4 **Answer: Page: 5.13-Dr.S.Senthil** We know, $\frac{m_a}{A} = \frac{D_{ab}\left[C_{a1} - C_{a2}\right]}{L}$ $\text{For cylinders, L} = r_2 - r_1;\ A = \frac{2\pi L\ (r_2 - r_1)}{\ln\left[\frac{r_2}{r_1}\right]}$ (5 M) $\text{Molar flux, (1)} \Rightarrow \frac{m_a}{2\pi L(r_2 - r_1)} = \frac{D_{ab}\left[C_{a1} - C_{a2}\right]}{(r_2 - r_1)}$ $\Rightarrow m_a = \frac{2\pi L.D_{ab}\left[C_{a1} - C_{a2}\right]}{\ln\frac{r_2}{r_1}} \quad [\because \text{ Length = 1m})$ (8 M) $m_a = 4.51\times10^{-11}\frac{\text{kg}-\text{mole}}{\text{s}}.$
5	**Co_2 and air experience equimolar counter diffusion in a circular tube whose length and diameter are 1.2 m, d is 60 mm respectively. The system is at a total pressure of 1 atm and a temperature of 273 k. The ends of the tube are connected to large chambers. Partial pressure of CO_2at one end is 200 mm og Hg while at the other end is 90mm of Hg. Calculate the following.1. Mass transfer rate of Co_2 and2. Mass transfer rate of air. (13 M)**BTL4 **Answer: Page: 5.28-Dr.S.Senthil**

P_{a1} = 200 mm of Hg = $\frac{200}{760}$bar

$\boxed{P_{a1} = 0.263 \text{ bar}}$ [$\therefore$ 1 bar = 760 mm of Hg]

$\Rightarrow \boxed{P_{a1} = 0.263 \times 10^5 N/m^2}$ [$\therefore$1 bar = $10^5 N/m^2$]

Partial pressure of CO_2 at other end

P_{a2} = 90 mm of Hg = $\frac{90}{760}$bar

$\boxed{P_{a2} = 0.118 \text{ bar}}$

$\Rightarrow \boxed{P_{a2} = 0.118 \times 10^5 N/m^2}$ (3 M)

We know, for equimolar counter diffusion, Molar flux, $\frac{m_a}{A} = \frac{D_{ab}}{GT}\left[\frac{P_{a1} - P_{a2}}{x_2 - x_1}\right]$ ....(1)

Where, D_{ab} – Diffusion coefficient – $m^2 s$

The diffusion coefficient – m^2/s

$\Rightarrow D_{ab} = 4.28 \times 10^{-3} \ m^2/h$

[From HMT data book, Page No.185]

$\Rightarrow D_{ab} = \frac{42.8 \times 10^{-3}}{3600} m^2/s$

$\Rightarrow \boxed{D_{ab} = \ 1.18 \times 10^{-5} m^2/s}$

G - Universal gas constant = 8314 $\frac{J}{\text{kg-mole-k}}$

$$(1) \Rightarrow \frac{m_a}{A} = \frac{1.18\times10^{-5}}{8314\times273}\left[\frac{0.263\times10^{5}-0.118\times10^{5}}{1.2}\right]$$

$$\text{Molar flux, } \frac{m_a}{A} 6.28\times10^{-8}\,\frac{\text{kg}-\text{mole}}{\text{m}^2-\text{s}}$$ (5 M)

$$\text{Molar flux of } CO_2,\ \frac{m_a}{A} = 6.28\times10^{-8}\,\frac{\text{kg}-\text{mole}}{\text{m}^2-\text{s}}$$

we know, Area, A = $\frac{\pi}{4}d_2 = \frac{\pi}{4}\times(0.060)^2$,

$$\underbrace{A = 2.82\times10^{-3}\text{m}^2}$$

$$\Rightarrow \frac{m_a}{A} = 6.28\times10^{-8}$$

$$m_a = 6.28\times10^{-8}\times2.82\times10^{-3}$$

$$m_a = 1.77\times10^{-10}\,\frac{\text{kg}-\text{mole}}{\text{s}}$$

We know,

Mass transfer rate = Molar transfer × Molecular weight of CO_2

$$= 1.77\times10^{-10}\times44$$

[∵ Molecular weight of CO_2 = 44, refer HMT data book, Page: No.187]

$$\boxed{\text{Mass transfer rate of } CO_2 = 7.78\times10^{-9}\text{kg/s}}$$

We know,

Molar transfer rate of air, m_b =

$$-1.77\times10^{-10}\,\frac{\text{kg}-\text{mole}}{\text{s}}\ [\because m_a = m_b]$$

Mass transfer rate = Molar transfer × Molecular weight

of air of air of air

= 1.77 × $10^{-10}\times29$ (5 M)

$$\boxed{\text{Mass transfer rate of air} = -5.13\times10^{-9}\text{kg/s.}}$$

6 **Two large tanks, maintained at the same temperature and pressure are connected by a circular 0.15 m diameter direct, which is 3 k in length. One tank contains a uniform mixture of 60 mole % ammonia and 40 mole % air and the other tank contains a uniform mixture of 20 mole % air and the other tank contains a uniform mixture of 20 mole % ammonia and 80**

mole % air. The system is at 273 K and 1.013 × 10^5 pa. Determine the rate of ammonia transfer between the two tanks. Assuming a steady state mass transfer. (13 M)BTL4

Answer: Page: 5.31-Dr.S.Senthil

We know, for equimolar counter diffusion,

$$\text{Molar flux, } \frac{m_a}{A} = \frac{D_{ab}}{GT}\left[\frac{P_{a1} - P_{a2}}{x_2 - x_1}\right]$$

Where,

G – Universal gas constant = 8314 $\frac{J}{kg - mole - k}$ (4 M)

Area, A = $\frac{\pi}{4} d_2 = \frac{\pi}{4} \times (0.15)^2$

D_{ab} = Diffusion coefficient of ammonia with air = 77.8× 10^{-3} m^2/h [From HMT data book, Page: No.185]

$$\Rightarrow D_{ab} = \frac{77.8 \times 10^{-3} m^2}{3600s}$$

$$\Rightarrow \boxed{D_{ab} = 2.16 \times 10^{-5}\ m^2/s}$$ (4 M)

$$(1) \Rightarrow \frac{m_a}{0.017} = \frac{2.16 \times 10^{-5}}{8314 \times 273}\left[\frac{0.6 \times 10^5 - 0.2 \times 10^5}{3}\right]$$

$$\text{Molar transfer rate of ammonia, } m_a = 2.15 \times 10^{-9} \frac{kg - mole}{s}$$

$$\begin{array}{lll} \text{Mass transfer} & = \text{Molar transfer rate} & \times\text{Molecular of} \\ \text{rate of ammonia} & \text{of ammonia} & \text{ammonia weight} \end{array}$$

$$= 2.15 \times 10^{-9} \times 17$$ (5 M)

$$\boxed{\text{Mass transfer rate of ammonia} = 3.66 \times 10^{-8} kg/s}$$

7

Determine the diffusion rate of water from the bottom of a test tube of 25 mm diameter and 35 mm long into dry air at 25°C. Take diffusion coefficient of water in air is 0.28 × 10^{-4} m^2/s. (13 M)(Nov 2018, Dec 2016, May 2013)BTL4

Answer: Page: 5.35-Dr.S.Senthil

We know, for isothermal evaporation.

Molar flux, $\frac{m_a}{A} = \frac{D_{ab}}{GT}\frac{P}{(x_2 - x_1)} in\left[\frac{P - P_{w2}}{P - P_{w1}}\right]$ ....(1)

[From equation (9)]

Where,

G - Universal gas constant - 8314 $\frac{J}{kg\text{ -mole-k}}$

$P - \text{Totalpressure} = 1\text{ bar} = 1\times10^5 N/m^2$ (5 M)

P_{w1} – Partial pressure at the bottom of the test tube

Corresponding to saturation temperature 25°C

At 25°C

$$\boxed{P_{w1} = 0.03166 \text{ bar}}$$

$$\boxed{P_{w1} = 0.03166\times10^5 N/m^2}$$

P_{w2} – Partial pressure at the top of the test tube, that is zero

Area, A = $\frac{\pi}{4}d^2 = \frac{\pi}{4}\times(0.025)^2$

$A = 4.90\times10^{-4} m^2$

Area A = (1) $\Rightarrow$ $\frac{m_a}{4.90\times10^{-4}}$

$$= \frac{0.28\times10^{-4}}{8314\times298}\times\frac{1\times10^5}{0.035}\ln\left[\frac{1\times10^5 - 0}{1\times10^5 - 0.03166\times10^5}\right]$$ (5 M)

$$\boxed{\text{Molar rate of water vapour } m_a = 5.09\times10^{-10}\frac{kg-mole}{s}.}$$

We know that,

Mass rate of water vapour = Molar rate of water vapour × Molecular weight of water vapour

[∴ Molecular weight of steam = 18 - Refer HMT data book] (3 M)

Mass transfer rate of water = $9.162\times10^{-9} kg/s$.

8 **Estimate the rate of diffusion of water vapour from a pool of water at the bottom of a well which is 6.2 m deep and 2.2 m diameter to dry ambient air over the top of the well. The entire system may be assumed at 30°C and one atmospheric pressure. The diffusion coefficient is 0.24 × 10^{-4} m^2/s. (13 M)**BTL4

Answer: Page: 5.38-Dr.S.Senthil

We know, for isothermal evaporation,

$$\frac{ma}{A} = \frac{D_{ab}}{GT}\frac{P}{(x_2 - x_1)} in\left[\frac{P - P_{w2}}{P - P_{w1}}\right] \quad ....(1)$$

Molar flux, where,

(5 M)

$$\text{Area, A} = \frac{\pi}{4}d^2 = \frac{\pi}{4}\times(2.2)^2$$

$$\boxed{A = 3.80\ m^2}$$

G – Universal gas constant – 8314 $\frac{J}{kg - mole - k}$

P_{w1} – Partial pressure at the bottom of the test tube corresponding to saturation temperature 30°C

At 30°C

P_{w1} = 0.04241 bar

$$\boxed{P_{w1} = 0.04241\times10^5 N/m^2}$$

P_{w2} = 0

$$(1) \Rightarrow ma/3.80 =$$

$$\frac{0.24\times10^{-4}}{8314\times303}\times\frac{1\times10^5}{6.2} in\left[\frac{1\times10^5 - 0}{1\times10^5 - 0.04241\times10^5}\right]$$

(5 M)

$$\Rightarrow\ m_a = 2.53\times10^{-8}\ \frac{kg - mole}{s}$$

$$\text{Molar rate of water} = 2.53\times10^{-8}\ \frac{kg - mole}{s}$$

We know,

Mass rate of water vapour = Molar rate of water vapour × Molecular weight of steam

$= 2.53\times10^{-8}\times18 = 4.55\times10^{-7} kg/s$

Diffusion rate of water = 4.55 $\times10^{-7} kg/s$. (3 M)

9 **An open pan 210 mm in diameter and 75 mm deep contains water at 25°C and is exposed to dry atmospheric air. Calculate the diffusion coefficient of water in air. Take the rate of diffusion of water vapour is 8.52 × 10^{-4} kg/h.(13 M)** BTL4

Answer: Page: 5.40-Dr.S.Senthil

	$\frac{m_a}{A} = \frac{D_{ab}}{GT}\frac{P}{(x_2 - x_1)} \times in\left[\frac{P-P_{w2}}{P-P_{w1}}\right]$ $m_a = \frac{D_{ab}\times A}{GT}\frac{P}{(x_2-x_1)}\times in\left[\frac{P-P_{w2}}{P-P_{w1}}\right]$ We know that, Mass rate of water vapour = Molar rate of water vapour × Molecular weight of steam $2.36\times10^{-7} = \frac{D_{ab}\times A}{GT}\times\frac{P}{(x_2-x_1)}\times in\left[\frac{P-P_{w2}}{P-P_{w1}}\right]\times18....(1)$ where, $A - \text{Area} = \frac{\pi}{4}d^2 = \frac{\pi}{4}\times(0.210)^2 = 0.0346\ m^2$ (8 M) $G -$ Universal gas constant = $8314\frac{1}{\text{kg-mole-k}}$ $P -$ total pressure = 1 bar = $1\times10^5\ N/m^2$ $P_{w1} -$ Partial pressure at the bottom of the test tube corresponding to saturation temperature 25°C At 25°C $P_{w1} = 0.03166$ bar $P_{w1} = 0.03166\times10^5\ N/m^2$ $P_{w2} =$ Partial pressure at the top of the pan, that is zero $P_{w2} = 0$ $(1) \Rightarrow 2.36\times10^{-7}$ $= \frac{D_{ab}\times.0346}{8314\times298}\times\frac{1\times10^5}{0.075}\times ln\left[\frac{1\times10^5-0}{1\times10^5-0.03166\times10^5}\right]\times18$ (5 M) $D_{ab} = 2.18\times10^{-5}\ m^2/s.$
10	**Estimate the diffusion rate of water from the bottom of a test tube 10mm in diameter and 15cm long into dry atmospheric air at 25°C. Diffusion coefficient of water into air is 0.255 × 10^{-4} m^2/s., (13 M)** BTL4 **Answer: Page: 5.28-Dr.S.Senthil** We know that for isothermal evaporation.

$$\text{Molar flux, } \frac{m_a}{A} - \frac{D_{ab}}{GT}\ln\left[\frac{P-P_{w2}}{P-P_{w1}}\right].....(1)$$

$$A - \text{Area} = \frac{\pi}{4}d^2 = \frac{\pi}{4}\times(.010)^2 = 7.85\times10^{-5}m^2$$

(5 M)

$$G - \text{Universal gas constant} = 8314\frac{J}{kg-mole-k}$$

$$P \text{ - Total pressure = 1 bar = 1 } \times10^5 \text{ N/m}^2$$

P_{w1} – Partial pressure at the bottom of the test tube corresponding to saturation temperature 25°C

At 25°C,

P_{w1} = 0.03166 bar

$P_{w1} = 0.03166 \times 10^5 N/m^2$

P_{w2} = Partial pressure at the top of the test tube that is zero.

P_{w2} = 0

$$(1) \Rightarrow \frac{m_a}{7.85\times10^{-5}}$$

$$= \frac{0.255\times10^{-4}}{8314\times298}\times\frac{1\times10^5}{0.15}\times\ln\left[\frac{1\times10^5-0}{1\times10^5-0.03166\times10^5}\right]$$ (5 M)

$$\text{Molar rate of water vapour, } m_a = 1.73\times10^{-11}\frac{kg-mole}{s}$$

We know that,

Mass rate of Water vapour = Molar rate of water vapour × Molecular weight of steam

$= 1.73\times10^{-11}\times18$

[∴ Molecular weight of steam = 18. Refer HMT data book]

$$\boxed{\text{Mass rate of water vapour} = 3.11\times10^{-10} kg/s.}$$

(3 M)

Part*C

1

Explain FICK's Law of Diffusion. (15 M)BTL2

Answer: Page: 5.3-Dr.S.Senthil

Consider a system shown in figure.

A partition separates the two gases a and b. When the partition is removed, the two gases

	diffuses through one other until the equilibrium is established throughout the system. (5 M) The diffusion rate is given by the Fick's law, which states that molar flux of an element per unit area is directly proportional to concentration gradient. $\frac{m_a}{A} \propto \frac{dc_a}{dx}$ $\frac{m_a}{A} = -D_{ab}\frac{dc_a}{dx}$ (5 M) $Na\frac{m_a}{A} - D_{ab}\frac{dc_a}{dx}$ where, $N_a = \frac{ma}{A}$ – Molar flux Unit is $\frac{kg\text{-}mole}{s\text{-}m^2}$ (or) Mass flux unit is $\frac{kg}{s\text{-}m^2}$ D_{ab} – Diffusion coefficient of species a and b - $\frac{m^2}{s}$ (5 M) $\frac{dc_a}{dx}$ – Concentration gradient
2	**Hydrogen gases at 3 bar and 1 bar are separated by a plastic membrane having thickness 0.25 mm. the binary diffusion coefficient of hydrogen in the plastic is 9.1 × 10^{-3} m^2/s. The solubility of hydrogen in the membrane is 2.1 × 10^{-3} $\frac{kg - mole}{m^3\ bar}$. An uniform temperature condition of 20° is assumed.(15 M)**BTL4 **Answer: Page: 5.19-Dr.S.Senthil** 1. Molar concentration on inner side, C_{a1} = Solubility × inner pressure C_{a2} = 2.1 × 10^{-3}× 3 C_{a1} = 6.3 × 10^{-3} $\frac{kg\ \text{-}\ mole}{m^3}$ Molar concentration on outer side C_{a1} = solubility × Outer pressure

$C_{a2} = 2.1 \times 10^{-3} \times 1$

$C_{a2} = 2.1 \times 10^{-3} \frac{\text{kg - mole}}{\text{m}^3}$ (5 M)

2. We know

$$\frac{m_o}{A} = \frac{D_{ab}}{L}\left[C_{a1} - C_{a2}\right]$$

$$\text{Molar flux, } = \frac{9.1}{} - \frac{(6.3\times10^{-3} - 2.1\times10^{-3})}{.25\times10^{-3}}\left[1.2-0\right] \quad \text{(5 M)}$$

$$\frac{m_a}{A} = 1.52\times10^{-6} \ \frac{\text{kg-mole}}{\text{s-m}^2}$$

3. Mass flux = Molar flux × Molecular weight

$$= 1.52\times10^{-6} \frac{\text{kg} - \text{mole}}{\text{s} - \text{m}^2} \times 2 \text{ mole}$$

$$[\because \text{ Molecular weight of } H_2 \text{ is } 2] \text{(5 M)}$$

$$\text{Mass flux} = 3.04\times10^{-6} \frac{\text{kg}}{\text{s} - \text{m}^2}.$$

3

Explain steady state Equimolar counter diffusion.(15 M)BTL2

Answer: Page: 5.23-Dr.S.Senthil

Consider two large chambers a and b connected by a passage as shown in figure.

N_a and N_b are the steady state molar diffusion rates of components a and b respectively.

Equimolar diffusion is defined as each molecule of ‘a’ is replaced by each molecule of ‘b’ and vice versa. The total pressure $P = P_a + P_b$ is uniform throughout the system.

$P = P_a + P_b$

Differentiating with respect to x

$$\frac{dp}{dx} = \frac{dp_a}{dx} + \frac{dp_h}{dx}$$

Since the total pressure of the system remains constant under steady state conditions.

$$\frac{dp}{dx} = \frac{dp_a}{dx} + \frac{dp_h}{dx} = 0$$

(5 M)

$$\Rightarrow \boxed{\frac{dp_a}{dx} = -\frac{dp_h}{dx}}$$

Under steady state conditions, the total molar flux is zero.

$$\Rightarrow N_a + N_b = 0$$

$$N_a = -N_b$$

$$\Rightarrow -D_{ab}\frac{A}{GT}\frac{dp_a}{dx} = D_{ab}\frac{A}{GT}\frac{dp_a}{dx}.........(5)$$

From Fick's law,

$$Na = -D_{ab}\frac{A}{GT}\frac{dp_a}{dx}$$

$$Nb = D_{ba}\frac{A}{GT}\frac{dp_b}{dx}$$

We know

$$\frac{dp_b}{d_x} - \frac{dp_a}{d_x}$$

(5 M)

substitute in Equation (5)

$$(5) \Rightarrow -D_{ab}\frac{A}{GT}\frac{dp_a}{dx} = -D_{ba}\frac{A}{GT}\frac{dp_a}{dx}$$

$$\Rightarrow D_{ab} = D_{ba} = D$$

We know,

$$Na = -D_{ab}\frac{A}{GT}\frac{dp_a}{dx}$$

interesting

$$N_a = \frac{m_a}{A} = \frac{D_{ab}}{GT}\int_1^2 \frac{dp_a}{dx}$$

$$\text{Molar flux, } Na = \frac{m_a}{A} = \frac{D_{ab}}{GT}\left[\frac{P_{a1} - P_{a2}}{x_2 - x_1}\right].....(6)$$

similarly,

$$\text{Molar flux, } N_b = \frac{m_b}{A} = \frac{D_{ab}}{GT}\left[\frac{P_{b1} - P_{b2}}{x_2 - x_1}\right]......(7)$$

(5 M)

Solved Problems on Equimolar Counter Diffusion

4

Ammonia and air in equimolar counter diffusion in a cylindrical tube of 2.5 mm diameter and 15m length. The total pressure is 1 atmosphere and the temperature is 25°C. One end of the tube is connected to a large reservoir of ammonia and the other end of the tube is open to atmosphere. If the mass diffusivity for the mixture is 0.28×10^{-4} m^2/s. Calculate the following, a) Mass rate of ammonia in kg/h, b) Mass rate of air in kg/h(15 M)BTL4

Answer: Page: 5.26-Dr.S.Senthil

Total pressure $P = P_{a1} + P_{a2}$

1 bar = $P_{a1} + 0$ [$\because$ open to atmosphere. So, $P_{a2} = 0$]

$$\Rightarrow P_{a1} = 1\,\text{bar}$$

$$\Rightarrow \boxed{P_{a1} = 1 \times 10^5 N/m^2}$$

$$\boxed{P_{a2} = 0}$$

For equimolar counter diffusion

$$\text{Molar flux, } \frac{m_a}{A} = \frac{D_{ab}}{GT}\left[\frac{P_{a1} - P_{a2}}{x_2 - x_1}\right] \text{[From equation 6] ...(1)}$$ (5 M)

Where, G – Universal gas constant = $8314 \ \frac{J}{kg - mole - k}$

$$A - \text{Area} = \frac{\pi}{4} d^2$$

$$= \frac{\pi}{4}(2.5 \times 10^{-3})^2$$

$$A = 4.90 \times 10^{-6} m^2$$ (5 M)

$$(1) \Rightarrow \frac{ma}{4.90 \times 10^{-6}} = \frac{0.28 \times 10^{-4}}{8314 \times 298} x \left[\frac{1 \times 10^5 - 0}{15}\right]$$

Molar transfer rate of ammonia, $m^a = 3.69 \times 10^{-13} \frac{kg - mole}{s}$.

We know,

Mass transfer rate of ammonia = Molar transfer rate of ammonia × Molecular of weight of ammonia

Mass transfer rate of ammonia = $3.69 \times 10^{-13} \times 17$

Molecular weight of ammonia = 17,

[refer HMT data, Page: No.187]

$\boxed{\text{Mass transfer rate of ammonia} = 6.27 \times 10^{-12} \text{kg/s}}$

$$\text{Mass transfer rate of ammonia} = 6.27 \times 10^{-12} \frac{\text{kg}}{//3600^{h}}$$ (2 M)

$\boxed{\text{Mass transfer rate of ammonia} = 2.25 \times 10^{-8} \text{kg/h}}$

We know,

$$\text{Molar transfer rate of air, } m_b = -3.69 \times 10^{-13} \frac{\text{kg} - \text{mole}}{\text{s}}$$

[Due to equimolar diffusion, $m_a = -m_b$]

Mass transfe rate of air = Molar transfer rate of air × Molecular weight of air

$= 3.69 \times 10^{-13} \times 29$

Mass transfer rate of air = $-1.07 \times 10^{-11} \text{kg/s}$

$$= -1.07 \times 10^{-11} \frac{\text{kg}}{1/3600^{h}}$$ (3 M)

Mass transfer rate of air = $-3.85 \times 10^{-8} \text{kg/h}$

5

An open pan of 150 mm diameter and 75 mm deep contains water at 25°C and is exposed to atmospheric air at 25°C and 50% R.H. Calculate the evaporation rate of water in grams per hour. (15 M)(Dec 2019, May 2017, Dec 2016, May 2014)BTL4

Answer: Page: 5.50-Dr.S.Senthil

Diffusion coefficient (D_{ab}) [water + air] at 25°C

$= 93 \times 10^{-3} \text{ m}^2/\text{h}$

$$\Rightarrow D_{ab} = \frac{93 \times 10^{-3}}{3600} \text{m}^2/\text{s}$$ (5 M)

$\boxed{D_{ab} = 2.58 \times 10^{-5} \text{m}^2/\text{s}}$.

Atmospheric air 50% RH (2)

We know that, for isothermal evaporation,

Molar flux, At 25°C, P_{w1} = 0.03166 bar ,$P_{w1} = 0.03166 \times 10^5$ N/m^2

P_{w2} = Partial pressure at the top of the test pan corresponding to 25°C and 50% relative humidity.

$$\frac{m_a}{A} = \frac{D_{ab}}{GT}\frac{P}{(x_2 - x_1)}\ln\left[\frac{P-P_{w2}}{P-P_{w1}}\right]......(1)$$

where,

A - Area = $\frac{\pi}{4}d^2 = \frac{\pi}{4}\times(.150)^2$

$\left[\text{Area} = 0.0176 \text{ m}^2\right]$ (5 M)

G – Universal gas constant = 8314 $\frac{\text{J}}{\text{kg-mole-K}}$

P – Total pressure = 1 bar = 1×10^5 N/m^2

P_{w1} – Partial pressure at the bottom of the test tube corresponding to saturation temperature 25°C

$$\frac{m_a}{A} = \frac{D_{ab}}{GT}\frac{P}{(x_2 - x_1)}\ln\left[\frac{P-P_{w2}}{P-P_{w1}}\right]......(1)$$

where,

A - Area = $\frac{\pi}{4}d^2 = \frac{\pi}{4}\times(.150)^2$

At 25°C $\left[\text{Area} = 0.0176 \text{ m}^2\right]$

G – Universal gas constant = 8314 $\frac{\text{J}}{\text{kg-mole-K}}$

P – Total pressure = 1 bar = 1×10^5 N/m^2

P_{w1} – Partial pressure at the bottom of the test tube corresponding to saturation temperature 25°C

$P_{w2} = 0.03166$ bar = $0.03166\times10^5\times0.50$

$P_{w2} = 0.03166\times10^5\times0.50$

$\boxed{P_{w2} = 1583 \text{ N/m}^2}$

$(1) \Rightarrow \frac{a}{0.0176}$

$$= \boxed{\frac{2.58\times10^{-5}}{8314\times298}\times\frac{1\times10^{5}}{0.075}\times\ln\left[\frac{1\times10^{5}-1583}{1\times10^{5}-0.03166\times10^{5}}\right]}$$

Molar rate of water vapour, $m_a = 3.96\times10^{-9}\,\frac{\text{kg}-\text{mole}}{\text{s}}$

Mass rate of = Molar rate of × Molecular weight
water vapour water vapour of steam

$= 3.96\times10^{-9}\times18$ (5 M)

Mass rate of water vapour = 7.13×10^{-8} kg/s.

$$= 7.13\times10^{-8}\times\frac{1000\text{g}}{1/3600^{\text{h}}}$$

$\boxed{\text{Mass rate of water vapour = 0.256 g/h}}$

6 **Air at 10°C with a velocity of 3 m/s flows over a flat plate. The plate is 0.3 m long. Calculate the mass transfer coefficient.(May 2019, Dec 2015)(15 M)**BTL4

Answer: Page: 5.57-Dr.S.Senthil

Properties of air at 10°C [From HMT data book, Page: No.22]

Kinematic viscosity. V = 14.16×10^{-6} m^2/s

We know that,

Reynolds Number, Re = $\frac{Ux}{\nu}$

$$= \frac{3\times0.3}{14.16\times10^{-6}}$$ (5 M)

$$\text{Re} = 0.63\times10^{5} < 5\times10^{5}$$

Since, Re < 5×10^{5}, flow is laminar

For Laminar flow, flat plate,

Sherwood Number (Sh) = 0.664 $(\text{Re})^{0.5}$ $(\text{Sc})^{0.333}$ ….(1)

[From HMT data book, Page: No.179]

Where,

Sc – Schmidt Number = $\frac{\nu}{D_{ab}}$......(2)

D_{ab} – Diffusion coefficient (water+Air) at 10°C = 8°C

$$= 74.1\times10^{-3}\ \frac{m^2}{3600s}$$ (5 M)

$$\boxed{D_{ab} = 2.50\times10^{-5} m^2/s.}$$

$$(2) \Rightarrow Sc = \frac{14.16\times10^{-6}}{2.05\times10^{-5}}$$

$$\boxed{Sc = 0.637}$$

Substitute Sc, Re values in equation (1)

$$(1) \Rightarrow Sh = 0.664\ (0.63\times10^5)^{0.5}(0.687)^{0.333}$$

$$\boxed{Sh = 147}$$

We know that,

Sherwood Number, $Sh = \frac{h_m x}{D_{ab}}$ (5 M)

$$\Rightarrow\ 147 = \frac{h_m \times 0.3}{2.05\times10^{-5}}$$

$$\boxed{\text{Mass transfer coefficient, } h_m = .01\ m/s.}$$

ME8694 HYDRAULICS AND PNEUMATICS L T P C

3 0 0 3

OBJECTIVES:

- To provide student with knowledge on the application of fluid power in process, construction and manufacturing Industries.
- To provide students with an understanding of the fluids and components utilized in modern industrial fluid power system.
- To develop a measurable degree of competence in the design, construction and operation of fluid power circuits.

UNIT I FLUID POWER PRINICIPLES AND HYDRAULIC PUMPS 9

Introduction to Fluid power – Advantages and Applications – Fluid power systems – Types of fluids - Properties of fluids and selection – Basics of Hydraulics – Pascal’s Law – Principles of flow - Friction loss – Work, Power and Torque Problems, Sources of Hydraulic power : Pumping Theory – Pump Classification – Construction, Working, Design, Advantages, Disadvantages, Performance, Selection criteria of Linear and Rotary – Fixed and Variable displacement pumps – Problems.

UNIT II HYDRAULIC ACTUATORS AND CONTROL COMPONENTS 9

Hydraulic Actuators: Cylinders – Types and construction, Application, Hydraulic cushioning – Hydraulic motors - Control Components : Direction Control, Flow control and pressure control valves – Types, Construction and Operation – Servo and Proportional valves – Applications – Accessories : Reservoirs, Pressure Switches – Applications – Fluid Power ANSI Symbols – Problems.

UNIT III HYDRAULIC CIRCUITS AND SYSTEMS 9

Accumulators, Intensifiers, Industrial hydraulic circuits – Regenerative, Pump Unloading, Double- Pump, Pressure Intensifier, Air-over oil, Sequence, Reciprocation, Synchronization, Fail-Safe, Speed Control, Hydrostatic transmission, Electro hydraulic circuits, Mechanical hydraulic servo systems.

UNIT IV PNEUMATIC AND ELECTRO PNEUMATIC SYSTEMS 9

Properties of air – Perfect Gas Laws – Compressor – Filters, Regulator, Lubricator, Muffler, Air control Valves, Quick Exhaust Valves, Pneumatic actuators, Design of Pneumatic circuit – Cascade method – Electro Pneumatic System – Elements – Ladder diagram – Problems, Introduction to fluidics and pneumatic logic circuits.

UNIT V TROUBLE SHOOTING AND APPLICATIONS 9

Installation, Selection, Maintenance, Trouble Shooting and Remedies in Hydraulic and Pneumatic systems, Design of hydraulic circuits for Drilling, Planning, Shaping, Surface grinding, Press and Forklift applications. Design of Pneumatic circuits for Pick and Place applications and tool handling in CNC Machine tools – Low cost Automation – Hydraulic and Pneumatic power packs.

TOTAL:45 PERIODS

TEXT BOOKS:

1. Anthony Esposito, “Fluid Power with Applications”, Pearson Education 2005.
2. Majumdar S.R., “Oil Hydraulics Systems- Principles and Maintenance”, Tata McGraw-Hill, 2001.

REFERENCES:

1. Anthony Lal, “Oil hydraulics in the service of industry”, Allied publishers, 1982.
2. Dudelyt, A. Pease and John T. Pippenger, “Basic Fluid Power”, Prentice Hall, 1987.
3. Majumdar S.R., “Pneumatic systems – Principles and maintenance”, Tata McGraw Hill, 1995
4. Michael J, Prinches and Ashby J. G, “Power Hydraulics”, Prentice Hall, 1989.
5. Shanmugasundaram.K, “Hydraulic and Pneumatic controls”, Chand & Co, 2006.

REGULATION :2017 **ACADEMIC YEAR : 2019-2020**
Subject Code:ME8694 **Year/Semester: III /06**
Subject Name: Hydraulics and Pneumatics **Subject Handler: Mr.S.Arun & Mr.S.Kannan**

UNIT I – FLUID POWER PRINCIPLES AND HYDRAULIC PUMPS

Introduction to Fluid power – Advantages and Applications – Fluid power systems – Types of fluids - Properties of fluids and selection – Basics of Hydraulics – Pascal’s Law – Principles of flow - Friction loss – Work, Power and Torque Problems, Sources of Hydraulic power : Pumping Theory – Pump Classification – Construction, Working, Design, Advantages, Disadvantages, Performance, Selection criteria of Linear and Rotary – Fixed and Variable displacement pumps – Problems.

PART * A

Q.No. **Questions**

1 **Define the term fluid power. BTL1**

Fluid power may be defined as the technology that deals with the generation, control and transmission of power using pressurized fluids.

2 **Compare hydraulic and pneumatic system. BTL2**

S.No	Hydraulic System	Pneumatic System
1.	It employs a pressurized liquid as a fluid.	It. employs a compressed gas usually air as a fluid.
2.	Generally, Hydraulic systems are designed as closed system.	Pneumatic systems are usually designed as open system.
3.	System get slow down if leakage	Leakage does not affect the system much

3 **What are the functions of hydraulic fluid? BTL2**

- To transmit fluid power efficiently to perform useful work.
- To lubricate the moving parts to minimize wear and friction.
- To absorb, carry and dissipate the heat generated within the system

4 **Write the importance of viscosity and what happens if viscosity is too high (or) too low. BTL2**

Viscosity is the most important property of a hydraulic fluid, as it determines the ability of a fluid to be pumped and transmitted through the system.

Too high viscosities (Heavy weight fluids) have the following effects.

- High resistance to flow, which causes sluggish operation (Difficult to flow).
- Increases power consumption.

Too low viscosities (Light weight fluids) have the following effects.

- Less precision control and slower responses.
- Increases Leakage losses past seals.

5 **List any four applications of fluid power system. BTL2**

- Agriculture : Hydraulically driven farm equipments.
- Automobile : Fluid power steering and braking systems.
- Defence : Missile Launch Systems, navigation controls.
- Transportation : Hydraulically powered overhead sky tram.

6	**List the advantages and disadvantages of hydraulic system. BTL2** Advantages of Hydraulic system ➢ Large load capacity with almost high accuracy and precision. ➢ Smooth movement. Disadvantages of Hydraulic system ➢ Hydraulic Elements needs to be machined to a high degree of precision. ➢ Leakage of Hydraulic oil poses problems to hydraulic operators.
7	**List the advantages and disadvantages of pneumatic systems. BTL2** Advantages of Pneumatic system ➢ Low inertia effect of pneumatic components due to light density of air. ➢ System is light in weight. Disadvantages of Pneumatic systems ➢ Suitable only for light loads or small loads. ➢ Availability of the assembly components is doubtful.
8	**What is the function of compressor in pneumatic system? BTL2** It is use to compress the incoming atmosphere air above 5 bar which is used as medium in pneumatic system.
9	**Name three basic methods of transmitting power. BTL2** ➢ Electrical power transmission, ➢ Mechanical power transmission, and ➢ Fluid power transmission, Hydraulic power transmission, and Pneumatic power transmission
10	**In comparison with hydraulic systems, why are pneumatic systems are suitable only for low load and low power applications? BTL4** Since pneumatic pressures are quite low due to the compressor design, the pneumatic systems are suitable only for low load and low power applications.
11	**What are the basic components that are required for a hydraulic system? BTL2** The six basic components of a hydraulic system are : ➢ Reservoir (or tank), ➢ Pump, ➢ Prime mover ➢ Valves, ➢ Actuator, and ➢ Fluid-transfer piping
12	**What is demulsibility? Write its significance. BTL2** The property of a hydraulic fluid to separate rapidly and completely from moisture and to resist emulsification is known as demulsibility. Significance: This property is significant because the operation of many hydraulic systems are conducive to the forming of moisture or of stable water-in-oil emulsions.
13	**What is oxidation stability? BTL2** Oxidation stability is defined as the ability of a liquid to resist reaction with oxygen or oxygen-containing compounds.

14 **List few required properties of a good hydraulic fluid. BTL2**

- Stable viscosity characteristics.
- Good lubricity.
- Compatibility with system materials.
- Stable physical and chemical properties.

15 **State the law that govern the fluid power system. BTL1**

Pascal's law states that the pressure generated at any point in a confined fluid acts equally in all directions.

16 **Differentiate between laminar and turbulent flow. BTL2**

A laminar flow is one in which paths taken by the individual particles do not cross one another and moves along well-defined paths. The laminar flow is characterized by the fluid flowing in smooth layers of lamina. A turbulent flow is that flow in which fluid particles move in a zig-zag way. The turbulent flow is characterized by continuous small fluctuations in the magnitude and direction of the velocity of the fluid particles.

17 **List out the various energy losses when liquid flows through a pipe. BTL2**

- Major energy losses: This is due to friction
- Minor energy losses: These losses are due to Losses in valves and pipe fittings. Sudden enlargement/Contraction of pipe, Bend in pipe, etc.

18 **Name any four hydraulic fluids that are commonly used. BTL2**

- Petroleum oils.
- Water-in-oil and oil-in-water emulsions.
- Glycols.
- Phosphate esters.

19 **Pump do not pump pressure. Justify the statement. BTL4**

In pump, fluid flow in the inlet line always takes place at negative pressure and hence a relatively low flow velocity is needed here. This causes the fluid to the pushed up \ and creates it to lift. Due to the resistance offered by the system to fluid flow, the pressure get raises to the required level. So, pumps do not pump pressure, but, they /produce fluid to flow.

20 **List the advantages of hydrostatic pumps over hydrodynamic pumps. BTL2**

- They are capable of generate high pressure (over 690 bar).
- They are relatively small and compact in size.
- High volumetric efficiency due to less leakages.

21 **Classify different types of pumps used in fluid power system. BTL2**

Based on the construction, Hydrostatic pumps are classified as

i) Gear pumps (Fixed displacement only)

- External Gear pump
- Internal Gear pump
- Lobe pump
- Screw pump
- Gerotor pump

ii) Vane pump (Fixed or variable displacement)

	➢ Balanced vane pump ➢ Unbalanced vane pump iii) Piston pump (Fixed or variable displacement) ➢ Axial design ➢ Radial design
22	**How the vane pump / piston pump can be made as variable displacement unit? BTL2** Variable displacement units can be made by either varying the eccentricity of rotor with respect to cam ring, in case of vane pumps or by varying the offset angle, in case of piston pumps.
23	**Why are positive displacement pumps universally used in fluid power industries? BTL2** Positive displacement pumps are primarily used where pressure development is the prime requirement. This type of pumps is capable of delivering high pressure fluid, so it is universally used in fluid power systems.
24	**What are piston pumps? Name the two basic types of piston pumps. BTL2** In piston pumps, the pumping action is affected by a piston that moves in a reciprocating cycle through a cylinder. Types: 1. Axial piston pumps, and 2. Radial piston pumps.
25	**How can you vary the displacement in an axial piston pump? BTL2** The variable displacement in an axial piston pump can be achieved by altering the angle of the swash plate (or offset angle). Because in axial pumps, this swing angle determines the piston stroke and hence the pump displacement.
26	**What are the advantages of screw pumps than other gear pumps? BTL2** ➢ Screws are continuous, most reliable. ➢ No pressure pulsation will occur. ➢ High speed operation is possible with less noise. ➢ No pump turbulence and oil churning.
	PART * B
1	**What are the desirable properties of hydraulic fluids? Discuss them in detail. BTL2** ➢ **Viscosity: (2M)** It is a measure of the fluid's internal resistance offered to flow. If the viscosity of the hydraulic oil is higher than recommended then, the viscous oil may not be able to pass through the pipes. The working temperature will increases because there will be internal friction. ➢ **Oxidation stability: (2M)** It is caused by a chemical reaction between the oxygen of the dissolved air and the oil. The oxidation of the oil creates impurities like sludge, insoluble gum and soluble acidic products which cause corrosion and make the operation sluggish. ➢ **Demulsibility: (2M)** It's an ability of a hydraulic fluid to separate rapidly from moisture and successfully resist emulsification. If oil emulsifies with water the emulsion will promote the destruction of lubricating value and sealant properties. ➢ **Lubricity: (2M)** Wear results in increase clearance which leads to all sorts of operational difficulties including fall of efficiency. Selecting a hydraulic oil care must be taken to select one which will be able to

lubricate the moving parts efficiently.

- **Flash point & Fire point: (3M)**

Flash point is the temperature at which a liquid gives off vapour in sufficient quantity to ignite momentarily or flash when a flame is applied. The minimum temperature at which the hydraulic fluid will catch fire and continue burning is called fire point.

- **Compressibility: (2M)**

All fluids are compressible to some extent. Compressibility of a liquid causes the liquid to act much like a stiff spring. The coefficient of compressibility is the fractional change in a unit volume of liquid per unit change of pressure.

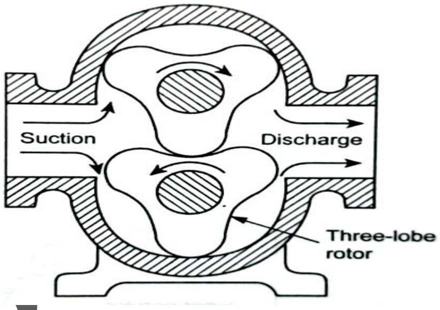
2 **With neat sketch explain the working of lobe pump and gerotor pump with advantages and disadvantages. BTL2**

Lobe Pump:

Working: (3M)

Gears replaced by lobes - lobes are driven independently and they do not have actual contact with each other - contact is prevented by external timing gears - lobes come out of mesh, they create expanding volume on the inlet side of the pump - flows into the cavity and is trapped by the lobes rotation -.liquid travels around interior of casing in pockets b/w lobes and casing - meshing of the lobes forces liquid through the outlet port under pressure.

Diagram: (3M)

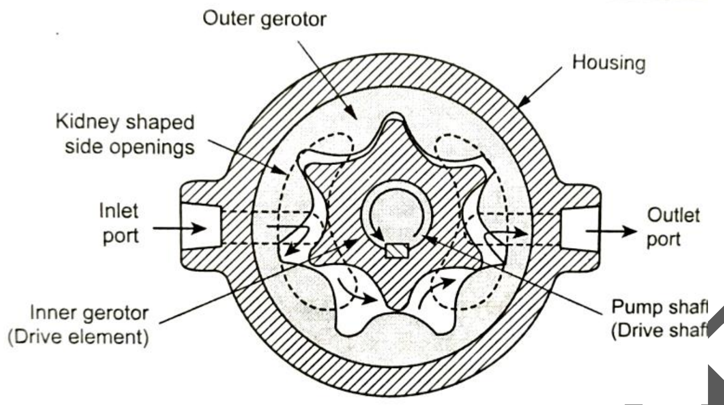


Gerotor pump:

Working: (3M)

Inner gerotor (driver) - outer gerotor (follower) - housing - outer gerotor has one more teeth than inner gerotor - both rotates in same direction - have different centre of rotation - when teeth disengage space b/w them increases - partial vacuum sucks oil inside the chamber - chamber reaches maximum volume suction stops - space diminishes with meshing teeth forces oil to discharge.

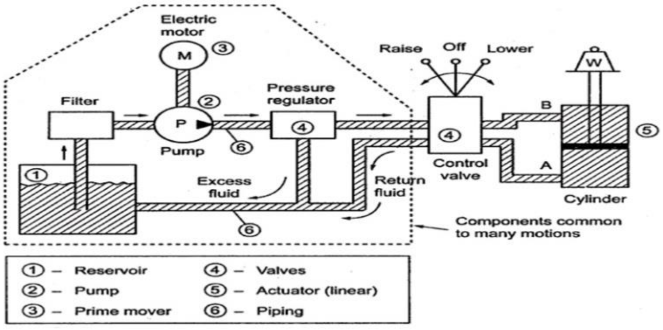
Diagram: (4M)



3 **With neat sketch explain the hydraulic and pneumatic fluid power systems. BTL2**

Hydraulic system: (6M)

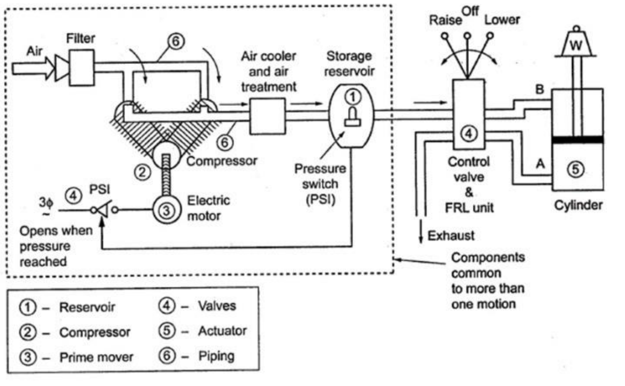
Reservoir - Pump - motor (prime mover) - Filter - Pressure relief valve - direction control valve - hydraulic cylinder (actuator)



General arrangement of a hydraulic system

Pneumatic system: (7M)

Motor (prime mover) - Compressor - Filter - Direction control valve - Pneumatic cylinder actuator)



4 **a. How to calculate frictional losses in common valves and fittings (8M) BTL5**

$H_L = K\left(\frac{V^2}{2g}\right)$ (2M)

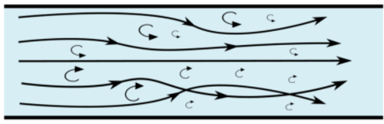
Where, K = Constant of proportionality called the K-factor.

$Pressure\ drop, \Delta P = H_L \times w_{oil}$ (2M)

Where, w_{oil} = Weight density of oil flowing through valves and fittings.

K-factors of common valves and fittings (4M)

b. Differentiate between laminar and turbulent fluid flow. (5M) BTL2

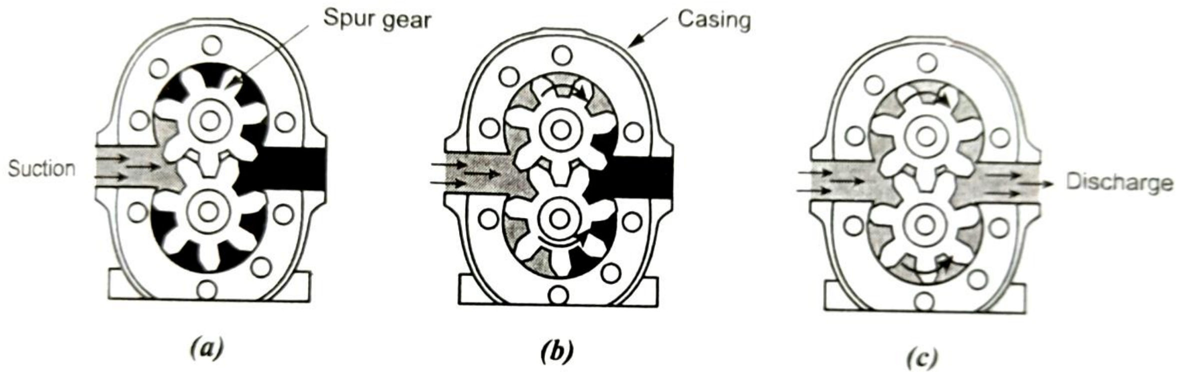
Laminar Flow	Turbulent Flow
Laminar flow is one in which paths taken by the individual particles do not cross one another and move along well defined paths. The laminar flow is characterised by the fluid flowing in smooth layers of laminae.	Turbulent flow is that flow in which fluid particles move in zig-zag way. The turbulent flow is characterised by continuous small fluctuations in the magnitude and direction of the velocity of the fluid particles.
	

5 **Explain the construction and working of a gear pump. BTL2**

Working: (4M)

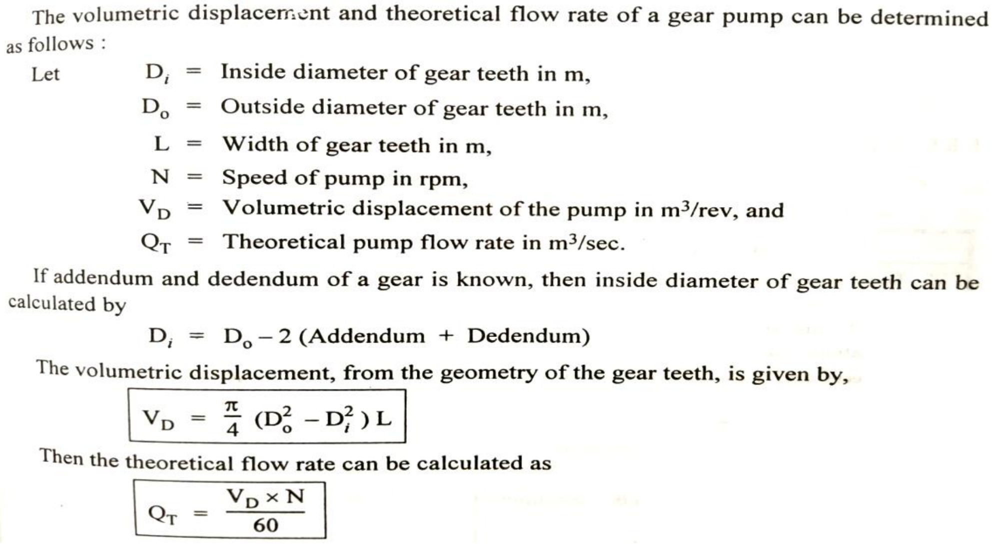
Two mating gear (driver and follower) - closely fitted casing - driver shaft coupled with prime mover - inlet and outlet are directly opposite to each other - larger straight ports are preferred for better performance - vacuum formed in the cavity b/w the teeth as they unmesh - pressure rise in pump produced by sequencing action on the fluid.

Diagram: (6M)



(a) (b) (c)

Analysis of volumetric displacement and theoretical flow rate: (3M)



The volumetric displacement and theoretical flow rate of a gear pump can be determined as follows :

Let D_i = Inside diameter of gear teeth in m,

D_o = Outside diameter of gear teeth in m,

L = Width of gear teeth in m,

N = Speed of pump in rpm,

V_D = Volumetric displacement of the pump in m³/rev, and

Q_T = Theoretical pump flow rate in m³/sec.

If addendum and dedendum of a gear is known, then inside diameter of gear teeth can be calculated by

$$D_i = D_o - 2\,(\text{Addendum} + \text{Dedendum})$$

The volumetric displacement, from the geometry of the gear teeth, is given by,

$$\boxed{V_D = \frac{\pi}{4}\left(D_o^2 - D_i^2\right) L}$$

Then the theoretical flow rate can be calculated as

$$\boxed{Q_T = \frac{V_D \times N}{60}}$$

6 **a. A gear pump has a 80 mm outside diameter, a 55 mm inside diameter and a 25 mm width. If the actual pump flow at 1600 rpm and rated pressure is 95 Lpm, what is the volumetric efficiency? (6M) BTL5**

Solution:

Actual Discharge, Q_A = 95 Lpm = 95 x 10^{-3} m^3/min

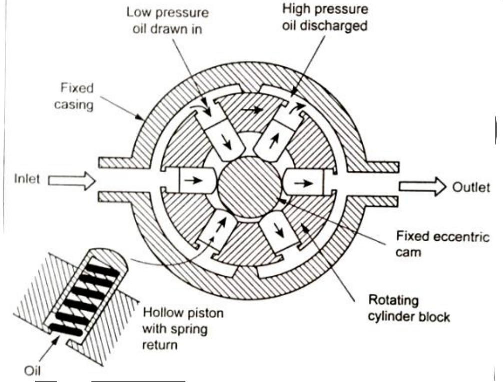
$Volumetric\ displacement, V_D = \frac{\pi}{4}(D_o^2 - D_i^2)L = 6.627 \times \frac{10^{-5}m^3}{rev}$ (2M)

Theoretical Discharge, $Q_T = V_D$ x N = 0.106 m^3/min (2M)

$Volumetric\ efficience, \eta_{vol} = \frac{Q_A}{Q_T} \times 100 = 89.62\ \%$ (2M)

b. Explain the radial piston with advantages and disadvantages of piston pump. (7M)

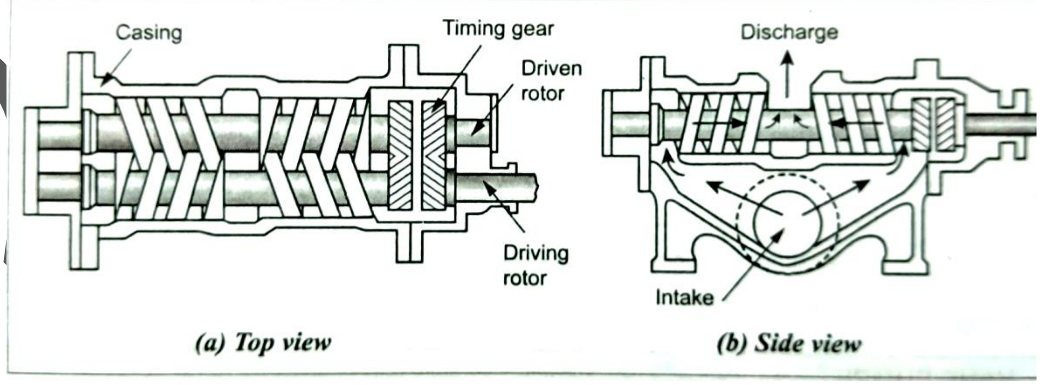
number of radial pistons in a cylinder block revolves around stationary eccentric cam - piston move perpendicularly to shaft centerline - eccentric cam causes in and out or pumping motion of the pistons.



7 **With neat sketch explain the working of screw pump and internal gear pump with advantages and disadvantages. BTL2**

Screw pump: (7M)

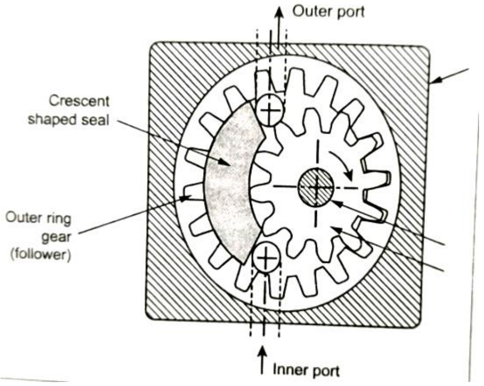
Axial flow positive displacement gear pump - two rotor screw with helical gears - meshing screws - sealed chamber - connected by timing gear - liquid moves forward along the axis with rotation of screw.



(a) Top view (b) Side view

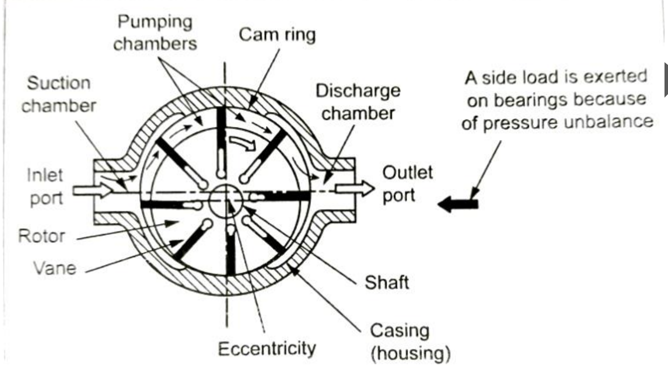
Internal gear pump: (6M)

Internal spur gear - outside ring gear - crescent shaped spacer - external housing - internal gear drives the external gear - cavity volume increases and suction occurs - oil trapped b/w internal and external gear teeth .



8 **With a neat sketch explain the principle and working of unbalanced vane pump and derive the expression for the output of vane pump. BTL2**

Diagram: (5M)



Working: (4M)

Rotor mounted off center - rectangular vanes free to move in radial slots - vanes thrown outwards by centrifugal force - eccentricity of revolving rotor produces vacuum at suction side causing inflow of liquid.

Expression: (4M)

$$Volumetric\ displacement, V_D = \frac{\pi}{2}(D_C + D_R)eL$$

where,

V_D = Volumetric displacement in m^3

D_C = Diameter of cam ring in m

D_R = Diameter of rotor in m

$$Eccentricity, e = \frac{(D_C + D_R)}{2}$$

L = Width of rotor in mIf N = Rotor speed in rpm, then

$Q_T = V_D$ x N

9 **a) A pump has a displacement of 80cm^3. It delivers 1.25 Lps at 1200rpm and 75 bar. If the prime mover input torque is 110N-m. Calculate i) overall efficiency ii) theoretical torque required to operate the pump. (8M) BTL5**

Solution:

$V_D = 80\ cm^3$; $Q_A = 1.25 \times 10^{-3}\ m^3/s$; N = 1200 rpm; $P = 75 \times 10^5 N/m^2$; T = 90 N-m

$\omega = \frac{2\pi N}{60} = 125.66 \frac{rad}{s}$ (2M)

$Overall\ Efficiency, \eta_0 = \frac{\mathrm{P \times Q_A}}{\mathrm{T_A \times \omega}} \times 100 = 82.89\%$ (3M)

$Theoretical\ Torque, T_T = \frac{V_D \times P}{2\pi} = 95.49\ N - m$ (3M)

b) Calculate the actual flow rate in units of Lps of a radial piston pump for the following specifications:

Number of pistons = 9; Diameter of piston = 25 mm; Maximum eccentricity = 10 mm; Speed of rotor = 1800 rpm; Volumetric efficiency = 95%. (5M) BTL5

Solution:

Y = 9; d = 25 mm; e = 10 mm; N = 1800 rpm; η = 95%

$Q_T = 0.5 eY\pi d^2 N\ =\ 0.159 \frac{m^3}{min}$ (3M)

$Q_A = Q_T \times \eta_{vol} = 0.151 \frac{m^3}{min}\ = \frac{0.151 \times 10^3}{60} = 2.516\ Lps$ (2M)

PART * C

1 **What types of fluids are available for hydraulic system? Explain each of them. BTL2**

Petroleum Oils: (3M)

- These are the most common among the hydraulic fluids which are used in a wide range of hydraulic applications.
- The characteristic of petroleum based hydraulic oils are controlled by the type of crude oil used.
- Naphthenic oils have low viscosity index so it is unsuitable where the oil temperatures vary too widely.
- The aromatics have a higher presence of benzene and they are more compatible with moderate temperature variation.
- Paraffinic oils have a high viscosity index and they are more suitable for the system where the temperature varies greatly.

Water glycols: (3M)

- These are solutions contains 35 to 55% water, glycol and water soluble thickener to improve viscosity.
- Additives are also added to improve anticorrosion, anti wear and lubricity properties.

Water oil emulsions: (3M)

- These are water-oil mixtures.
- They are of two types oil-in-water emulsions or water-in-oil emulsions.
- The oil-in-water emulsion has water as the continuous base and the oil is present in lesser amounts as the dispersed media.
- In the water-in-oil emulsion, the oil is in continuous phase and water is the dispersed media.

Phosphate Ester: (3M)

- It results from the incorporation of phosphorus into organic molecules.

- They have high thermal stability.
- They serve as an excellent detergent and prevent building up of sludge.

Water: (3M)

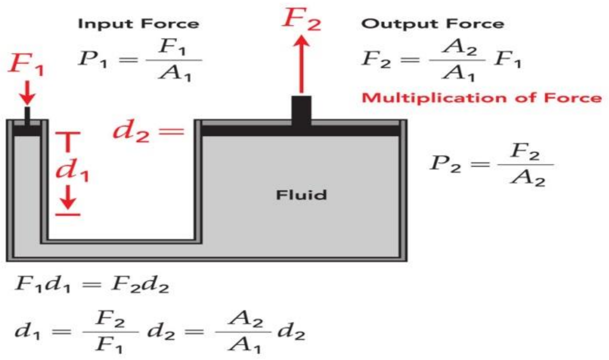
- The least expensive hydraulic fluid is water.
- Water is treated with chemicals before being used in a fluid power system. This treatment removes undesirable contaminates.

2 **a. State and explain Pascal's law and With neat sketch, explain the hydraulic jack. (7M) BTL1**

Pascal Law: (2M)

It states that the pressure generated at any point in a confined fluid acts equally in all directions.

Hydraulic jack: (5M)



b. List the advantages and disadvantages of fluid power system. (8M) BTL2

Advantages: (4M)

- No breakage as in mechanical transmission.
- Self lubricated with the hydraulic liquid itself.
- Overloads can easily controlled by using relief valves.
- Simplicity and compactness

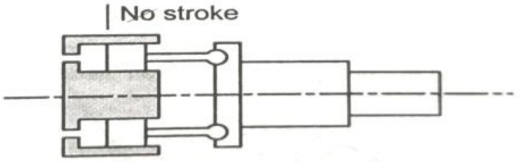
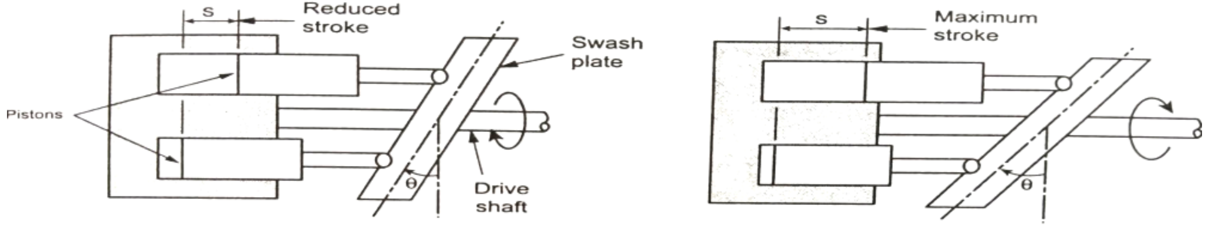
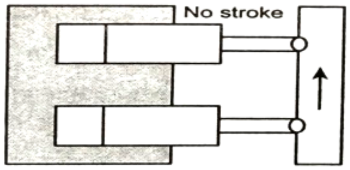
Disadvantages: (4M)

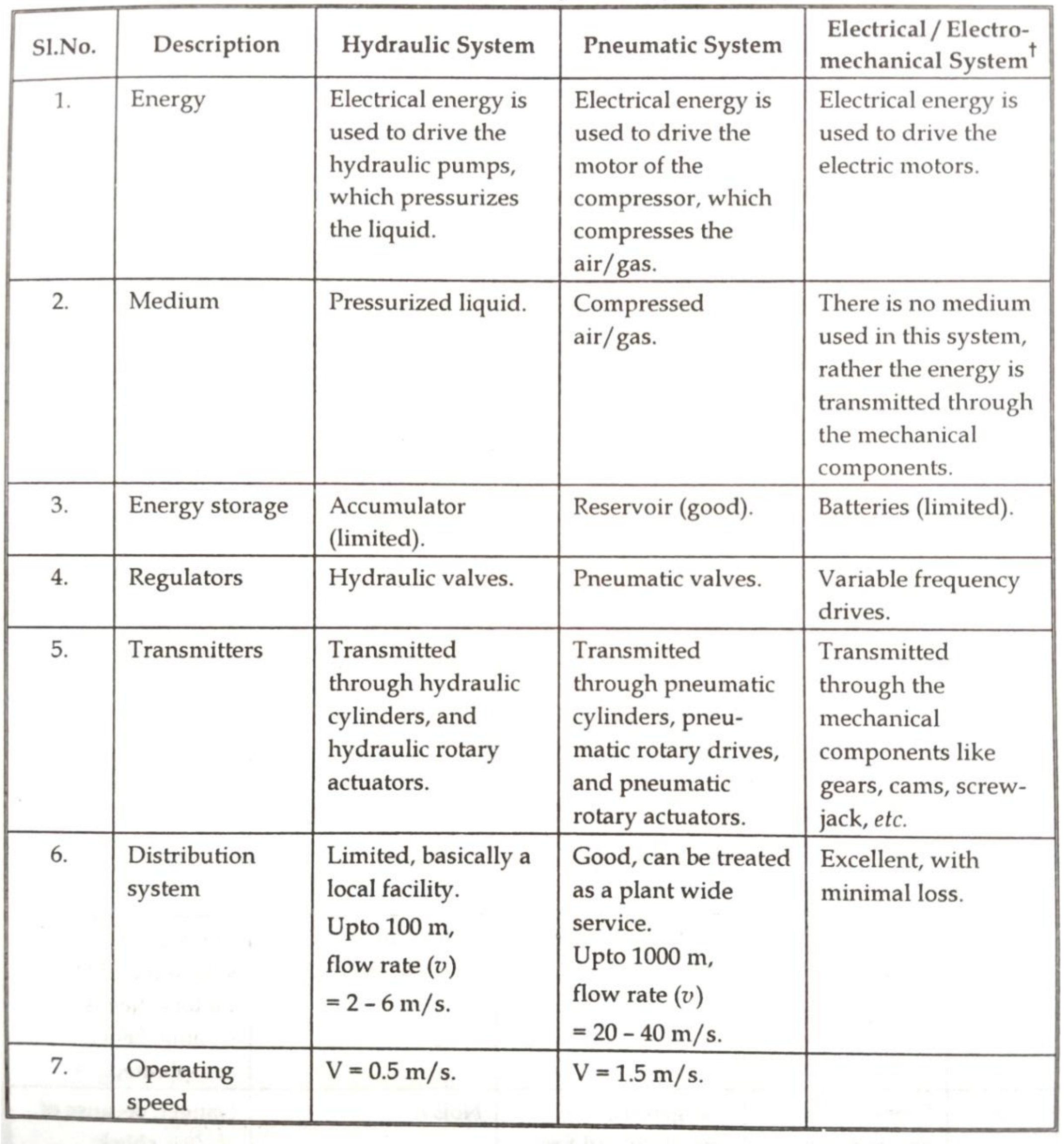
- Leakage of oil or compressed air
- Busting of oil lines, air tanks
- More noise in operation.

3 **Explain the working of bent axis and swash plate design of piston pump with advantages and disadvantages. BTL2**

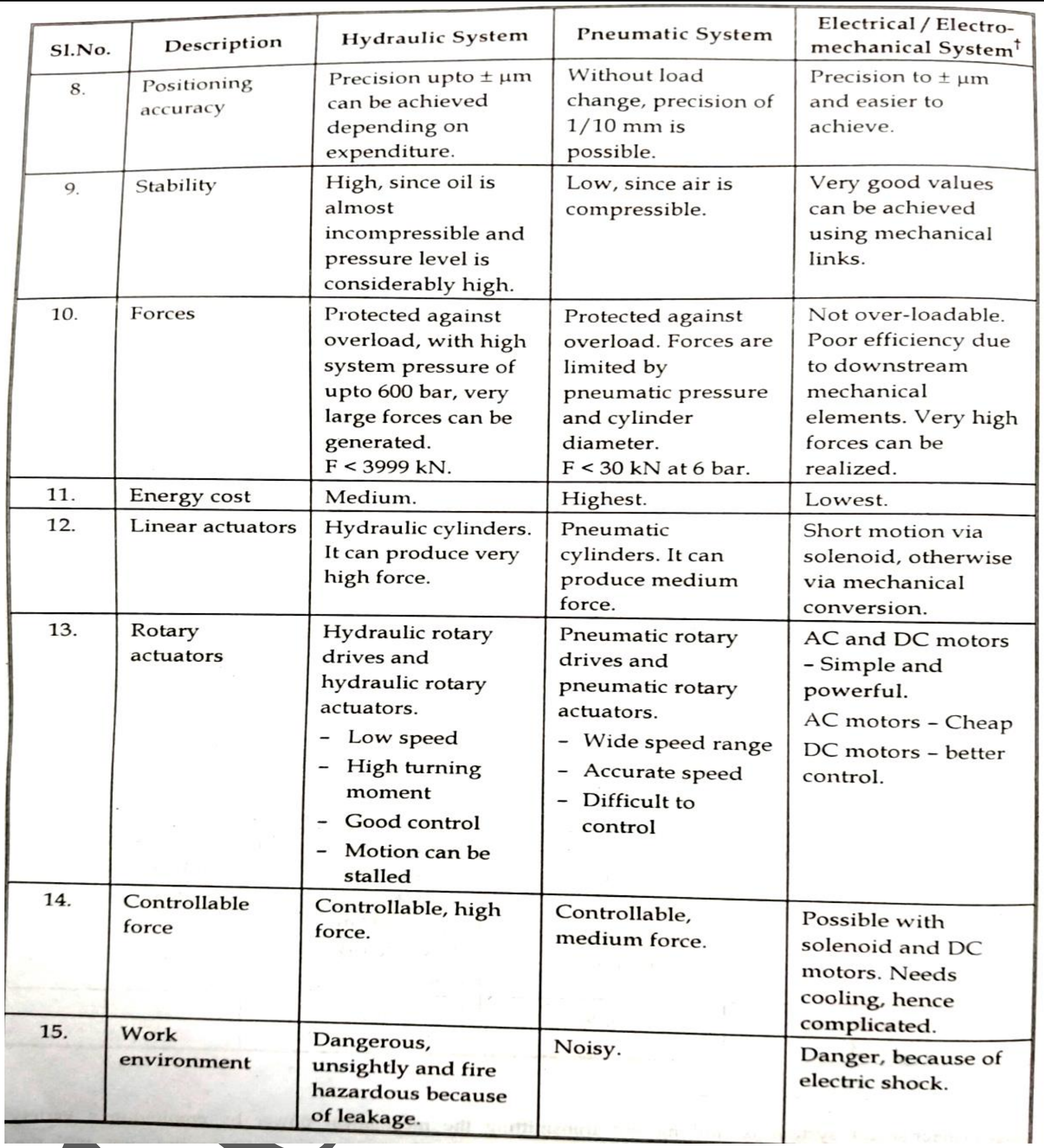
Bent axis piston pump: (8M)

Cylindrical block rotating with drive shaft - offset angle relative to centerline - pistons and cylinders arranged along a circle - ball and socket joints connect piston rods with drive shaft - distance b/w drive shaft flange and cylinder block changes - piston moves in and out of cylinder.

	 *(a) Lesser offset angle (partial displacement)* *(b) Maximum offset angle (maximum displacement)*  *(c) Zero offset angle (no displacement)* Swash plate piston pump: (7M) Variable displacement capability - altering the angle of swash plate - angle of tilt determines piston stoke - increase swash plate angle will increase piston stoke - when swash plate is vertical no displacement.  *(a) Decreased swash plate angle (partial displacement)* *(b) Maximum swash plate angle (Maximum displacement)*  *(c) Zero swash plate angle (no displacement)*
4	**Compare between hydraulic, pneumatic and electromechanical power system**. **BTL4**



Sl.No.	Description	Hydraulic System	Pneumatic System	Electrical / Electro-mechanical System†
1.	Energy	Electrical energy is used to drive the hydraulic pumps, which pressurizes the liquid.	Electrical energy is used to drive the motor of the compressor, which compresses the air/gas.	Electrical energy is used to drive the electric motors.
2.	Medium	Pressurized liquid.	Compressed air/gas.	There is no medium used in this system, rather the energy is transmitted through the mechanical components.
3.	Energy storage	Accumulator (limited).	Reservoir (good).	Batteries (limited).
4.	Regulators	Hydraulic valves.	Pneumatic valves.	Variable frequency drives.
5.	Transmitters	Transmitted through hydraulic cylinders, and hydraulic rotary actuators.	Transmitted through pneumatic cylinders, pneumatic rotary drives, and pneumatic rotary actuators.	Transmitted through the mechanical components like gears, cams, screw-jack, *etc.*
6.	Distribution system	Limited, basically a local facility. Upto 100 m, flow rate (v) = 2 – 6 m/s.	Good, can be treated as a plant wide service. Upto 1000 m, flow rate (v) = 20 – 40 m/s.	Excellent, with minimal loss.
7.	Operating speed	V = 0.5 m/s.	V = 1.5 m/s.	



Sl.No.	Description	Hydraulic System	Pneumatic System	Electrical / Electro-mechanical System†
8.	Positioning accuracy	Precision upto ± μm can be achieved depending on expenditure.	Without load change, precision of 1/10 mm is possible.	Precision to ± μm and easier to achieve.
9.	Stability	High, since oil is almost incompressible and pressure level is considerably high.	Low, since air is compressible.	Very good values can be achieved using mechanical links.
10.	Forces	Protected against overload, with high system pressure of upto 600 bar, very large forces can be generated. F < 3999 kN.	Protected against overload. Forces are limited by pneumatic pressure and cylinder diameter. F < 30 kN at 6 bar.	Not over-loadable. Poor efficiency due to downstream mechanical elements. Very high forces can be realized.
11.	Energy cost	Medium.	Highest.	Lowest.
12.	Linear actuators	Hydraulic cylinders. It can produce very high force.	Pneumatic cylinders. It can produce medium force.	Short motion via solenoid, otherwise via mechanical conversion.
13.	Rotary actuators	Hydraulic rotary drives and hydraulic rotary actuators. - Low speed - High turning moment - Good control - Motion can be stalled	Pneumatic rotary drives and pneumatic rotary actuators. - Wide speed range - Accurate speed - Difficult to control	AC and DC motors – Simple and powerful. AC motors – Cheap DC motors – better control.
14.	Controllable force	Controllable, high force.	Controllable, medium force.	Possible with solenoid and DC motors. Needs cooling, hence complicated.
15.	Work environment	Dangerous, unsightly and fire hazardous because of leakage.	Noisy.	Danger, because of electric shock.

UNIT II – HYDRAULIC ACTUATORS AND CONTROL COMPONENTS

Hydraulic Actuators: Cylinders – Types and construction, Application, Hydraulic cushioning – Hydraulic motors - Control Components : Direction Control, Flow control and pressure control valves – Types, Construction and Operation – Servo and Proportional valves – Applications – Accessories : Reservoirs, Pressure Switches – Applications – Fluid Power ANSI Symbols – Problems.

PART * A

Q.No.	Questions
1	**Define fluid power Actuator. Classify its types. BTL2** Fluid power actuators are devices that perform useful work by extracting energy from the fluid and convert it to mechanical energy. Actuators transmits and controls the fluid power efficiently to provide correct force and speed for any job ranging from simplex to complex. Fluid power actuators may be either linear type or rotary type. There are two types of fluid power actuators. They are (1) Linear actuators (2) Rotary actuators. Linear actuators provide linear motion while rotary actuators provide rotary mechanical motion.
2	**Name different types of hydraulic cylinders. BT2** ➢ Single acting cylinders, ➢ Double acting cylinders, ➢ Telescoping cylinders, ➢ Tandem cylinder and ➢ Through rod cylinders.
3	**By what means, single-acting cylinders are retracted? BTL2** The single-acting cylinders are retracted using gravity or by the inclusion of compression spring at the rod end of the cylinders.
4	**What is meant by cylinder cushioning? BTL2** When the pressurised fluid is allowed to enter inside the cylinder, the piston accelerates and travels in the cylinder barrel. If the piston is allowed to travel at the same speed till the end of the stroke, it will hit the end cap with a great impact. To avoid this impact, the piston needs to decelerate at the end of the travel. The arrangement made at the end caps to achieve the same is called 'cylinder cushion'.
5	**What do you mean by double-rod cylinder? BTL2** A double-rod cylinder, also known as through-rod cylinder has piston rods extending from both ends of the cylinder. These cylinders produce equal force and speed on both sides of the cylinder.
6	**Why are double-acting cylinders known as differential cylinders? BTL2** Since the piston rod is attached at one side only, the cylinder exerts greater force when extending [F = P x A_{piston}] than when retraction [F = P x (A_{piston} - A_{rod})]. This results in different pressure levels on either side of the piston and that's why double-acting cylinders are also called as differential cylinders.
7	**What do you mean by a limited rotation hydraulic motor? BTL2**

The limited-rotation motors provide rotary output motion over a finite angle. Usually rotation of the shaft of these motors is 90°, 180°, or 270°.

8 **Name the basic types of rotary actuators. BTL2**

- Continuous rotary actuator, and (a) Gear motor, (b) Vane motors, and (c) Piston motors.
- Limited rotation hydraulic motors. (a) Vane type, and (b) Piston type.

9 **List any four types of pressure control valves. BTL2**

- Pressure-compensated valves
- Unloading valves
- Pressure relief valve
- Sequence valves
- Counterbalance valves
- Pressure reducing valve

10 **What are fluid power symbols? BTL2**

Fluid power symbols are used to represent individual components in fluid power circuit diagrams, which identify components and their functions uniquely.

11 **What are actuation devices and list them? BTL2**

Actuation devices are components used in hydraulics/pneumatic circuits that are used for shifting the valve spool from one position to another. The types of actuation devices are:

- Manual actuation devices
- Mechanical actuation devices
- Pilot operated actuation devices
- Solenoid operated actuation devices

12 **What is two-way valve? BTL2**

This particular valve has two ports, labeled P and A. P is connected to the pump line and A is the outlet to the system.

13 **What is shuttle valve? BTL2**

A valve that has two inlets and one outlet is known as shuttle valve. The outlet receives the flow from the inlet whichever is at a higher pressure.

14 **Classify the control valves. BTL2**

Based on the function, control valves are classified into three types.

- Direction control valves
- Pressure control valves
- Flow control valves

15 **What are the functions of control valves? BTL2**

The main functions of control valves are

- To regulate the pressure through a system
- To control and limit flow to the actuator
- To maintain contact pressure ratio between output and input to actuator.

16 **Distinguish between pressure reducing valve and pressure relief valve. BTL2**

Pressure reducing valve	**Pressure relief valve**

It is type of hydraulic pressure control valve that controls the maximum pressure in a branch of a circuit.	It is a type of pressure control valve that limits the maximum pressure in a hydraulic or pneumatic circuit.
The reducing valve reads the pressure downstream.	The relief valve reads the pressure upstream.
The pressure reducing valve has an external drain.	The pressure relief valve does not have an external drain.

17 **What are the three types of control valves based on their configuration? BTL2**

- ➢ Poppet (or seat) valves
- ➢ Sliding spool valve and
- ➢ Rotary spool valves

18 **Name various types of pressure control valves. BTL2**

- ➢ Pressure limiting (or relief) valves,
- ➢ Pressure reducing valves,
- ➢ Sequence valves,
- ➢ Counter balance valves, and
- ➢ Unloading valves.

19 **What is the use of a pressure relief valve in a hydraulic system? BTL3**

The pressure relief valve protects a system from excessive fluid pressure over and above the design pressure limit.

20 **What is the use of sequence valve? BTL2**

It is a type of hydraulic pressure control valve that is used to force two actuator to be operated in a pre- determined sequence.

21 **What is the purpose of a pressure reducing valve? BTL2**

A pressure reducing valve is used to supply a prescribed reduced outlet pressure in a circuit and to maintain it at a constant value.

22 **What are flow control valves? Why are they referred as speed-control valves? BTL2**

Flow control valves, also known as volume-control valves, are used to regulate the rate of fluid flow to different parts of a hydraulic system. Since control of flow rate is a means by which the speed of hydraulic machine elements is governed, therefore flow control valves are also referred as speed-control valves.

23 **What are sequence valves? BTL2**

The sequence valves are used to control the fluid flow to ensure several operations in a particular order of priority in the system.

24 **What is the function of servo system? BTL2**

Generally, hydraulic direction control valves are working with many actuating devices, especially solenoids. Solenoids can be operated under two states: shifted and not shifted. So, solenoid valve can be shifted open to allow flow or closed to block flow. But servo systems are able to precisely position the valve spool between the open and closed positions. This allows the flow to be throttled (metered) through the valve and provides precise flow control as well as direction control. Simply, servo systems are integration of DCV with FCV.

25 **What are proportional control valves? BTL2**

It is an infinite variable position valves. They use a variable force direct current solenoid to control the output from the main spool.

PART * B

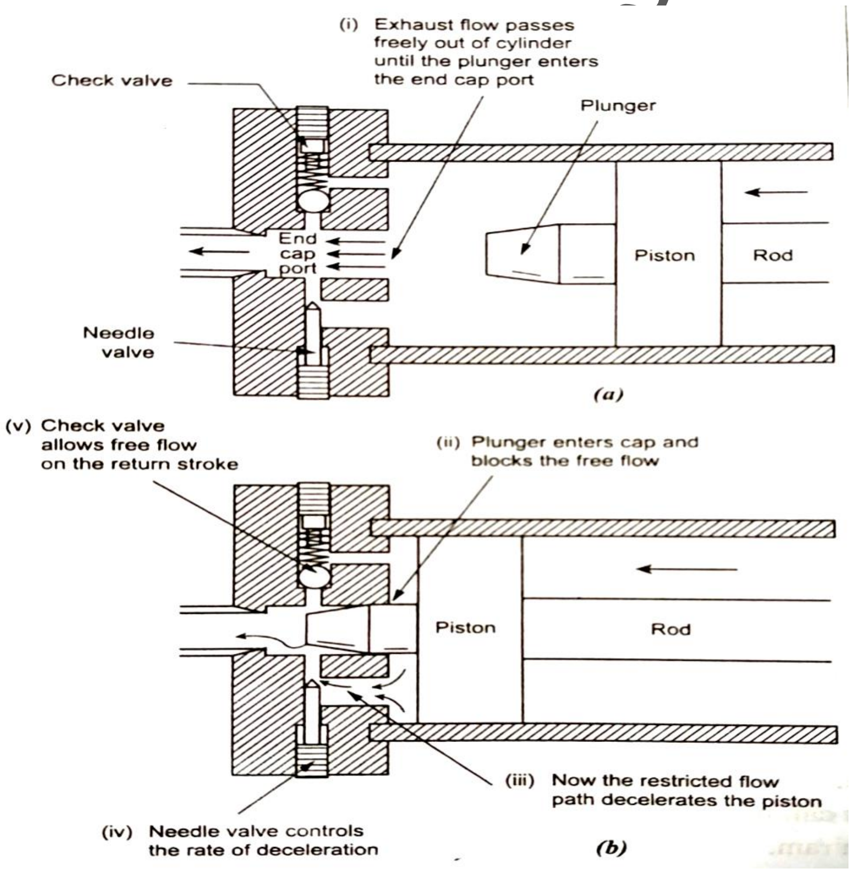
1 **How cylinder cushioning takes place in cylinders? Explain with diagram. BTL2**

When the pressurised fluid is allowed to enter inside the cylinder, the piston accelerates and travels in the cylinder barrel. If the piston is allowed to travel at the same speed till the end of the stroke, it will hit the end cap with great impact. To avoid this impact, the piston needs to decelerate at the end of the travel. the arrangement made at the end caps to achieve the same is called cylinder cushion. (3M)

Operation: (5M)

- Exhaust flow passes freely out of cylinder until the plunger enter the end cap port.
- Plunger enters cap and blocks the free flow
- Now the restricted flow path decelerates the piston
- Needle valve controls the rate of deceleration
- check valve allows free flow on the return stroke

Diagram: (5M)



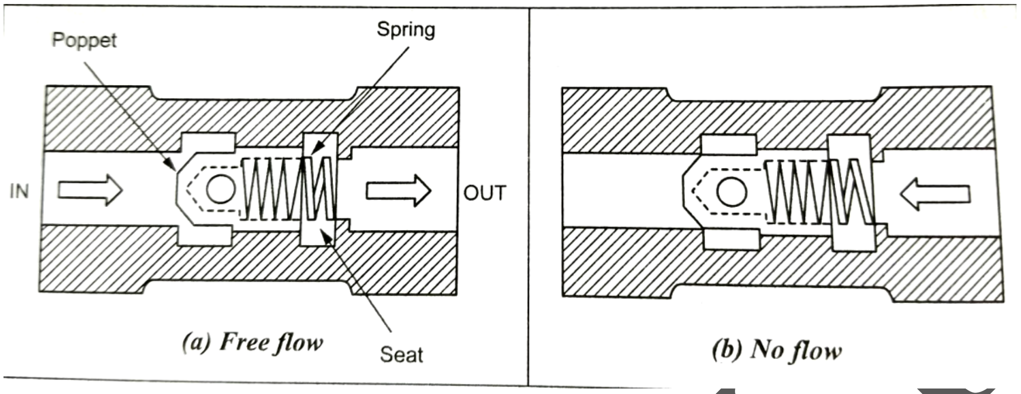
2 **With neat sketches explain the working of simple check valve and pilot operated check valve. BTL2**

Simple Check Valve: (6M)

Flow - normal direction - pressure acts against spring tension. Pressure overcomes spring force -

valve allows free flow.

Flow - opposite direction - spring force pushes poppet in closed position - no flow permitted.



(a) Free flow (b) No flow

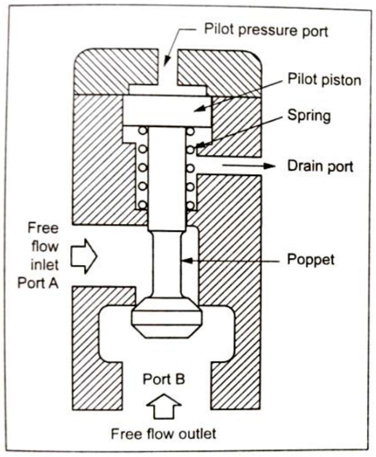
Pilot operated Check valve: (7M)

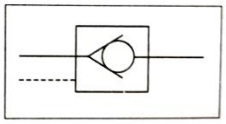
Free flow - Port A to Port B.

Reverse flow - poppet in closed position - no flow.

Reverse flow - Port B to Port A - pilot pressure applied through pilot pressure port.

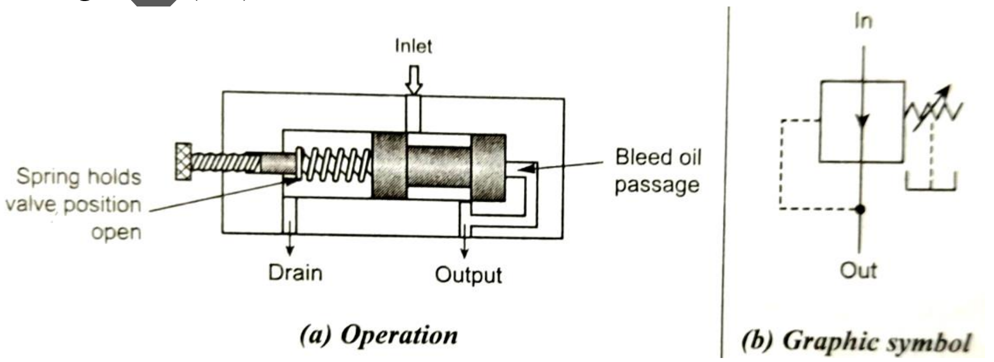
Applications: hydraulic jack (hydraulically lock the cylinder)





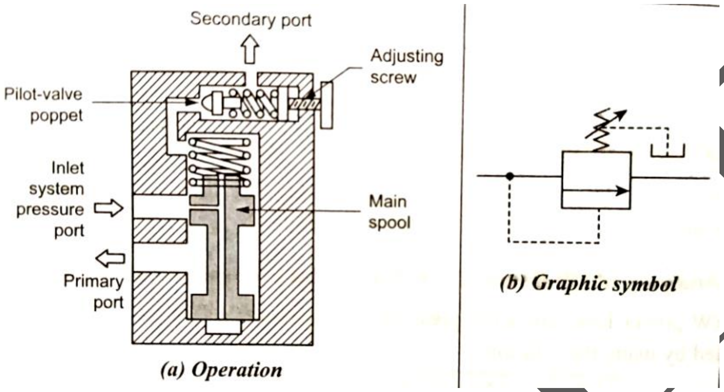
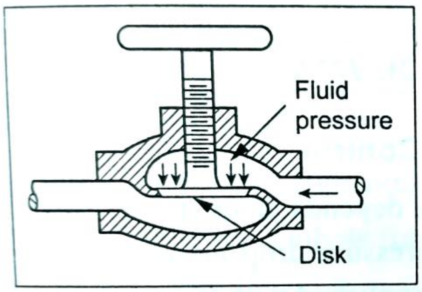
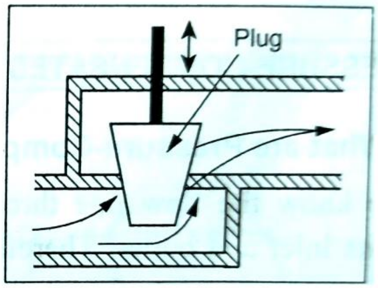
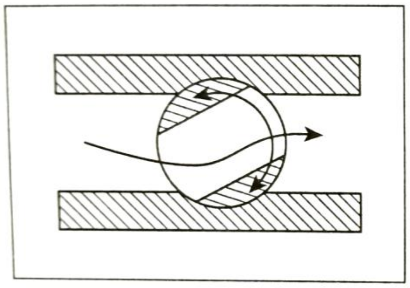
3 **In detail write the working of pressure reducing valve and sequence valve with neat sketches. BTL2**

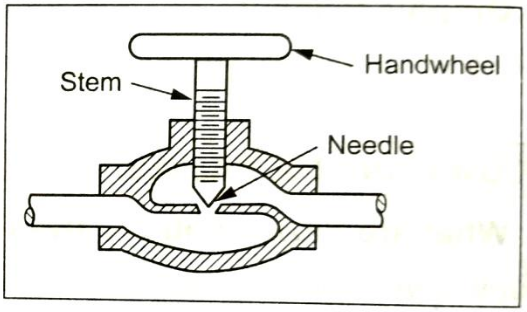
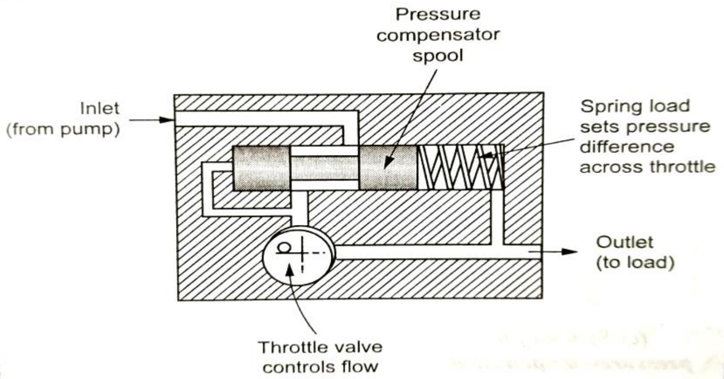
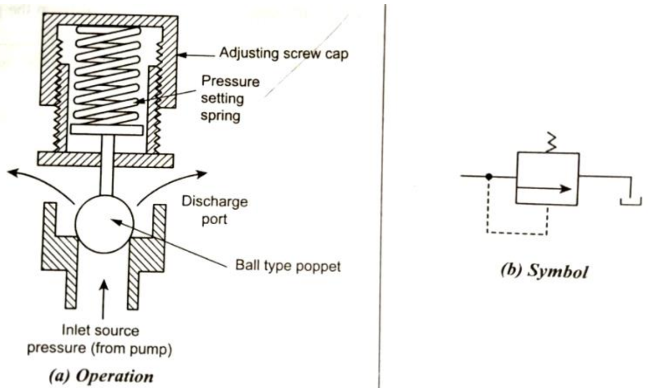
Pressure reducing valve: (6M)



(a) Operation (b) Graphic symbol

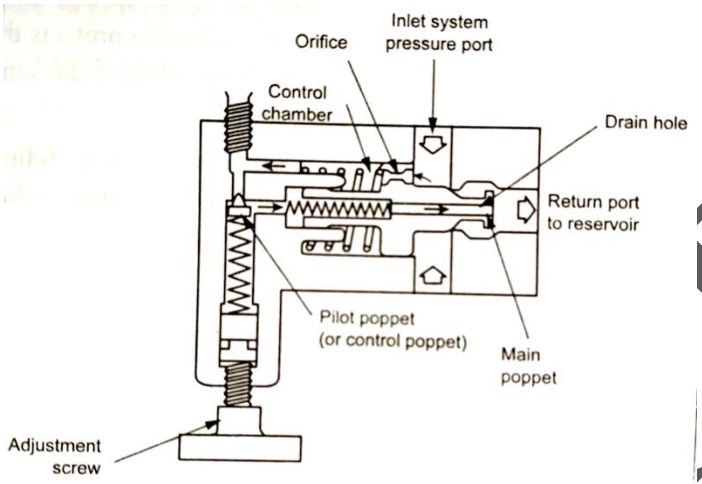
Spring loaded spool to control downstream pressure - valve setting pressure - free flow - outlet pressure increases - spool moves left - partly blocks outlet port - drain passage provided to drain

	fluid to tank. Sequence valve: (7M) These valves are used to control the fluid flow to ensure several operations in a particular order of priority in the system. Preset valve pressure - allows fluid from primary port to operate first phase - when pressure exceeds - spool moves up - flow diverted to secondary port to operate the second phase.  (a) Operation (b) Graphic symbol
4	**Explain in detail the different types of FCV. BTL2** Globe valve: (6M) Disk type globe valve is also called butterfly valve consists of a large disc which is rotated inside the pipe, the angle determining the flow rate. Plug type globe valve has a tapered plug that control the flow rate by varying the vertical plug position. Ball type globe valve has a ball with a through hole which is rotated inside a machined seat.  *Disk-type globe valve*  *Plug-type globe valve*  *Ball-type globe valve*

	Needle valve: (2M) Adjusted manually to control the flow rate of fluid through valve. Have smaller flow area and high pressure drop then the globe valve.  *Needle valve* Pressure compensated flow control valve: (5M) Spool controls the size of inlet orifice - maintains constant pressure drop across the throttle valve. Inlet pressure increase - spool closes the inlet passage - permits fluid flow for which throttle is set. 
5	**Explain with neat sketches of simple pressure relief valve and compound relief valve. BTL2** Simple pressure relief valve: (6M) Inlet pressure overcomes force exerted by spring - valve opens - fluid directed to sump. Adjusting screw to adjust screw pressure. Types: Ball, poppet, sliding pool  *(a) Operation* *(b) Symbol* Compound pressure relief valve: (7M)

Stage 1: Movable poppet allows fluid to escape to reservoir when system pressure exceeds.

Stage 2: Pilot valve poppet - pressure limit adjustment screw - fluid passes from inlet to control chamber - pressurised fluid escapes through centrally drilled drain hole.



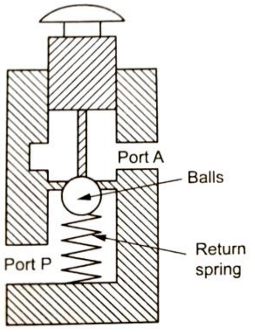
PART * C

1 **How position valves can be classified? Explain each of them. BTL2**

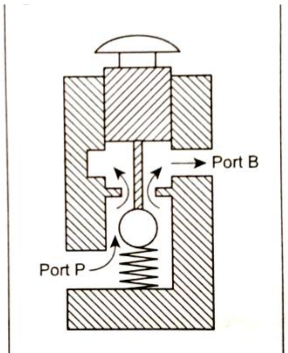
2/2 Direction Control Valve: (3M)

Position 1: When the push button is in normal position, spring and fluid pressure force the ball up, therefore flow is blocked.

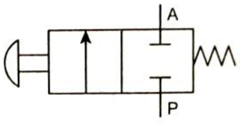
Position 2: When the pressure of the push button pushes the ball off its seat, then the flow is permitted.



(a) Poppet position 1



(b) Poppet position 2

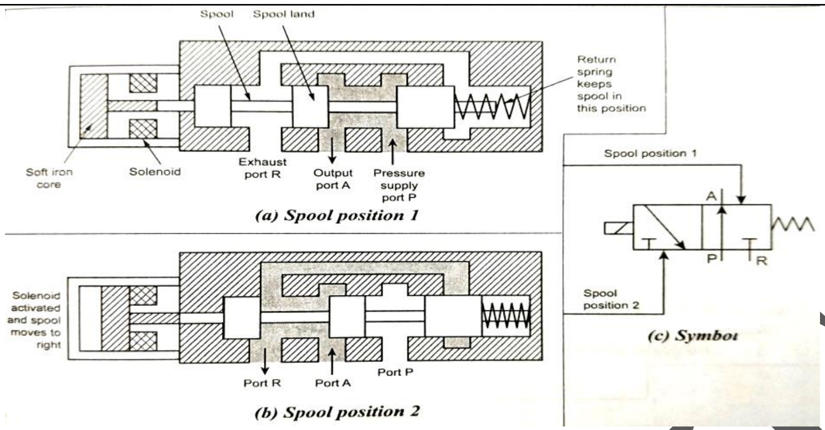


(c) Symbol

3/2 Direction Control Valve: (3M)

Spool position 1: Flow from Port P to Port A - Port R remains closed.

Spool position 2: Port P closed, flow from Port A to Port R



(a) Spool position 1

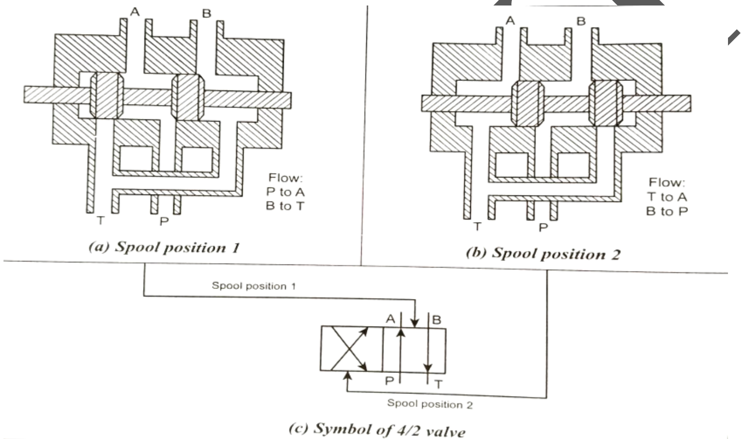
(b) Spool position 2

(c) Symbol

4/2 Direction Control Valve: (4M)

Spool position 1: Flow from Port P to Port A & Port B to Port T

Spool position 2: Flow from Port P to Port B & Port A to Port T



(a) Spool position 1

(b) Spool position 2

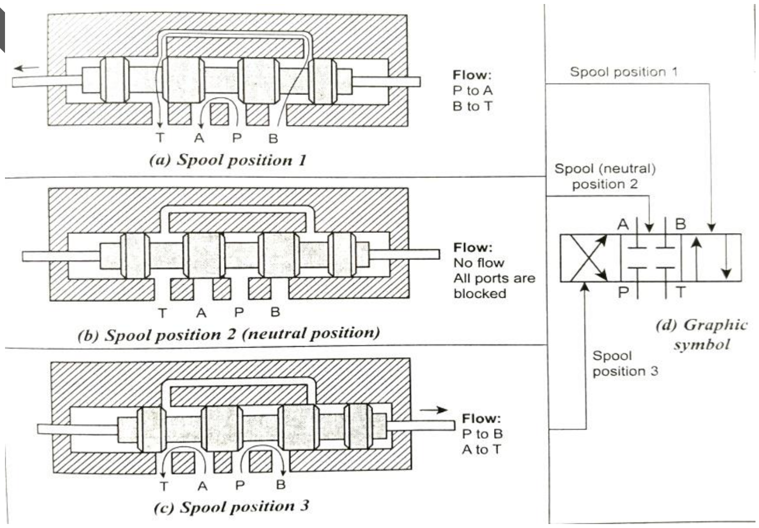
(c) Symbol of 4/2 valve

4/3 Direction Control Valve: (5M)

Spool position 1: Flow from Port P to Port A & Port B to Port T

Spool position 2: Flow from Port P to Port T, Port A & B closed

Spool position 3: Flow from Port P to Port B & Port A to Port T



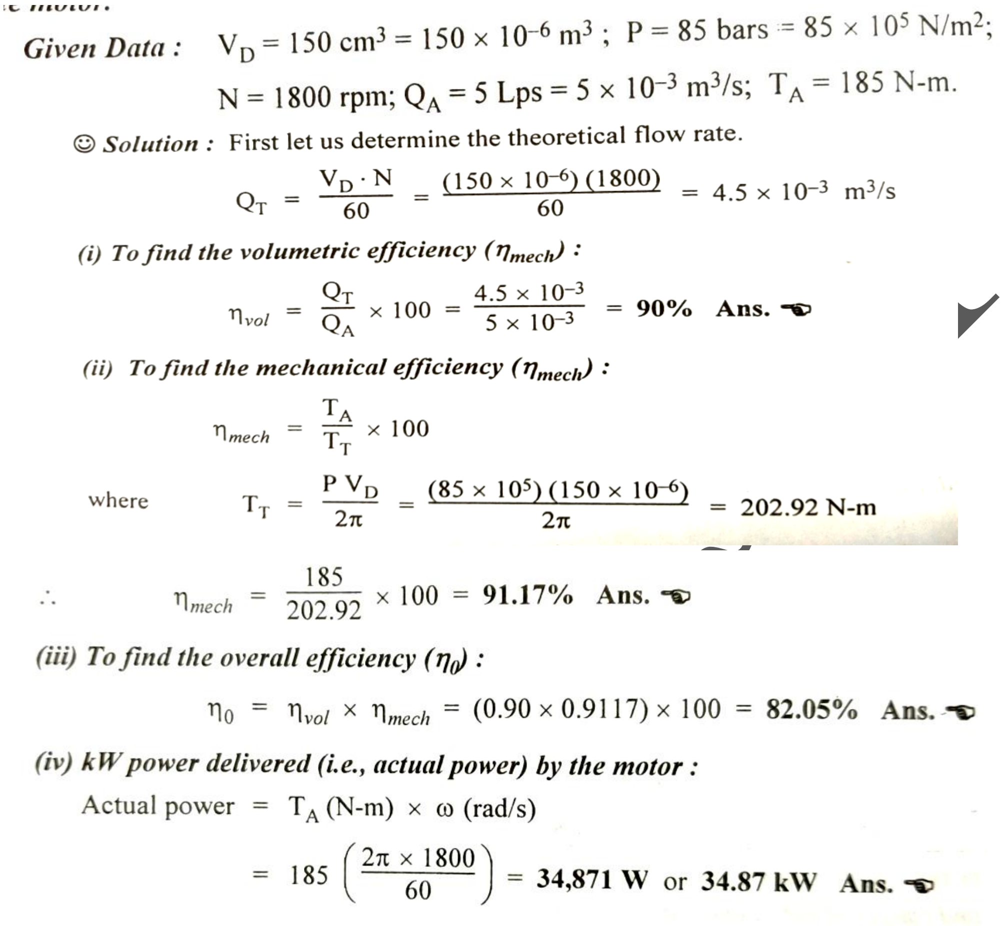
(a) Spool position 1

(b) Spool position 2 (neutral position)

(c) Spool position 3

(d) Graphic symbol

2 **A hydraulic motor has a displacement of 150 cm^3 and operates with a pressure of 85 bar and a speed of 1800rpm. The actual flow rate consumed by the motor is 5 Lps and actual torque delivered by the motor is 185 N-m. Find (i) Volumetric efficiency (ii) Mechanical efficiency (iii) Overall efficiency (iv) Power delivered by the motor. BTL5**



Given Data : $V_D = 150\ cm^3 = 150 \times 10^{-6}\ m^3$; $P = 85$ bars $= 85 \times 10^5\ N/m^2$;

$N = 1800$ rpm; $Q_A = 5$ Lps $= 5 \times 10^{-3}\ m^3/s$; $T_A = 185$ N-m.

☺ ***Solution :*** First let us determine the theoretical flow rate.

$$Q_T = \frac{V_D \cdot N}{60} = \frac{(150 \times 10^{-6})(1800)}{60} = 4.5 \times 10^{-3}\ m^3/s$$

(i) To find the volumetric efficiency (η_{mech}) :

$$\eta_{vol} = \frac{Q_T}{Q_A} \times 100 = \frac{4.5 \times 10^{-3}}{5 \times 10^{-3}} = \mathbf{90\%}$$ **Ans.** ☜

(ii) To find the mechanical efficiency (η_{mech}) :

$$\eta_{mech} = \frac{T_A}{T_T} \times 100$$

where $$T_T = \frac{P\ V_D}{2\pi} = \frac{(85 \times 10^5)(150 \times 10^{-6})}{2\pi} = \mathbf{202.92\ N\text{-}m}$$

$$\therefore \quad \eta_{mech} = \frac{185}{202.92} \times 100 = \mathbf{91.17\%}$$ **Ans.** ☜

(iii) To find the overall efficiency (η_0) :

$$\eta_0 = \eta_{vol} \times \eta_{mech} = (0.90 \times 0.9117) \times 100 = \mathbf{82.05\%}$$ **Ans.** ☜

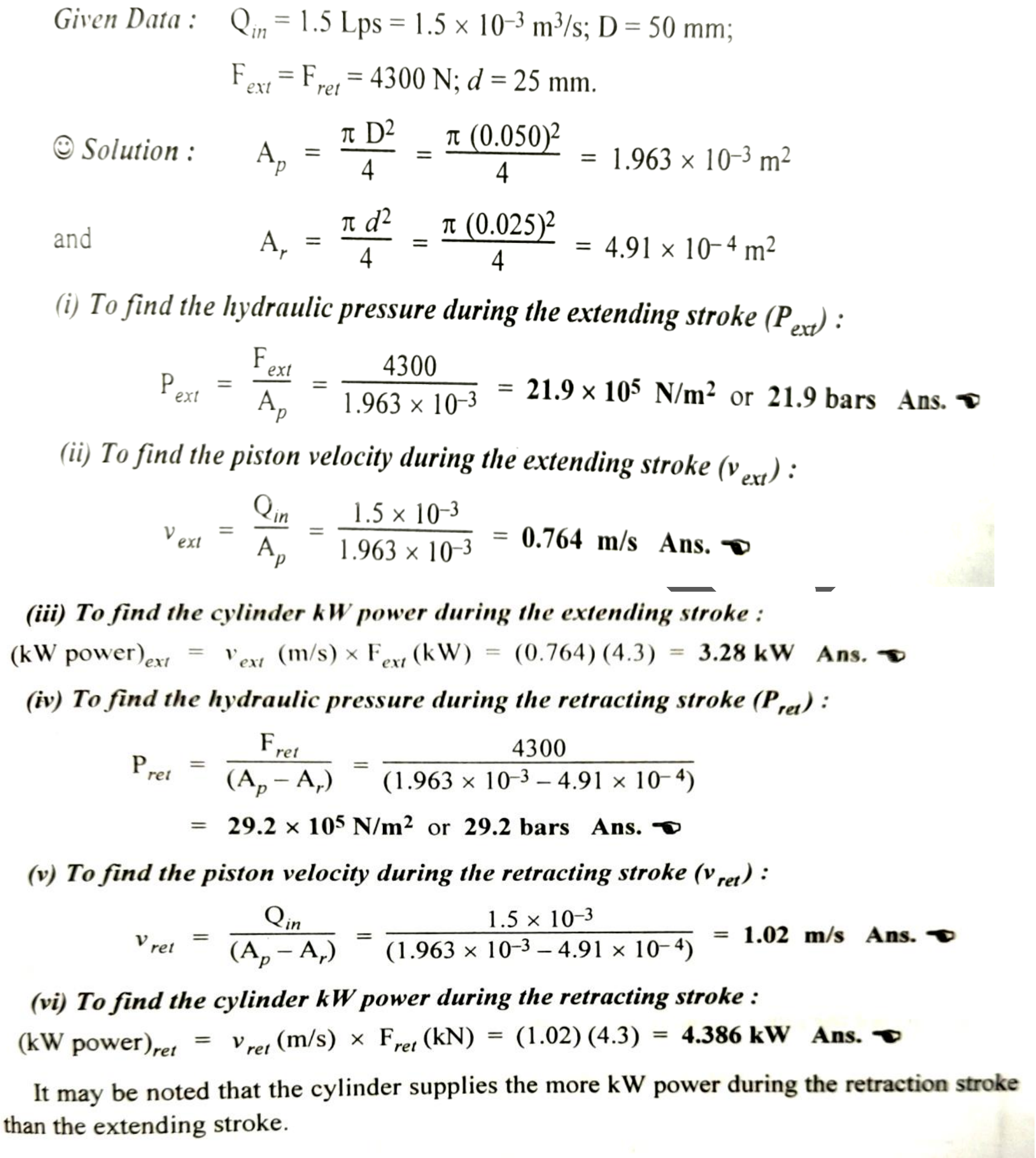
(iv) kW power delivered (i.e., actual power) by the motor :

$$\text{Actual power} = T_A\ (\text{N-m}) \times \omega\ (\text{rad/s})$$

$$= 185 \left(\frac{2\pi \times 1800}{60} \right) = \mathbf{34{,}871\ W} \text{ or } \mathbf{34.87\ kW}$$ **Ans.** ☜

3 **A pump supplies oil 1.5 Lps to a 50 mm diameter double acting hydraulic cylinder. If the load is 4300N (extending and retracting) and the rod diameter is 25 mm, find: BTL5**

(i) Hydraulic pressure during the extending stroke
(ii) Piston velocity during the extending stroke
(iii) Cylinder kW power during the extending stroke
(iv) Hydraulic pressure during the retracting stroke
(v) Piston velocity during the retracting stroke
(vi) Cylinder kW power during the retracting stroke



Given Data : $Q_{in} = 1.5$ Lps $= 1.5 \times 10^{-3}$ m³/s; D = 50 mm;

$F_{ext} = F_{ret} = 4300$ N; $d = 25$ mm.

☺ *Solution :*

$$A_p = \frac{\pi D^2}{4} = \frac{\pi (0.050)^2}{4} = 1.963 \times 10^{-3} \text{ m}^2$$

and

$$A_r = \frac{\pi d^2}{4} = \frac{\pi (0.025)^2}{4} = 4.91 \times 10^{-4} \text{ m}^2$$

(i) To find the hydraulic pressure during the extending stroke (P_{ext}) *:*

$$P_{ext} = \frac{F_{ext}}{A_p} = \frac{4300}{1.963 \times 10^{-3}} = \mathbf{21.9 \times 10^5 \text{ N/m}^2} \text{ or } \mathbf{21.9 \text{ bars}}$$ **Ans.** ☜

(ii) To find the piston velocity during the extending stroke (v_{ext}) *:*

$$v_{ext} = \frac{Q_{in}}{A_p} = \frac{1.5 \times 10^{-3}}{1.963 \times 10^{-3}} = \mathbf{0.764 \text{ m/s}}$$ **Ans.** ☜

(iii) To find the cylinder kW power during the extending stroke :

$$(\text{kW power})_{ext} = v_{ext} \text{ (m/s)} \times F_{ext} \text{ (kW)} = (0.764)(4.3) = \mathbf{3.28 \text{ kW}}$$ **Ans.** ☜

(iv) To find the hydraulic pressure during the retracting stroke (P_{ret}) ***:***

$$P_{ret} = \frac{F_{ret}}{(A_p - A_r)} = \frac{4300}{(1.963 \times 10^{-3} - 4.91 \times 10^{-4})}$$

$$= \mathbf{29.2 \times 10^5 \text{ N/m}^2} \text{ or } \mathbf{29.2 \text{ bars}}$$ **Ans.** ☜

(v) To find the piston velocity during the retracting stroke (v_{ret}) ***:***

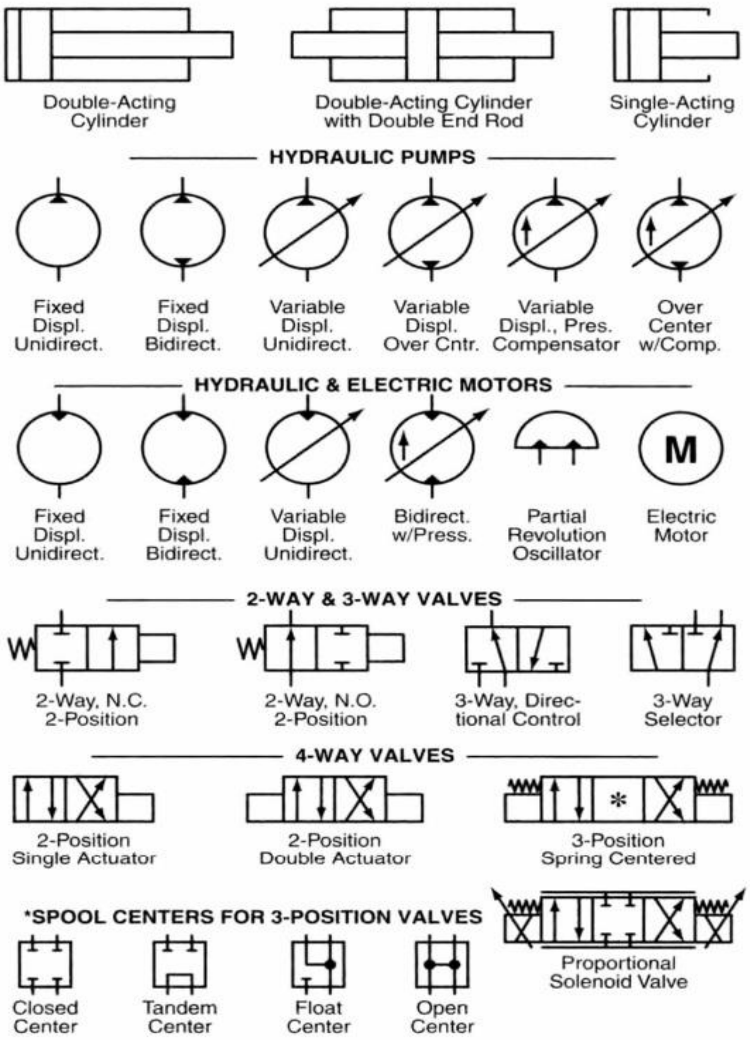
$$v_{ret} = \frac{Q_{in}}{(A_p - A_r)} = \frac{1.5 \times 10^{-3}}{(1.963 \times 10^{-3} - 4.91 \times 10^{-4})} = \mathbf{1.02 \text{ m/s}}$$ **Ans.** ☜

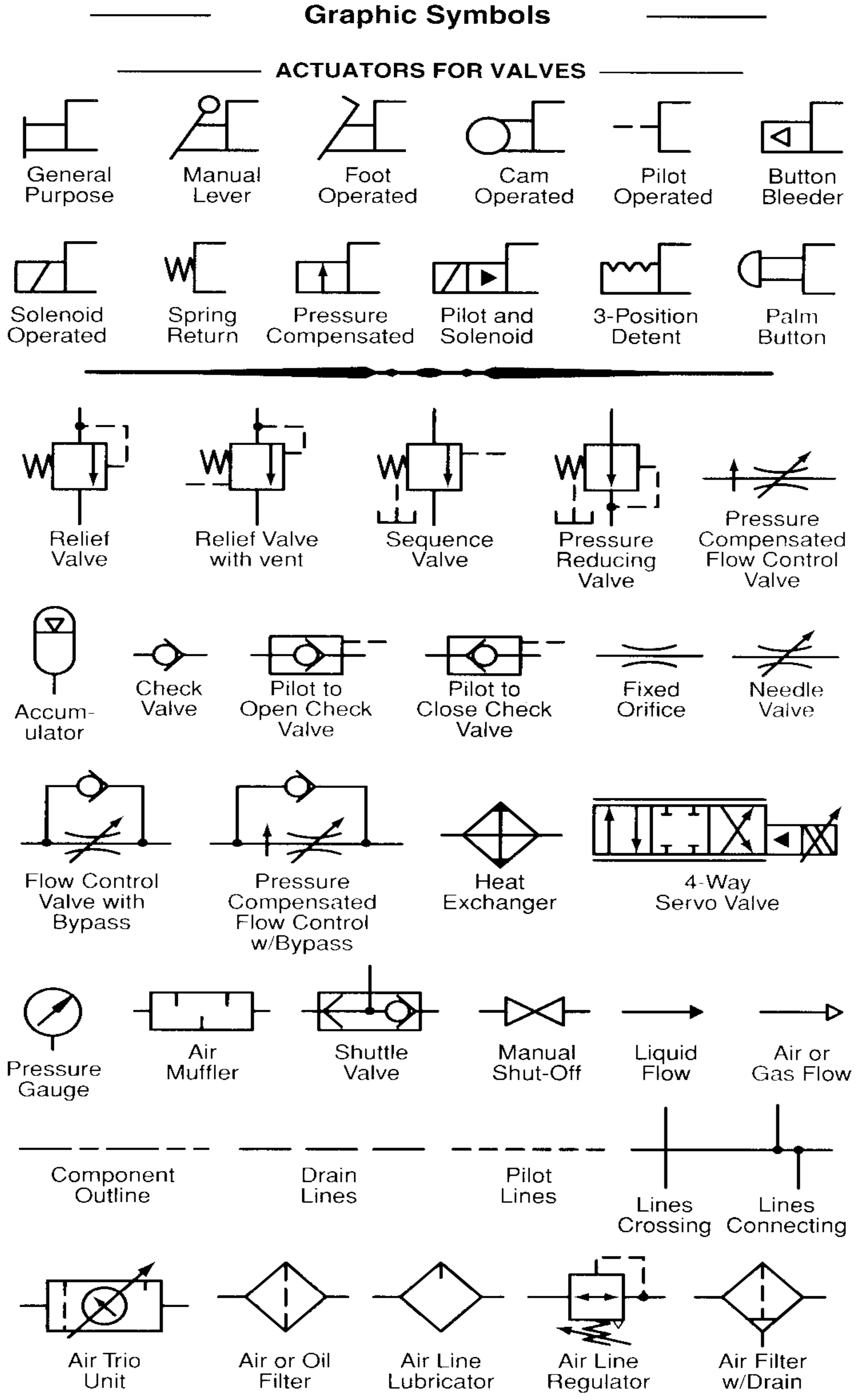
(vi) To find the cylinder kW power during the retracting stroke :

$$(\text{kW power})_{ret} = v_{ret} \text{ (m/s)} \times F_{ret} \text{ (kN)} = (1.02)(4.3) = \mathbf{4.386 \text{ kW}}$$ **Ans.** ☜

It may be noted that the cylinder supplies the more kW power during the retraction stroke than the extending stroke.

4	**List and sketch the fluid power ANSI symbol for the five basic classifications. BTL1**


Double-Acting Cylinder
Double-Acting Cylinder with Double End Rod
Single-Acting Cylinder
HYDRAULIC PUMPS
Fixed Displ. Unidirect.
Fixed Displ. Bidirect.
Variable Displ. Unidirect.
Variable Displ. Over Cntr.
Variable Displ., Pres. Compensator
Over Center w/Comp.
HYDRAULIC & ELECTRIC MOTORS
M
Fixed Displ. Unidirect.
Fixed Displ. Bidirect.
Variable Displ. Unidirect.
Bidirect. w/Press.
Partial Revolution Oscillator
Electric Motor
2-WAY & 3-WAY VALVES
2-Way, N.C. 2-Position
2-Way, N.O. 2-Position
3-Way, Directional Control
3-Way Selector
4-WAY VALVES
2-Position Single Actuator
2-Position Double Actuator
*
3-Position Spring Centered
*SPOOL CENTERS FOR 3-POSITION VALVES
Proportional Solenoid Valve
Closed Center
Tandem Center
Float Center
Open Center


Graphic Symbols
ACTUATORS FOR VALVES
General Purpose
Manual Lever
Foot Operated
Cam Operated
Pilot Operated
Button Bleeder
Solenoid Operated
Spring Return
Pressure Compensated
Pilot and Solenoid
3-Position Detent
Palm Button
Relief Valve
Relief Valve with vent
Sequence Valve
Pressure Reducing Valve
Pressure Compensated Flow Control Valve
Accum-ulator
Check Valve
Pilot to Open Check Valve
Pilot to Close Check Valve
Fixed Orifice
Needle Valve
Flow Control Valve with Bypass
Pressure Compensated Flow Control w/Bypass
Heat Exchanger
4-Way Servo Valve
Pressure Gauge
Air Muffler
Shuttle Valve
Manual Shut-Off
Liquid Flow
Air or Gas Flow
Component Outline
Drain Lines
Pilot Lines
Lines Crossing
Lines Connecting
Air Trio Unit
Air or Oil Filter
Air Line Lubricator
Air Line Regulator
Air Filter w/Drain

UNIT III – HYDRAULIC CIRCUITS AND SYSTEMS

Accumulators, Intensifiers, Industrial hydraulic circuits – Regenerative, Pump Unloading, Double-Pump, Pressure Intensifier, Air-over oil, Sequence, Reciprocation, Synchronization, Fail-Safe, Speed Control, Hydrostatic transmission, Electro hydraulic circuits, Mechanical hydraulic servo systems.

PART * A

Q.No.	Questions
1	**What is the function of accumulator? BTL2** Accumulators are temporary storage devices that stores the potential energy of a hydraulic fluid under pressure and acts as a secondary source as demanded by the system.
2	**What are the types of accumulator? BTL2** Based on the source of dynamic force to maintain pressure, the accumulators are classified as ➢ Weight or gravity-loaded accumulator ➢ Spring-loaded accumulator ➢ Gas-loaded accumulator The first two are categorized as mechanical accumulators and third one as hydro-pneumatic accumulator.
3	**What is electromechanical relay? BTL2** A relay is a electrically actuated switch which open or close when its corresponding coil is energized. These relays are commonly used for energizing and de-energizing the solenoids as they require high current to operate.
4	**What is the use of intensifier? Mention its applications. BTL2** A pressure intensifier or booster is a device which generates pressures to a greater value than the pump discharge pressure by using fluid power. Intensifier finds many applications of which, important are listed below. ➢ Burst testing machines ➢ High pressure clamping devices ➢ Moulding machines ➢ Spot-welding machines ➢ Riveting machines
5	**What type of gas is used in gas loaded accumulators and why oxygen not used for this purpose? BTL2** Inert gas is used in gas loaded accumulators and oxygen is not used for this purpose because it catches fire and cause explosion.
6	**What is the use of air-to-hydraulic pressure booster? BTL2** The air-to-hydraulic pressure booster is a device used for converting compressed air into the higher hydraulic pressure, which is required for operating hydraulic cylinders.
7	**What are the basic requirements for parallel cylinder synchronizing system? BTL2** Two cylinders must be identical, but no cylinders are really identical, as manufacturing tolerances may vary.

Load should be divided equally for both cylinders to extend in exact synchronization.

8 **What are the constituents of hydraulic power pack? BTL2**

- Cylinder,
- Hydraulic pump,
- Hydraulic oil,
- Reservoir

9 **What is air-oil intensifier? BTL2**

An air-oil intensifier circuit, which drives a cylinder over a large distance at low pressure and then over a small distance at high pressure

10 **What is hydraulic fuse? BTL2**

Hydraulic fuse is a device used in hydraulic systems to prevent hydraulic pressure from exceeding an allowable value in order to protect circuit components from damage.

11 **What is the function of bleed-off circuit? BTL2**

Bleed off circuits control the fluid flow rate by bleeding off the excess flow back to the tank. This is accomplished by providing a additional line parallel to the system pressure line. To slow down the actuator, some of the flow is bled off through this line, thereby reducing the flow to the actuator. It may be noted that, opening a bleed off FCV, slows down the actuator, whereas, opening a meter in or meter out FCV increases the actuator speed.

In this system the flow control valve is placed in the line loading to the inlet port of the cylinder.

12 **What is the difference between meter-in circuit and meter-out circuit? BTL2**

Meter - in Circuit	**Meter - out Circuit**
In this system the flow control valve is placed in the line leading to the inlet port of the hydraulic system.	In this system the flow control valve is placed in the outlet line of the hydraulic system.
It controls the oil flow rate into the cylinder.	It controls the oil flow rate out of the cylinder.
Less pressure is developed in the rod end of the cylinder while it is extending	Excessive pressure is developed in the rod end of the cylinder while it is
If meter-in is desired point the arrow toward the cylinder port.	If meter-out is desired point the arrow away from the cylinder port.

13 **What is the use of a regenerative circuit? BTL2**

A regenerative circuit is used to speed up the extending speed of the double-acting cylinder.

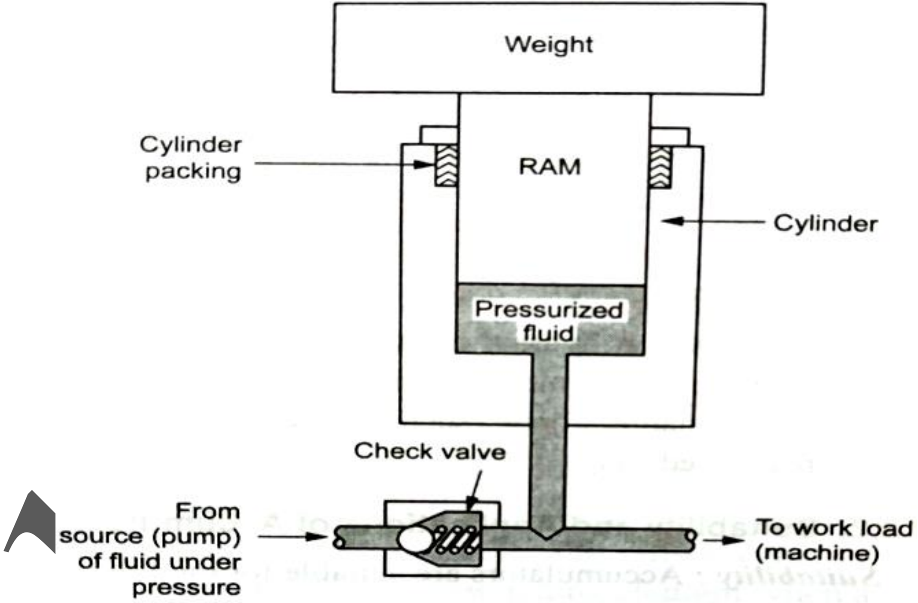
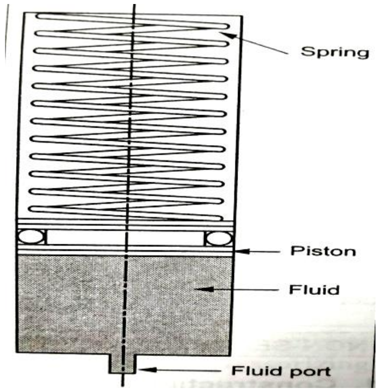
14 **What is the purpose of a fail-safe circuit? BTL2**

Fail safe circuit is designed to safeguard the operator, the machine, and the workpiece. It prevents any possible injury to the operator or damage to the machine and the workpiece.

15 **What is meant by an air-over-oil system? BTL2**

The air-over-oil system was both air and oil to obtain the advantages of each medium. By the use of these two media, the quick action of air and the smooth high-pressure action of oil can be blended.

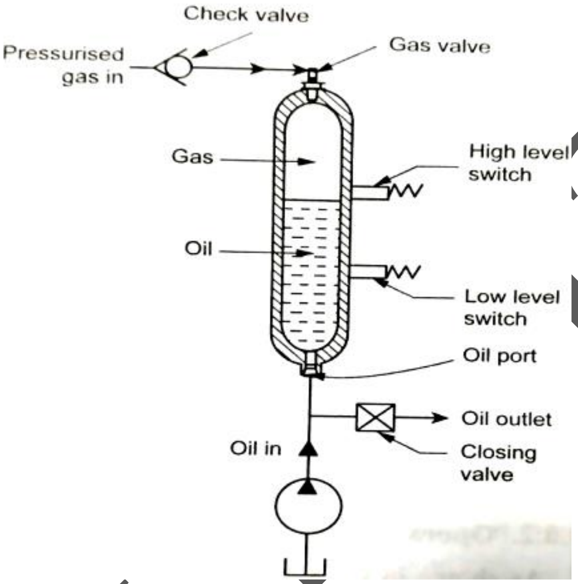
16	**What are hydropneumatic circuits? BTL2** In some applications, the hydraulic and pneumatic circuits are coupled to get best use of the advantages of both oil and air mediums. These combination circuits are known as hydropneumatic or pneumohydraulic circuits.
17	**Name the three ways of applying flow control valves in a fluid power circuit. BTL2** ➢ Meter-in circuit, ➢ Meter-out circuit and ➢ Bleed-off circuit.
18	**Why is extension stroke faster than retraction stroke in a regenerative circuit? BTL4** This is because oil flow from the rod end regenerates with the pump flow to provide a total flow rater, which is greater than the pump flow rate to the blank end of the cylinder.
19	**What do you mean by sequencing of cylinders? Name some applications where it would be desirable to have sequencing of two cylinders. BTL2** In many applications, the operation of two hydraulic cylinders is required to be performed in sequence one after the another. This is known as sequencing of cylinders. Applications : (i) In a drilling machine, clamping and drilling operations should be performed in a sequence. ii) In a punching machine, clamping and punching operations should be performed in a sequence.
20	**What do you mean by synchronization of cylinders? Name some applications where it would be desirable to have two cylinders synchronized in movement. BTL2** Synchronization of cylinders is the process of making cylinders to perform identical task at same rate. Application: The application of synchronizing of two cylinders can be found in material handling equipment to push heavy components. Also they are widely used in packing industries.
21	**List any two advantages of employing hydro pneumatic circuits. BTL2** ➢ Using the combination circuit, the quick action of air and smooth, high pressure action of oil can be blended. ➢ These circuits increase the performance of the equipment.
22	**List the applications of an intensifier. BTL2** ➢ Burst testing machines, ➢ High pressure clamping devices, ➢ Moulding machines, ➢ Spot-welding machines, ➢ Riveting machines, ➢ Hydraulic pressing and ➢ Punching machines etc.,
23	**What is an intensifier? BTL2** Intensifer is an ancillary part used in hydraulic system to increase the pressure of hydraulic liquid.
24	**What are the advantages of electrohydraulic servo systems over hydromechanical servo systems? BTL2** ➢ The electrohydraulic servo system can easily achieve the precision remote control of position, force, and speed of actuator.

	➢ They guarantee the higher flexibility of operation. ➢ They ensure better control of fluid compressiblity, system stiffness and dynamic behaviour of load. ➢ They also ensure correct ratio of force and speed that leads to higher energy conversion.
25	**Define the terms 'lap' and 'null' with respect to servo valves. BTL1** Lap is the length relationship between the metering lands to the spool and the port openings in the sleeve or body. Null is the relational condition between the spool and valve port where the vale supplies no control flow at zero load pressure drop.
	PART * B
1	**With neat sketch, write the different types of accumulator with advantages and disadvantages that are used in hydraulic system. BTL2** Weight loaded Accumulator: (5M) Idle periods of driven machine - fluid supplied till ram move to uppermost end - maximum preesure is accumulated - working stroke - accumulated energy discharged.  Spring loaded Accumulator: (4M)  Hydraulic fluid is forced into accumulator cylinder - spring compressed - pressure depend on

preloading and size of spring - fluid discharged from accumulator - spring expands and approaches its free length.

Gas loaded Accumulator: (4M)

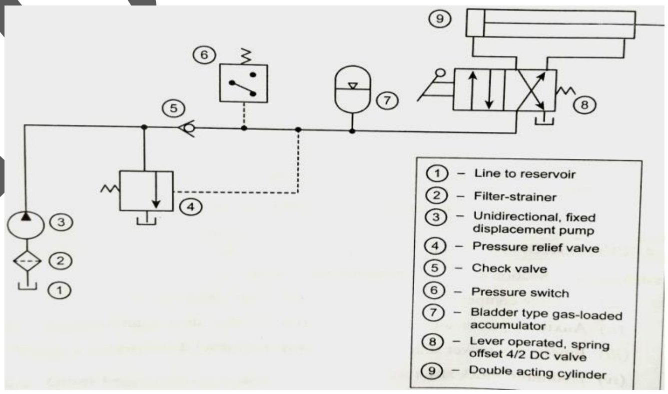
Pressurisation achieved by introducing pressurizing gas into container - when pressure increases oil enters into oil port - reduction of volume of gas increases its pressure - limit switches actuated by oil to limit the pressure.



2 **Explain with suitable circuit, how an accumulator can be used as leakage compensator and as emergency power source. BTL2**

Accumulator as leakage compensator: (7M)

When maximum pressure is reached, the pressure switch stops the pump motor. The leakage of oil is replaced by the volume of the accumulator and the rate of leakage in the cylinder



Accumulator as emergency power source: (6M)

In some hydraulic applications, it is necessary to retract the pistons of cylinder to their starting position; even there may be an electrical power failure. In such applications, the accumulator can be used as an emergency power source to retract the piston of the cylinder.

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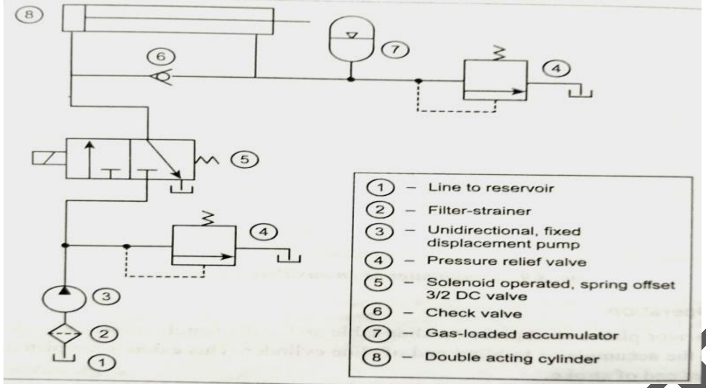

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How air over oil circuit can be used to have the advantages of air and oil. BTL2

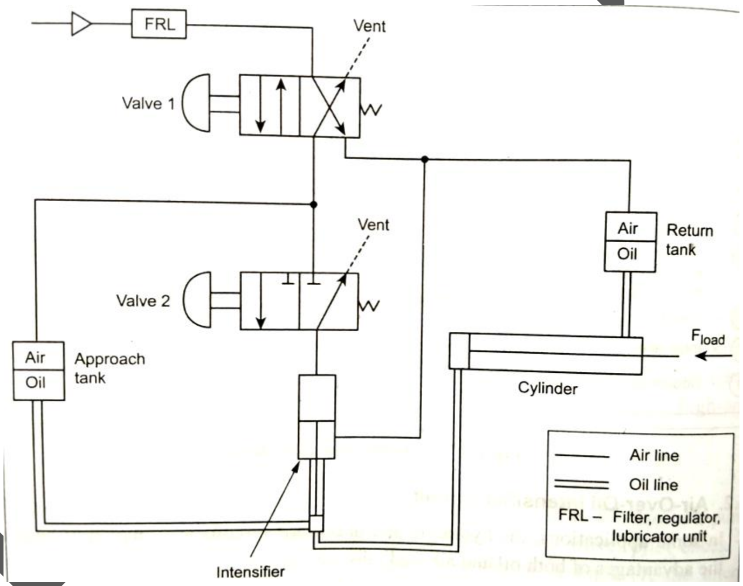
Extension: (3M)

4/2DC valve shifted to left mode - air forces the oil to blind end through bottom of intensifier.

Retraction: (3M)

4/2DC valve shifted to right mode - air flow is blocked - air from top of intensifier vented to atmosphere - completes the high pressure portion of cycle.

Circuit: (7M)



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Explain the working of a pressure intensifier with advantages and applications. BTL2

A hydraulic intensifier is a device which converts a large volume, low pressure fluid supply into a proportionately small volume high pressure fluid outlet. (2M)

Applications: (2M)

Punching presses, riverting machines, spot welder, tubing fixtures, high pressure holding fixtures, pressure testing machines.

Advantages: (2M)

Eliminates need of expensive, high pressure pumps - compact and simple - low power input - small volume of oil, heat generated is minimum - kW power requirements remain constant.

Construction: (3M)

Two pistons (low pressure and high pressure) - common piston rod - larger piston exposed from
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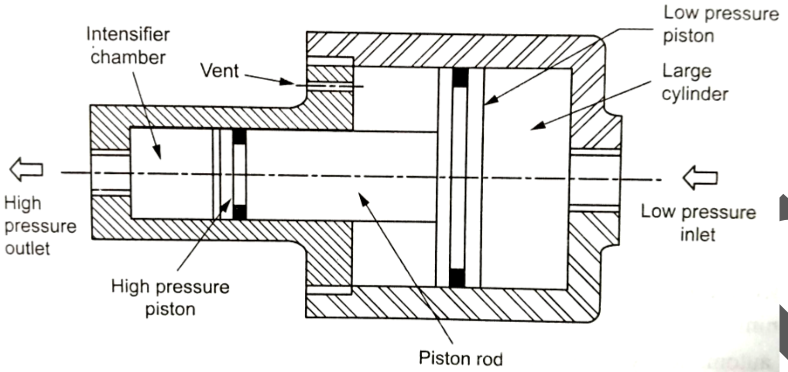
low pressure pump - neglecting losses due to friction - small end piston exerts force on fluid.

Diagram: (4M)



5 **Explain the two handed safety circuit. BTL2**

Fail safe circuit - safeguard operator, machine and workpiece - prevent any possible injury or damage. (1M)

Construction: (1M)

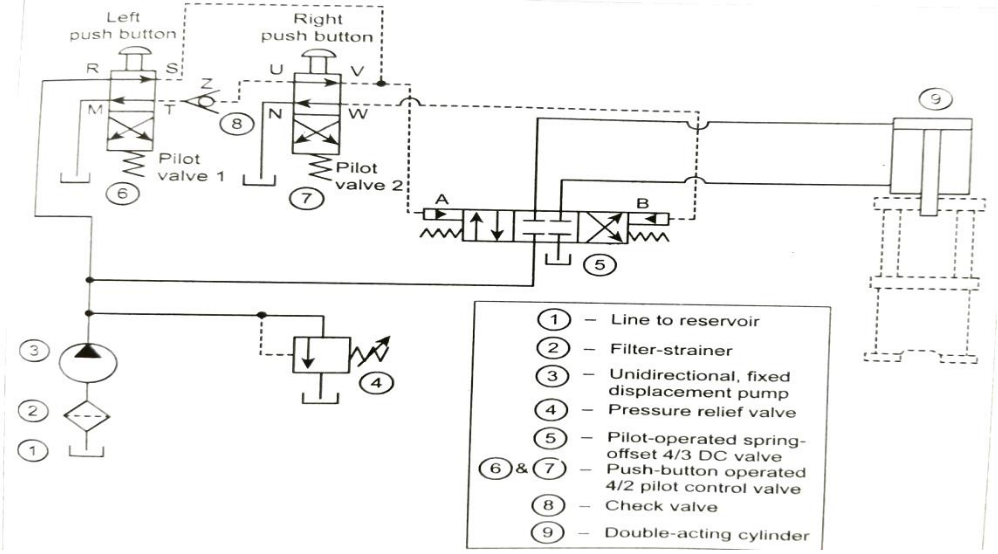
Filter - unidirectional fixed displacement pump - pressure relief valve - pilot operated spring offset 4/3 DC valve - push button operated 4/2 pilot control valve - check valve - double acting cylinder.

Working: (3M)

Extension of cylinder takes place only when the operator depresses both the push buttons.

Retraction of cylinder takes place when the operator releases both the push buttons.

Circuit: (8M)



6 **Explain the automatic cylinder reciprocation circuit. BTL2**

Construction: (1M)

Filter - unidirectional fixed displacement pump - pressure relief valve - pilot operated spring centered 4/3 DC valve - sequencing valves - check valves - double acting cylinder.

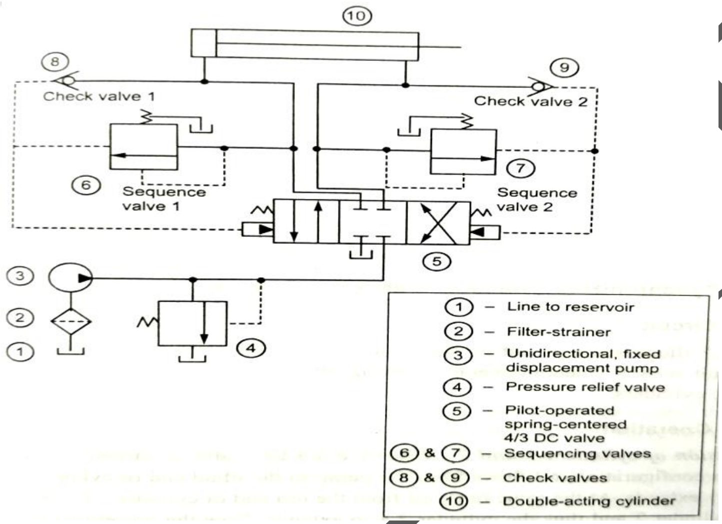
Retraction: (2M)

4/3 DC valve shifted to left - oil flows from pump to rod end - retraction of cylinder - check valve 1 prevent shifting DC valve - end of stroke pressure build up - sequence valve 1 opens - pilot pressure signal shifts DC valve to right.

Extension: (2M)

4/3 DC valve in right mode - oil flows from pump to blind end - extension of cylinder - check valve 2 prevents shifting DC valve - end of stroke pressure builds up - sequence valve 2 opens - pilot pressure signal shifts DC valve to left.

Circuit: (8M)

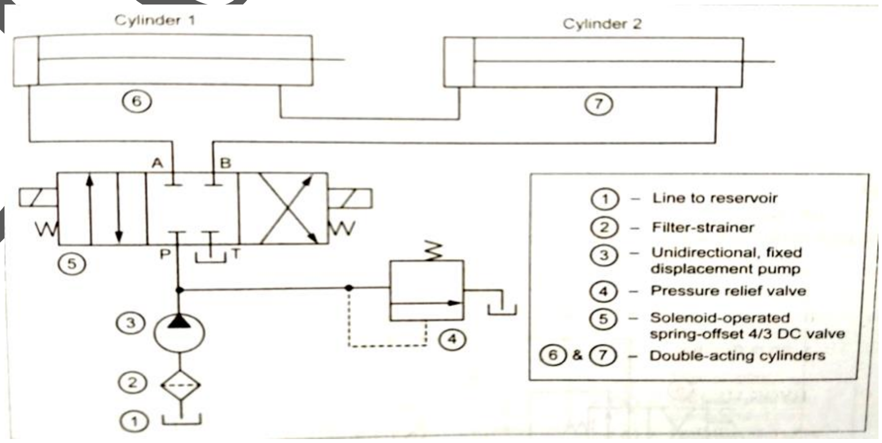


7 **How synchronizing of cylinder is possible in series piping? BTL2**

There are many industrial applications require nearly perfect synchronization of movement of two or more cylinders in order to complete some phase of operation. to accomplish the identical task from the cylinders at the same rate, synchronization circuits are employed. (1M)

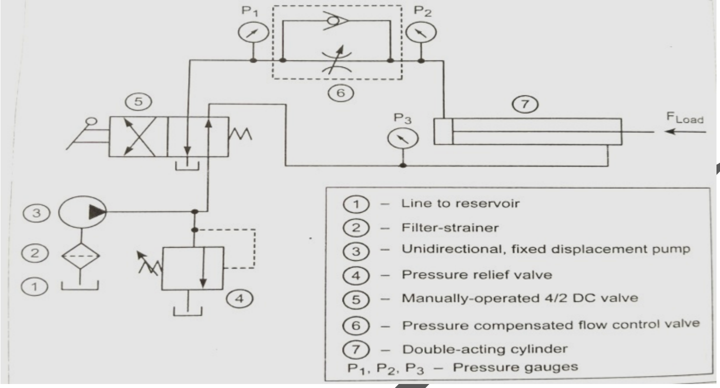
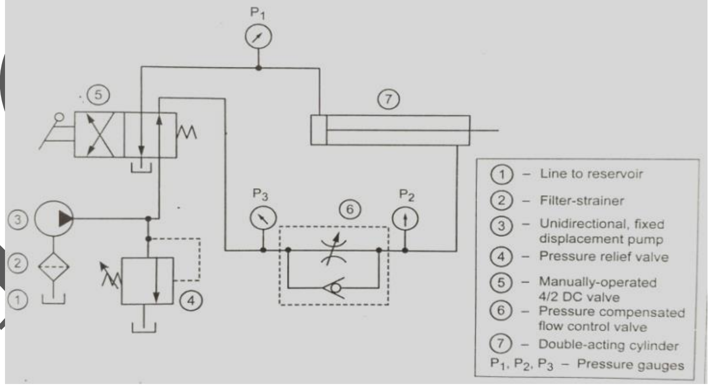
Circuit: (8M)

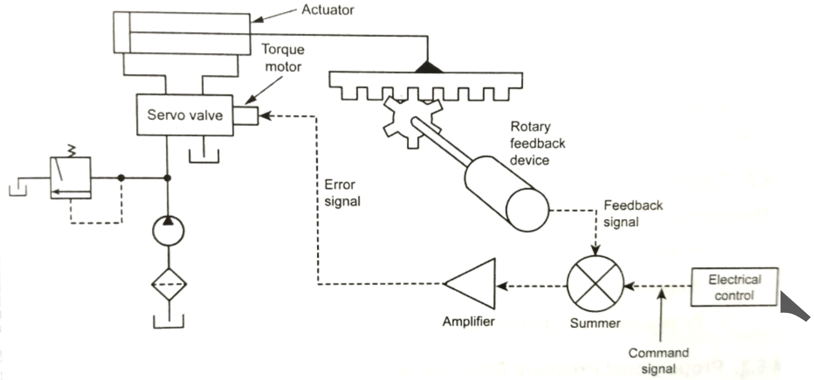
Filter - unidirectional fixed displacement pump - pressure relief valve - solenoid operated spring offset 4/3 DC valve - double acting cylinders.



Extension of cylinder 1 and 2: (2M)

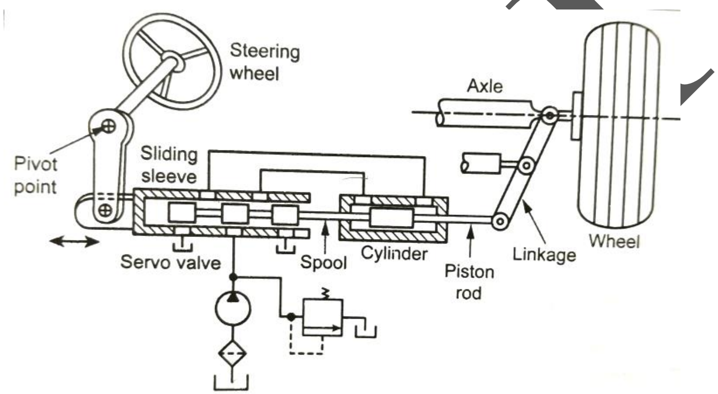
4/3 DC valve shifted to left - oil flows from pump to blind end of cylinder 1 - piston 1 extends - oil from rod of cylinder 1 flows to blind end of cylinder 2 - piston 2 extends.

	Retraction of cylinder 1 and 2: (2M) 4/3 DC valve shifted to right - oil flows from pump to rod end of cylinder 2 - piston 2 retracts - oil from blind of cylinder 2 flows to rod end of cylinder 1 - piston 2 retracts.
8	**Explain the speed control circuit of hydraulic system. BTL2** Construction: (1M) Filter - unidirectional fixed displacement pump - pressure relief valve - manually operated 4/2 DC valve - pressure compensated flow control valve - double acting cylinder - pressure gauges. Meter in circuit: (6M) Pressure compensated flow control valve connected to blind end of the cylinder - extension is controlled - retraction at full speed  Meter out circuit: (6M) Pressure compensated flow control valve connected to rod end of the cylinder - retraction is controlled - extension at full speed 
	PART * C
1	**With an example how electro hydraulic servo system works. BTL2** Operation: (7M) Feedback device attached to actuator - actuator position or speed - electric signal to servo valve. Feedback signal comparison with electrical input - not intended - electronic summer - error signal. Accurate control relative to position, speed, pressure and load. Diagram: (8M)



2 **Discuss the construction and working of a Mechanical hydraulic servo system with a diagram. BTL2**

Diagram: (8M)



Operation: (7M)

Input - turning of steering wheel - command signal - servo system.

Valve sleeve - steering cylinder - valve spool attached to linkage - cuts off oil flow to cylinder - motion of output wheel - desired position - feedback line.

3 **Develop a circuit for punch- press application. BTL3**

Intensifier circuit in punching press application:

Construction: (2M)

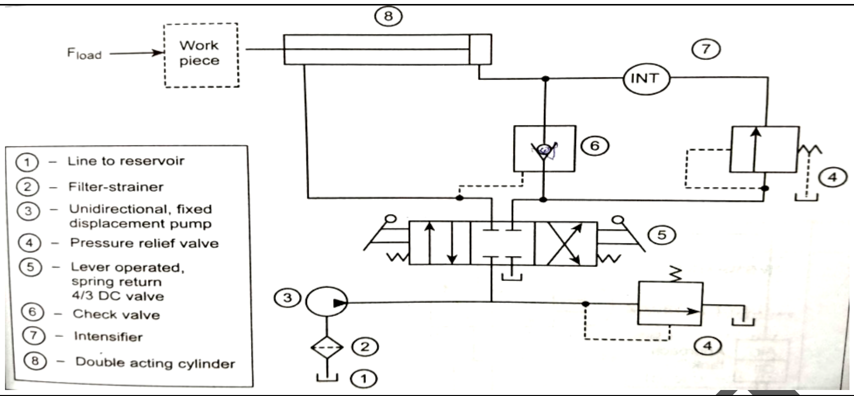
Filter - unidirectional fixed displacement pump - pressure relief valve - lever operated spring return 4/3 DC valve - check valve - intensifier - double acting cylinder.

Working: (5M)

4/2 valve shifted to right side position - oil flow to blind end - sequence valve opens and supplies flow to intensifier - low pressure input to high pressure output - pilot check valve allows to blind end.

4/2 valve shifted to left side position - oil flow to rod end - pilot signal opens check valve - cylinder retract to starting position.

Circuit: (8M)

F_{load}
Work piece
8
7
INT
6
4
5
3
2
1
4
① – Line to reservoir
② – Filter-strainer
③ – Unidirectional, fixed displacement pump
④ – Pressure relief valve
⑤ – Lever operated, spring return 4/3 DC valve
⑥ – Check valve
⑦ – Intensifier
⑧ – Double acting cylinder

UNIT IV – PNEUMATIC AND ELECTRO PNEUMATIC SYSTEMS

Properties of air – Perfect Gas Laws – Compressor – Filters, Regulator, Lubricator, Muffler, Air control Valves, Quick Exhaust Valves, Pneumatic actuators, Design of Pneumatic circuit – Cascade method – Electro Pneumatic System – Elements – Ladder diagram – Problems, Introduction to fluidics and pneumatic logic circuits.

PART * A

Q.No.	Questions
1	**What is a quick exhaust valve? BTL2** Quick exhaust valve is a special purpose three way pneumatic valve that increases the cylinder rod speed by dumping the exhaust air directly to the atmosphere from the cylinder. Use of quick exhaust valves, permits increased cylinder velocities and needs smaller, less expensive DCV. This eliminates the need for exhaust air to travel from the cylinder to the main control valve through long restricted pipe lines.
2	**Name the factors to be considered for designing fluid power circuits. BTL2** Any circuit design should involve the three major considerations ➢ Safety of system/operation ➢ System performance of function/operation. ➢ Efficiency of system/operation.
3	**What is the purpose of fluid conditioners? BTL2** The purpose of fluid conditioners is to make the compressed air more acceptable and suitable fluid medium for the pneumatic system components as well as for operating personnel.
4	**How do pneumatic actuators differ from hydraulic actuators? BTL2** Generally pneumatic actuators are of lighter construction and of lesser weight when compared to that of hydraulic actuators. This is because the pneumatic actuators are used mostly for low or medium pressure applications only.
5	**What is a FRL unit? BTL2** The combination of filter, regulator, and lubricator is often labelled as FRL unit or service unit
6	**What is the purpose of a shuttle valve in a pneumatic circuit? BTL2** Shuttle valves are used when control is required from more than one power source. They are generally used to shift the fluid flow from the second and back up source, when the main source becomes inoperative
7	**What is fluidics? BTL1** Fluidics is the technology that utilizes fluid flow phenomena in components and circuits to perform a wide variety of control functions.
8	**What advantages does fluidics offer? BTL2** ➢ Fluidic devices offer exceptional thermal and physical stability and ruggedness. ➢ They are completely insensitive to radiation, even of extremely high loads. ➢ They are not affected by severe vibration and shock.

- They are not susceptible to wear and tear.

9 **Where are fluidic control systems preferred than other control systems? BTL2**

Fluidic control systems are preferred over other control systems in areas subject to nuclear radiation, magnetic flux, temperature extremes, vibration, and mechanical shock.

10 **State the Coanda effect. BTL1**

"When a stream of fluid meets other stream, the effect is to change its direction of flow and effect is the fluid sticks to the wall."

11 **Name four fluidic devices. BTL2**

- Bistable flip-flop,
- Flip-flop with start-up preference,
- SRT flip-flop,
- OR/NOR gate.

12 **What is a bistable flip-flop? BTL2**

A bistable flip-flop provides controlled assurance as to which of the two output ports will deliver the power stream. It is normally used as a memory device.

13 **What is a monostable device? BTL2**

A monostable device is required to perform monostable function which is analogous to spring return function. In this device, when the control signal is removed, the device will switch back to the favoured output.

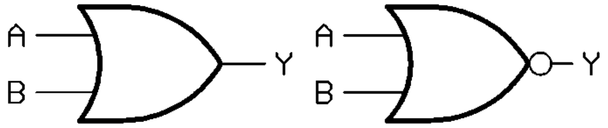
14 **When do you use a flip-flop with start-up preference? BTL2**

A flip-flop with start-up preference is used in applications where a specific output is required when the power supply is first turned ON and all controls are OFF.

15 **What is the use of truth table in logic devices? BTL2**

A truth table helps to describe the functioning of that particular logic device.

16 **Give the symbol and truth table for fluidic OR/NOR gate. BTL1**



Truth Table			
Inputs		Output	
A	B	OR	NOR
0	0	0	1
0	1	1	0
1	0	1	0
1	1	0	0

17 **What is Boolean algebra? Write its two functions relative to fluid power systems. BTL2**

Boolean algebra is'algebra of logic'. This is the algebra of proportions where only two possibilities - true or false - are allowed. Boolean algebra provides the following two functions:

It provides a means by which a logic circuit can be reduced to its simplest form.

It allows for the quick synthesis of a circuit that is to perform desired logic operations.

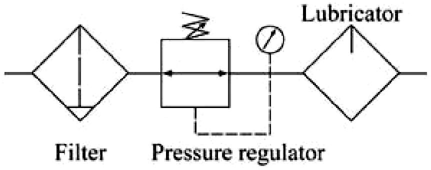
18	**Name four fluid sensors that are used in fluid power systems. BTL2** ➢ Back-pressure sensor. ➢ Cone-jet Proximity sensor, ➢ Interruptible-jet sensor, and ➢ Contact sensing.
19	**Define Ladder diagram. BTL1** It is a special standard schematic representation of the physical components arrangement and its way of connections made between them. It is so called because the circuit devices are connected in parallel across the AC line form something looks like a ladder.
20	**What is a PLC? BTL2** A programmable logic controller (PLC) is a user-friendly electronic computer designed to perform logic functions such as AND, OR, or NOT for controlling the operation of industrial equipment and processes.
21	**List any four advantages that PLCs provide over electromechanical relay control systems. BTL2** ➢ PLCs are more reliable and faster in operation. ➢ They are smaller in size and can be more readily expanded. ➢ They require less electrical power. ➢ They have very few hardware failures when compared to electromechanical relays.
22	**What is a solenoid? BTL2** It is electromechanical electromagnets that convert the electrical power into mechanical force to operate fluid power valves remotely. It consists of a coil wrapped removable iron core (Armature). When the solenoid is energized, the magnetic created causes the armature to shift the valve spool.
23	**Define relay. BTL1** Relay is an electrically actuated switch which open or close when its corresponding coil is energized. These relays are commonly used for energizing and de-energizing the solenoids as they require high current to operate.
24	**Write few applications of electrohydraulic servo valve. BTL2** It is employed in more sophisticated control systems such as on tape controlled machine tools, high speed printing presses, press brakes etc.
25	**What is cascade method in pneumatics? BTL2** It involves dividing the sequence into groups with each group’s manifold (power or main pressure line) being supplied with pneumatic power (pressure) one at a time and in sequence.
	PART * B
1	**Explain the FRL trio unit in pneumatic system. BTL2** Description: (6M) Compressor: Pressure vessel with stored compressed air Emulsion made of lubricating oil and condensate. Polluted compressed air, oil, water, solid matter.

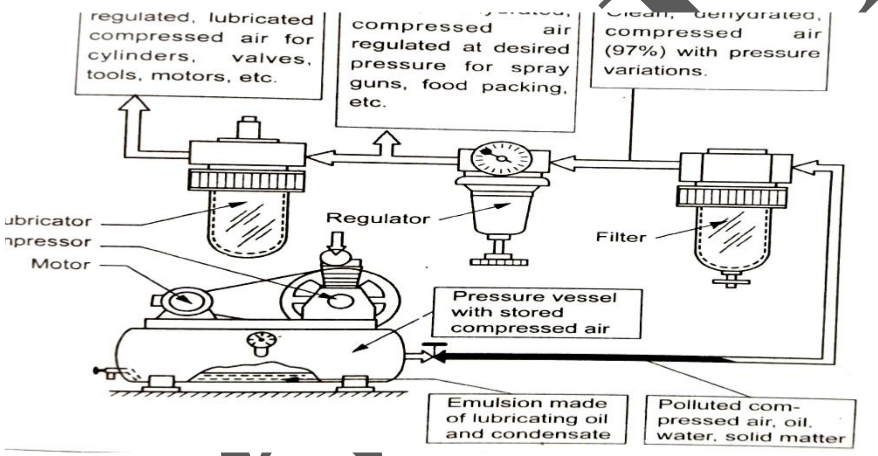
Filter: Clean, dehydrated, compressed air with pressure variations.

Regulator: Clean, dehydrated, compressed air regulated at desired pressure for spray guns, food packing, etc.

Lubricator: Clean, dehydrated, regulated, lubricated compressed air for cylinders, valves, tools, motors etc.

Diagram: (7M)

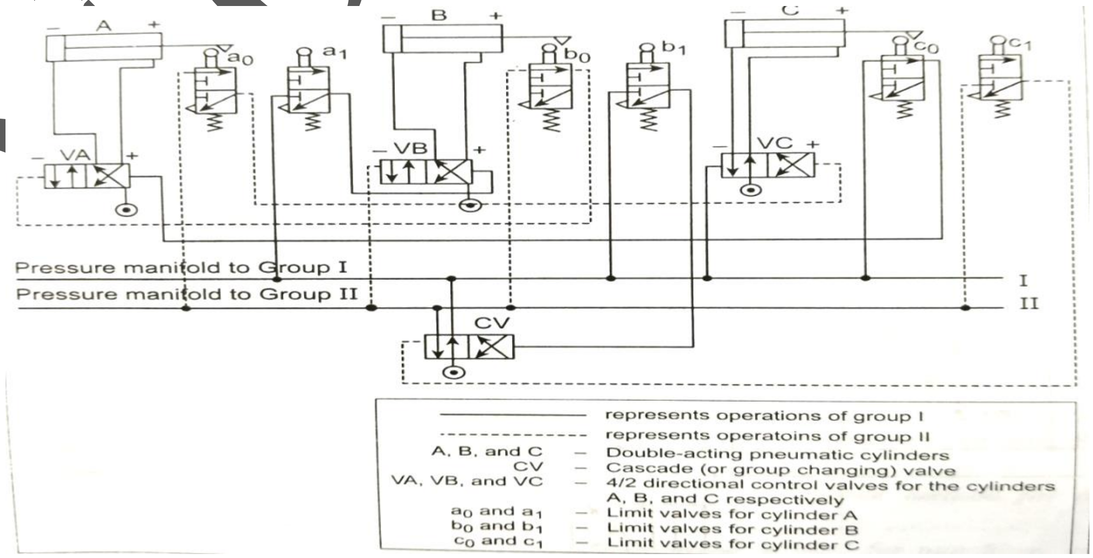




2

Design a system in which cylinder A is used to clamp the workpiece, cylinder B is used for punching and cylinder C removes the workpiece from the station using cascade method. BTL4

Circuit: (8M)



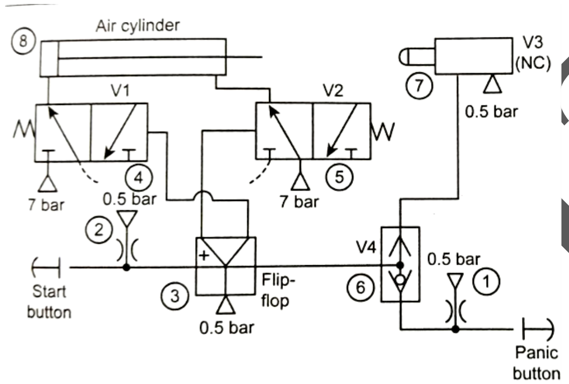
Working: (5M)

Step 1: Sequence: $A^+B^+B^-A^-C^+C^-$
Step 2: No. of groups: 2
Step 3: No. of pressure lines: 2
Step 4: No. of pilot operated 4/2 DC valve = No. cylinders = 3
No. of limit valves = 6.
No. of cascade valves = 1

3

How the control of air cylinder using preferenced flip-flop is made? BTL2

Circuit: (7M)



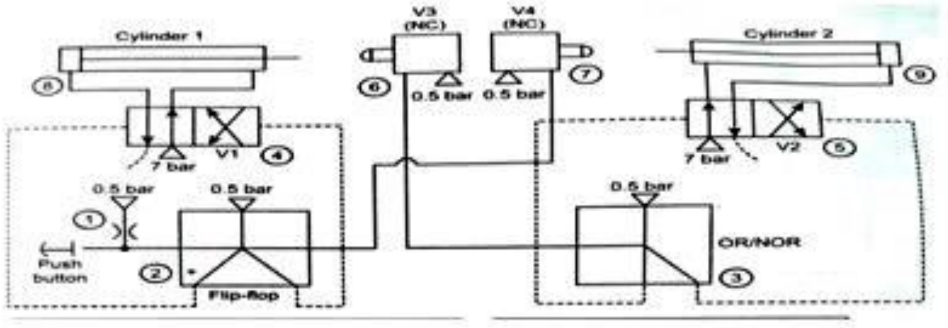
Construction: (6M)

1 & 2 - Back pressure sensors, 3 - preferenced flip flops, 4 & 5 - pilot operated 3/2 control valves, 6 - shuttle valves, 7 - normally closed limit switch, 8 - double acting air cylinder, 0.5 bar represents pressure of the fluidic (pilot) air, 7 bar represents pressure f main air supply.

4

Explain the fluidic sequence control of two pneumatic cylinders. BTL2

Circuit: (7M)



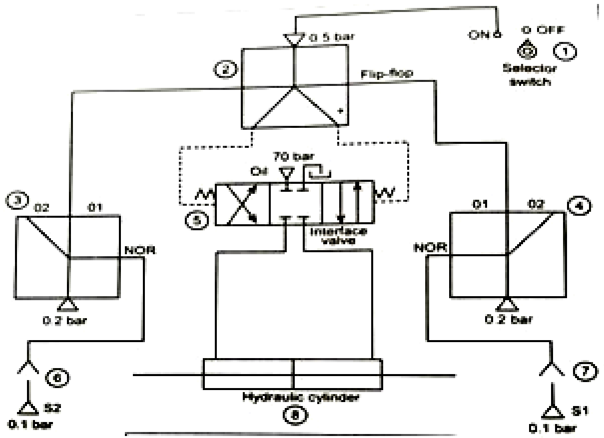
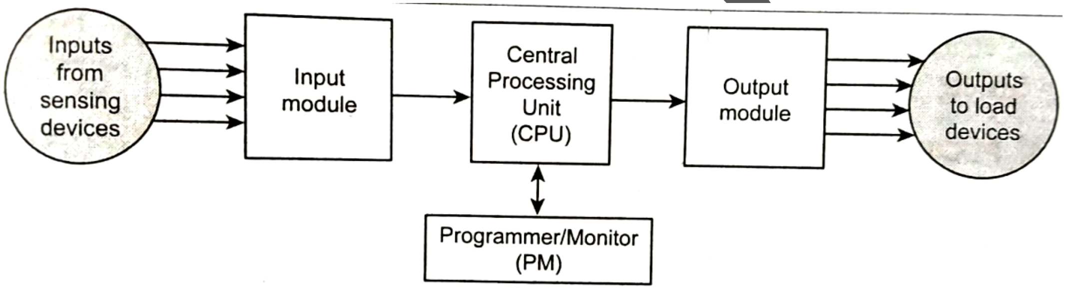
Construction: (6M)

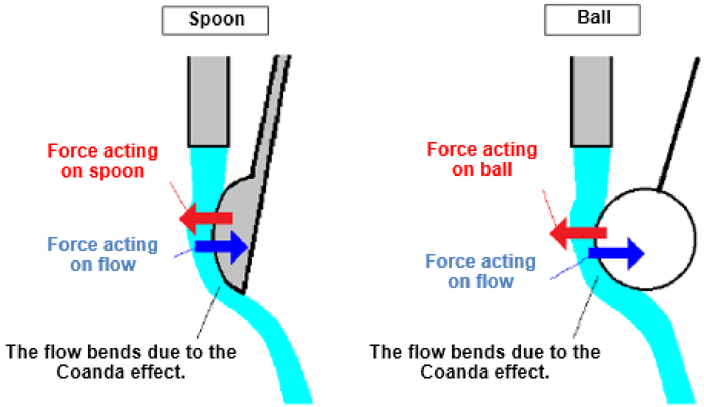
1 - Back pressure sensor, 2 - preferenced flip flop, 3 - OR/NOR gate, 4 & 5 - pilot operated 4/2 control valve, 6 & 7 - normally closed limit switches, 8 & 9 - double acting pneumatic cylinders, 0.5 bar represents pressure of the fluidic air, 7 bar represents pressure of the main air supply.

5

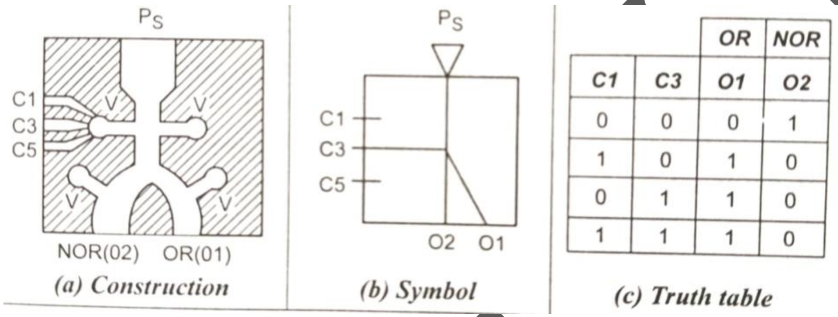
How the continuous reciprocation of a hydraulic cylinder using fluidic controls is made? BTL2

Circuit: (7M)

	 Construction: (6M) 1 - selector switch, 2 - preferenced flip flop, 3 & 4 - NOR gate, 5 - pilot operated 4/3 interface valve, 6 & 7 - interruptible jet sensor, 8 - hydraulic cylinder
6	**Explain the elements of PLC with neat diagram. BTL2** Diagram: (5M)  Description: (8M) Central processing unit: i) receives input data from various sensing elements ii) executes the stored program iii) delivers corresponding output signal to various load control devices. Programmer/monitor: Allows user to enter desired programme into RAM - relay logic determines sequence of operation of system controlled. Input/output module: Transforms signals received from or sent to the fluid power interface devices - push button, switches, pressure switches, limit switches, solenoid coils, motor relay coils, indicator lights.
	PART * C
1	**Define Coanda effect. Discuss how this effect useful to develop a monostable and bistable-flip flop device. BTL1** Coanda effect: (3M) When a stream of fluid meets other stream, the effect is to change its direction of flow and effect is the fluid sticks to the wall.

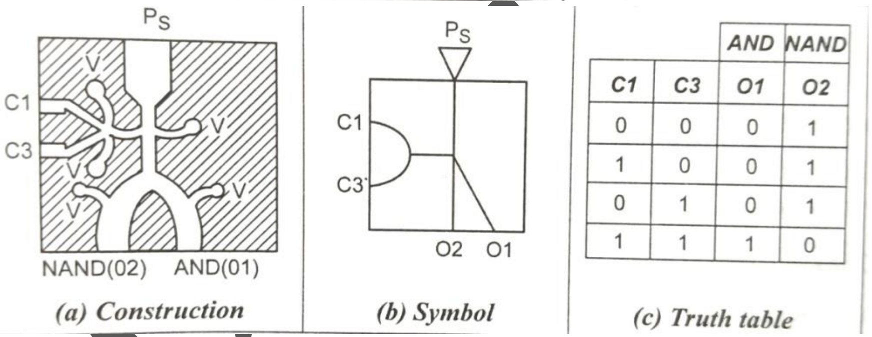


Monosatble flip flop: (6M)



(a) Construction (b) Symbol (c) Truth table

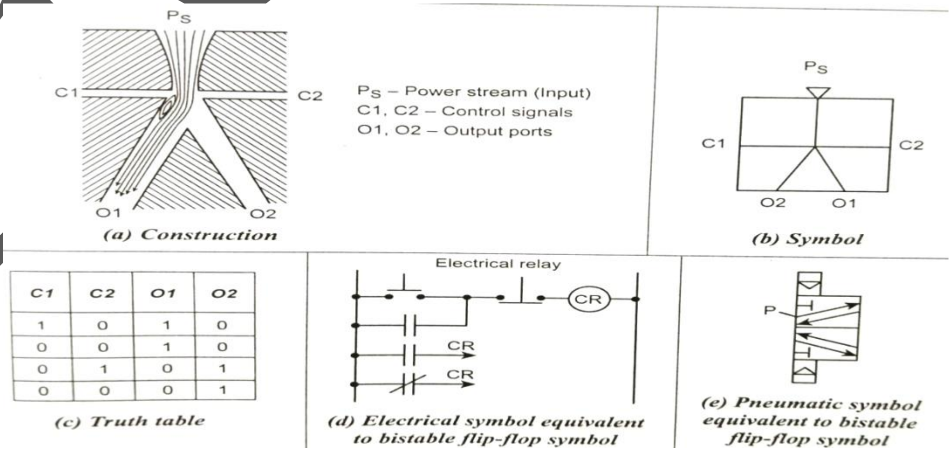
		OR	NOR
C1	C3	O1	O2
0	0	0	1
1	0	1	0
0	1	1	0
1	1	1	0



(a) Construction (b) Symbol (c) Truth table

		AND	NAND
C1	C3	O1	O2
0	0	0	1
1	0	0	1
0	1	0	1
1	1	1	0

Bistable filp flop: (6M)



(a) Construction (b) Symbol

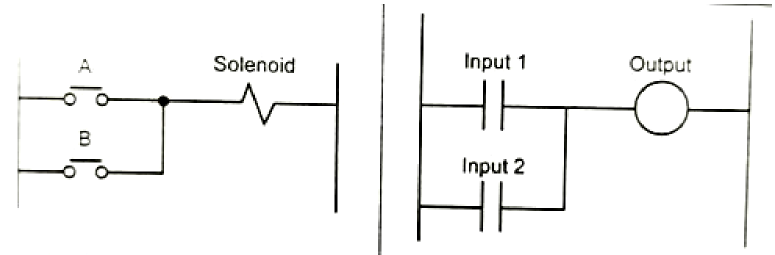
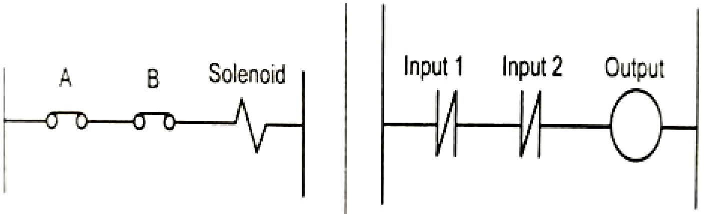
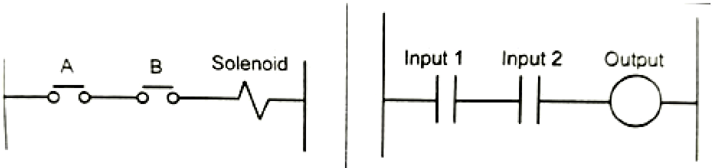
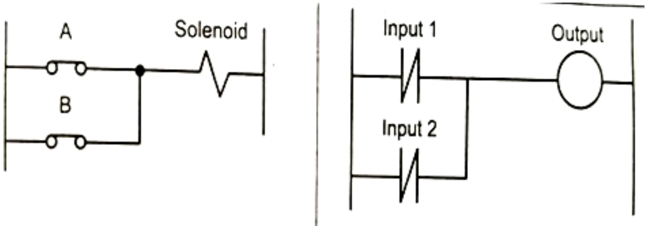
C1	C2	O1	O2
1	0	1	0
0	0	1	0
0	1	0	1
0	0	0	1

(c) Truth table (d) Electrical symbol equivalent to bistable flip-flop symbol (e) Pneumatic symbol equivalent to bistable flip-flop symbol

2 **Explain the PLC ladder programs for logic functions. BTL2**

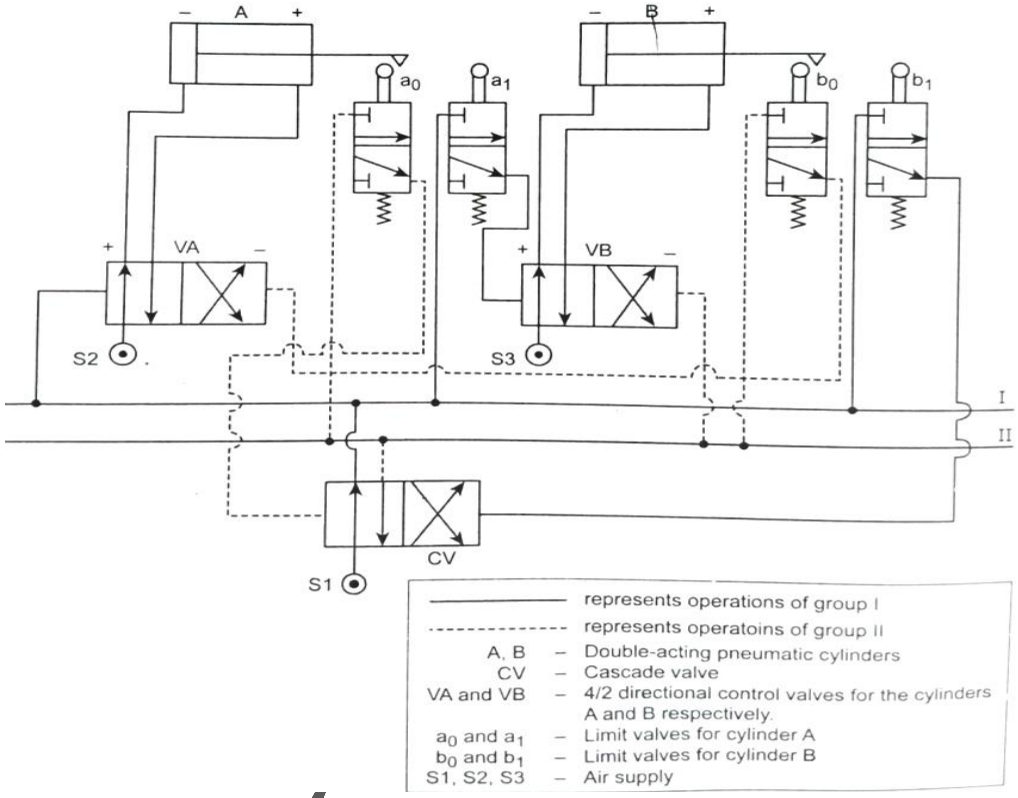
Descriptions: (3M)

The logic functions (such as AND, OR, NOR, etc) can be obtained by comibinations of switches

	(such as limit switches, solenoids coils, etc). The following sections show how PLC ladder programs for such combinations. OR Logic: (3M)  *(a) OR logic situation* *(b) PLC ladder diagram* NOR Logic: (3M)  *(a) NOR logic situation* *(b) PLC ladder diagram* AND Logic: (3M)  *(a) AND logic situation* *(b) PLC ladder diagram* NAND Logic: (3M)  *(a) NAND logic situation* *(b) PLC ladder diagram*
3	**Develop an electropneumatic circuit by cascade method for the following sequence: A+B+B-A- where A and B stand for cylinders, (+) indicates extension and (-) retraction of cylinders. BTL4** Working: (5M) Step 1: Sequence: $A^+B^+B^-A^-$ Step 2: No. of groups: 2 Step 3: No. of pressure lines: 2 Step 4: No. of pilot operated 4/2 DC valve = No. cylinders = 2 No. of limit valves = 4.

No. of cascade valves = 1

Circuit: (10M)



UNIT V – TROUBLE SHOOTING AND APPLICATIONS

Installation, Selection, Maintenance, Trouble Shooting and Remedies in Hydraulic and Pneumatic systems, Design of hydraulic circuits for Drilling, Planning, Shaping, Surface grinding, Press and Forklift applications. Design of Pneumatic circuits for Pick and Place applications and tool handling in CNC Machine tools – Low cost Automation – Hydraulic and Pneumatic power packs.

PART * A

Q.No.	Questions
1	**What is trouble shooting in hydraulic system? BTL2** Finding the faults in various components of hydraulic system like pump, strainer, valve, cylinder and taking remedies to work in proper condition.
2	**Define Drilling operation. BTL1** Drilling is the operation of producing a cylindrical hole of required diameter and depth by removing metal by the rotating edge of a cutting tool called drill.
3	**Mention the selection criteria of pneumatic systems. BTL2** ➢ The force or Load required to work must be light or medium and suitable for light weight applications. ➢ If the application requires speed, a medium amount of pressure, and only a fairly accurate feed, then an air pneumatic system can be used.
4	**Name any two faults that can be found in hydraulic systems. BTL2** Usage of low capacity pump and leakage in the hydraulic cylinder can lead to hazardous cause of breakdown of hydraulic system.
5	**What is a tree-branching chart? BTL2** Tree-branching chart is a chart used to simplify the troubleshooting process. This chart asks a question which has only two possible answers-Yes or No. The answer determines the next step to be taken in fault analysis. This chart helps to develop a logical and rapid approach to fault diagnosis.
6	**List any two selection criteria of hydraulic systems. BTL2** Pressure or force produced at the output should be high and the usage of hydraulic system occupies more floor space. It also depends on ➢ Purpose ➢ Stroke requirement ➢ Thrust ➢ Speed ➢ Acceleration and deceleration ➢ Cylinder mountings ➢ Special seal requirement.
7	**Define a low cost automation. BTL1** Low cost automation is a technology that creates some degree of automation around the existing

equipment, tools, methods, people etc. using mostly standard component. A wide range of activities such as loading, feeding, clamping, machining, welding, forming and packing can be subjected to low cost automation.

8 **What are the benefits of low cost automation? BTL2**

- Reduce manual controls without changing the basic set up.
- Low investment
- Increased labor productivity
- Consistent quality
- Better utilization of material.

9 **Define a power pack. BTL1**

Power pack consists of a pump, electric motor, reservoir and associated valve assembled to one unit to supply pressurized fluid. They are relatively small in size and provide functions of pressure, direction and flow control within the basic package.

10 **List three causes for low or erratic pressure in a hydraulic system**. **BTL2**

- Very low relief valve setting
- Leakage of pump delivery within the system
- Pump slipping its entire volume.

11 **List five things that can cause a noisy pump. BTL2**

- Misalignment of pump and prime mover
- Air remains in pump casing
- Pump bolts very loose
- Very high viscosity of oil
- Pump running too fast.

12 **If a pneumatic cylinder has erratic motion, name the causes. BTL4**

- Valve sticking or binding
- Cylinder sticking or binding.

13 **List four basic requirements on which the life of the fluid power systems depend. BTL2**

- Properly installed equipments
- Properly trained personnel
- Planned preventive maintenance
- Efficient troubleshooting.

14 **If an air cylinder produces erratic cylinder action, identify the probable causes and also give remedies for them. BTL4**

Probable Causes	Remedies
Valve sticking or binding	Check for dirt or gummy deposits Check for worn parts
Cylinder sticking or binding	Check for over tightened packing on rod seal or piston. Check for misalignment or worn parts.

15 **List any two types of faults that can be found in each of the components of a FRL unit. BTL4**

Faults in filter:

- Excessive pressure drop through filter
- Contaminants carried through the filter.

Faults in a regulator:

- Air often escaping from vent hole
- Chatter and vibration

Faults in a lubricator:

- Oil not delivered from the lubricator
- Delayed oil delivery.

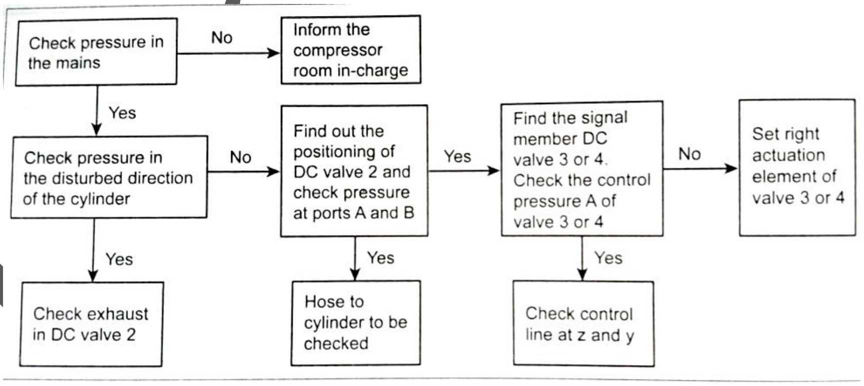
16

If a pump is delivering insufficient or no oil, what are all the possible causes and also give remedies for them. BTL4

Probable Causes	Remedies
Wrong direction of shaft	Must be reserved immediately to prevent seizure.
Pump shaft turning too slowly to prime itself.	Check minimum speed recommendation and momentarily increase rpm, to rectify.
Clogged strainer or suction pipeline.	Clean strainer or suction pipeline. Remove foreign matter.
Air leak in suction line.	Add oil and check oil level in reservoir. Check for leaks and repair.

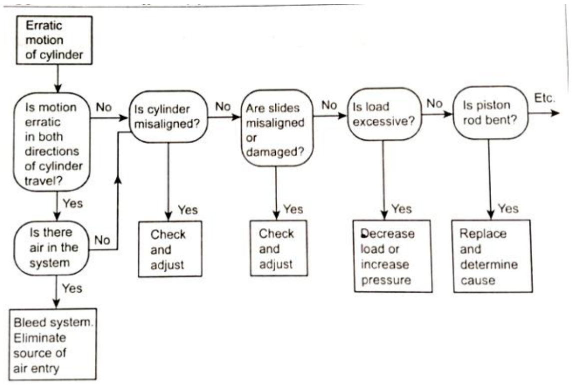
17

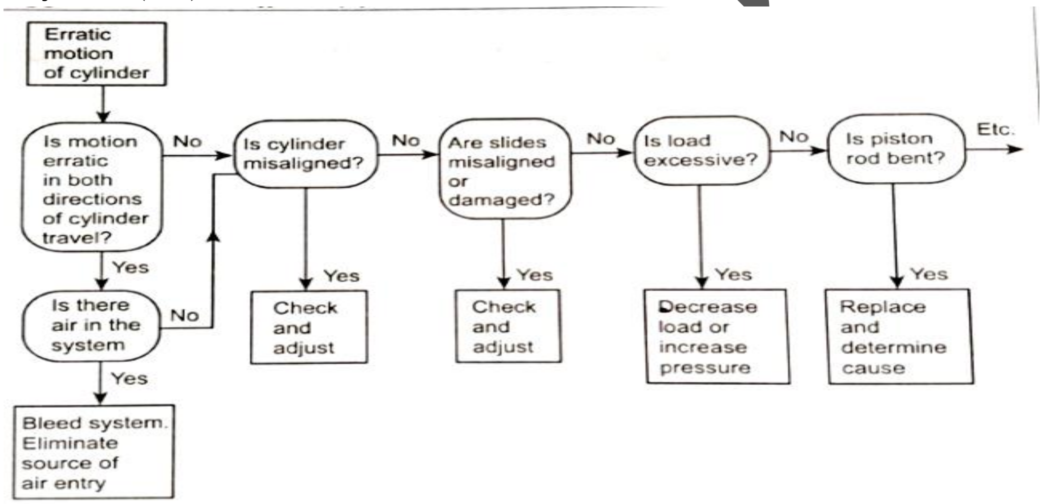
Illustrate the fault find using troubleshooting chart for pneumatic system. BTL1

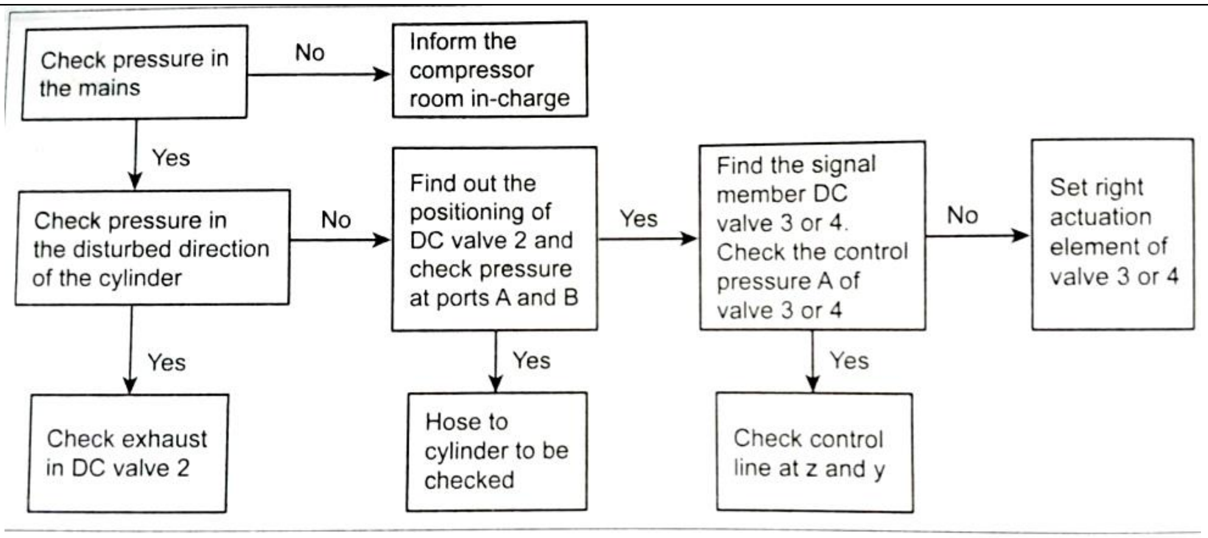
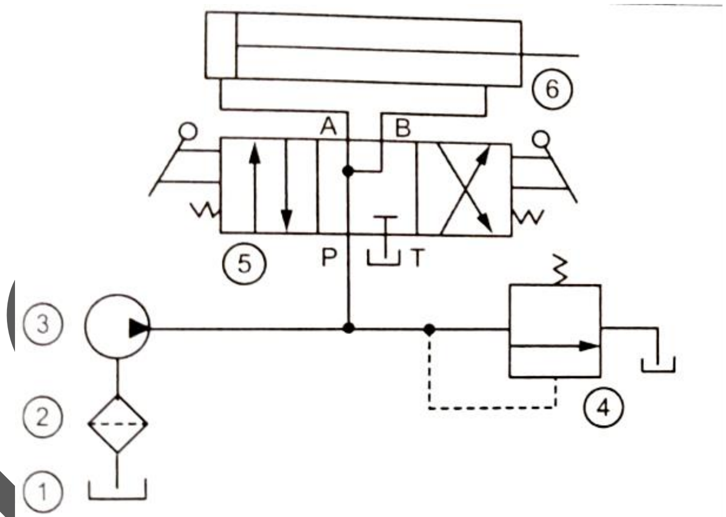


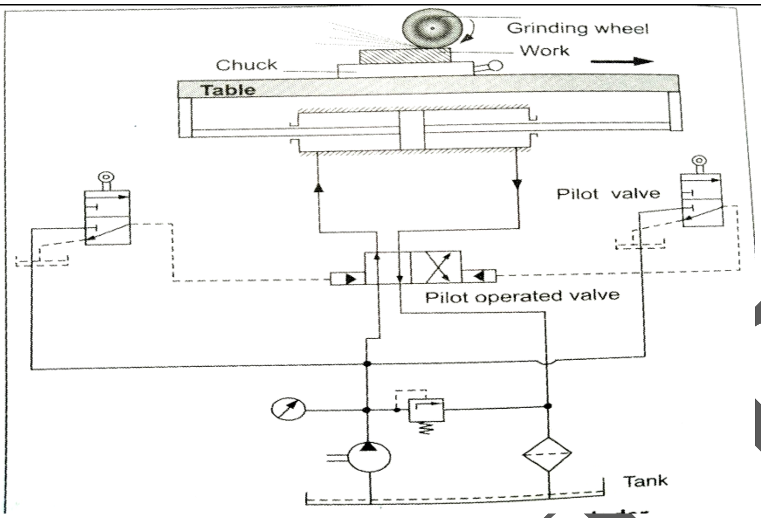
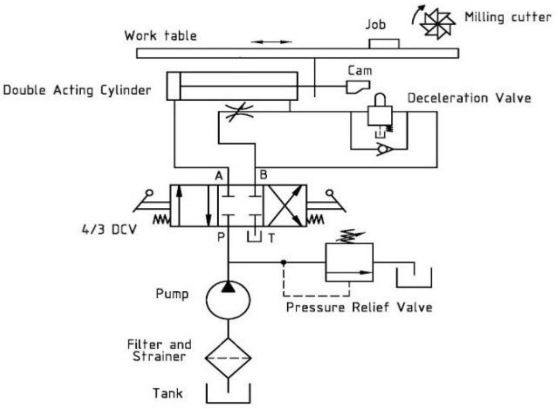
18

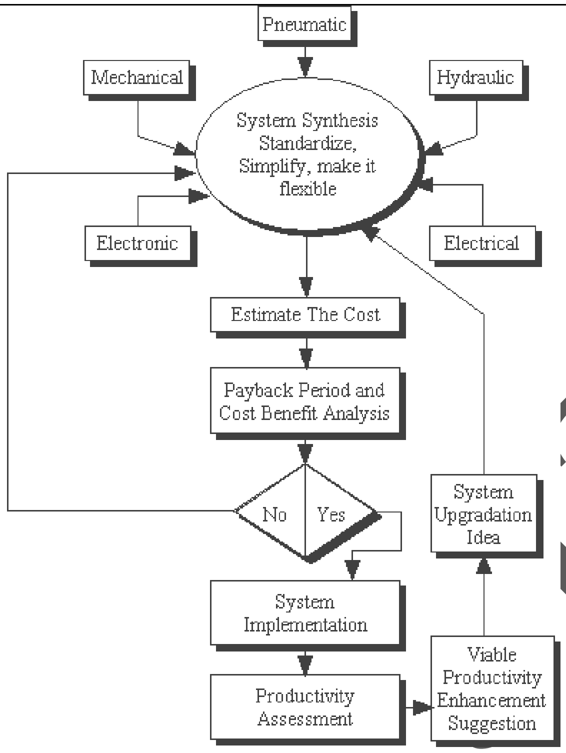
Illustrate the fault find using troubleshooting chart hydraulic system. BTL1



19	**List any two types of faults that can be found in each of the follwing hydraulic valve: (i) Directional control valve, and (ii) Flow control valve. BTL2** Faults in a DC valve may be: ➢ Faulty or incomplete shifting, or ➢ Cylinder creeping or drifting. Faults in a flow control valve may be: ➢ Variation in feed, or ➢ External leakage.
20	**Mention any two roles of pneumatic systems in low cost automation. BTL2** Pneumatic systems are popularly used for low cost automation (LCA) applications due to their low cost, ease of fabrication, and safe operation.
	PART * B
1	**Explain in detail how trouble shooting of hydraulic and pneumatic system are done. BTL2** Trouble shooting refers to an organised and systematic study of the problem and a logical approach to the difficulty faced in a system. (1M) Hydraulic system: (6M)  Pneumatic system: (6M)

	
2	**Explain how drilling circuit can be designed for any drilling operation. BTL4** Construction: (5M) Filter, pump, motor, pressure relief valve, double acting cylinder, 4/3 lever operated spring return DCV. Circuit: (8M) 
3	**How surface grinding can be used by hydraulic circuit. BTL4** Construction: (5M) Filter, pump, motor, pressure relief valve, double rod double acting cylinder, 4/2 pilot operated DCV, pilot valve. Circuit: (8M)

	
4	**Design a hydraulic circuit for planning machine operation. BTL4** Construction: (5M) Filter, pump, motor, pressure relief valve, double acting cylinder, 4/3 lever operated DCV, flow control valve, limit switch, deceleration valve. Circuit: (8M) 
5	**Describe the basic concepts of low cost automation with suitable example. BTL2** ➢ Low cost automation is a technology that creates some degree of automation around the existing equipment, tools, methods, people etc. using mostly standard component available in the market. ➢ A wide range of activities such as loading, feeding, clamping, machining, welding, forming and packing can be subjected to low cost automation ➢ Low cost automation is very useful for process industries, manufacturing, chemical, oil or pharmaceuticals. Many operations in food processing can also be done by low cost automation system. Methodology:

	 Benefits: ➢ Reduce manual controls without changing the basic set up. ➢ Low investment ➢ Increased labor productivity ➢ Consistent quality ➢ Better utilization of material.
	PART * C
1	**Design and draw a circuit using the hydraulic components for the Shaping operation. BTL4** Construction: (5M) Double rod cylinder, flow control valves, limit switches, 4/2 solenoid operated DCV, filter, pump, pressure relief valve, motor. Circuit: (10M)

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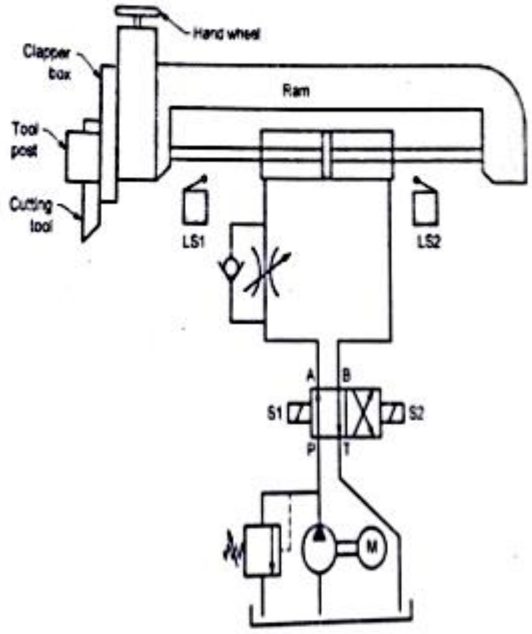

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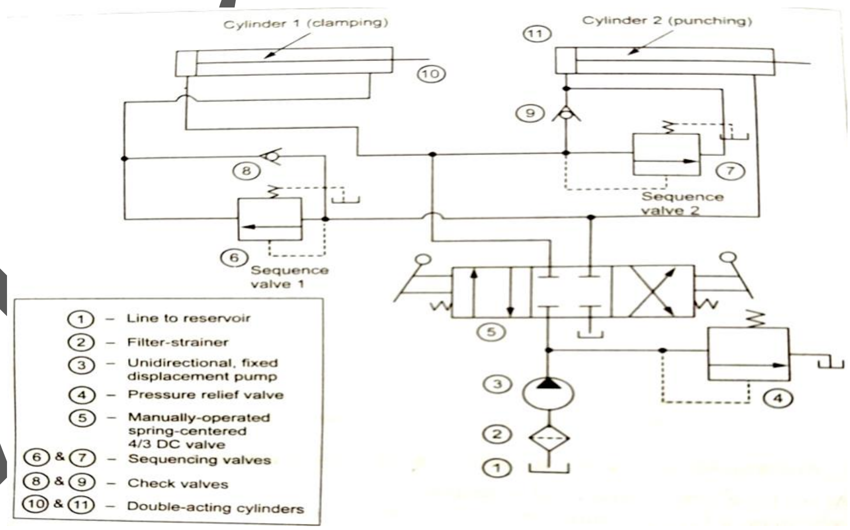
Design a circuit using the hydraulic components for the Punching & press operation. BTL4

Construction: (5M)

1 - Line to reservoir, 2 - filter strainer, 3- unidirectional fixed displacement pump, 4 - pressure relief valve, 5 - manually operated spring centered 4/3 DC valve, 6 & 7 - sequence valve, 8 & 9 - check valve, 10 & 11 - double acting cylinders.

Circuit: (10M)



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<tr><td>3</td><td>

Explain in detail about various faults in pneumatic components. BTL2

Compressor: unusual noise, inadequate performance.

Filters: excessive pressure drop, contaminants carried through filter, moisture in downstream air, plastic blow crazed and breaking.

Regulators: regulator cannot reach high set point, set point becomes too high, air often escaping from vent hole, pressure too low when air is flowing, chatter and vibration, delay or lack of reverse flow.
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	Lubricators: oil not delivered from the lubricator, oil delivery is delayed, too much oil delivery, poor component performance even with oil delivery, reservoir bowl crazed. **Air cylinder:** cylinder fails to move load when valve is actuated, erratic cylinder action, cylinder body seal leak, rod gland leak, excessive piston seal wear. **Valves:** valve blows to exhaust, poppet chatters, spool valve action is sluggish, air flow is normal only in actuated position, solenoid buzzes, solenoid burns out, sequence valve gives erratic timing, flow control valve does not respond to adjustment.
4	**Explain in detail about various faults in hydraulic components. BTL2** **Pump:** delivering insufficient or no oil, developing unstable or zero pressure, making noise, pump oil over heated, internal leakage around pump, excessive wear, breakage of parts inside pump housing. **Relief valve:** Erratic pressure, no or low pressure, excessive noise or chatter. **Direction control valves:** Faulty or incomplete shifting, cylinder creeping or drifting. **Hydraulic cylinders:** Piston packing failing too often, reduced speed, insufficient force available or no movement at all. **Hydraulic motor:** Motor turning in wrong direction, absence of proper speed and torque, external oil leakage from fluid motor, times of operation longer than specified. **Accumulator:** Sudden drop of pressure when position of selector valve is changed, no pressure available after pump is stopped, sluggish response. **Sequencing valves:** Premature movement of secondary operation, no movement or slow secondary operation.

ME8091 **AUTOMOBILE ENGINEERING** **L T P C**

3 0 0 3

OBJECTIVES:

- To understand the construction and working principle of various parts of an automobile.
- To have the practice for assembling and dismantling of engine parts and transmission system

UNIT I VEHICLE STRUCTURE AND ENGINES 9

Types of automobiles, vehicle construction and different layouts, chassis, frame and body, Vehicle aerodynamics (various resistances and moments involved), IC engines –component, function sand materials, variable valve timing (VVT).

UNIT II ENGINE AUXILIARY SYSTEMS 9

Electronically controlled gasoline injection system for SI engines, Electronically controlled diesel injection system (Unit injector system, Rotary distributor type and common rail direct injection system), Electronic ignition system (Transistorized coil ignition system, capacitive discharge ignition system), Turbo chargers (WGT, VGT), Engine emission control by three way catalytic converter system, Emission norms (Euro and BS).

UNIT III TRANSMISSION SYSTEMS 9

Clutch-types and construction, gear boxes- manual and automatic, gear shift mechanisms, Over drive, transfer box, fluid flywheel, torque converter, propeller shaft, slip joints, universal joints ,Differential and rear axle, Hotchkiss Drive and Torque Tube Drive.

UNIT IV STEERING, BRAKES AND SUSPENSION SYSTEMS 9

Steering geometry and types of steering gear box-Power Steering, Types of Front Axle,Types of Suspension Systems, Pneumatic and Hydraulic Braking Systems, Antilock Braking System(ABS), electronic brake force distribution (EBD) and Traction Control.

UNIT V ALTERNATIVE ENERGY SOURCES 9

Use of Natural Gas, Liquefied Petroleum Gas, Bio-diesel, Bio-ethanol, Gasohol and Hydrogen in Automobiles- Engine modifications required –Performance, Combustion and Emission Characteristics of SI and CI engines with these alternate fuels - Electric and Hybrid Vehicles, Fuel Cell

Note: Practical Training in dismantling and assembling of Engine parts and Transmission Systems should be given to the students.

TOTAL: 45 PERIODS

OUTCOMES:

- Upon completion of this course, the students will be able to identify the different components in automobile engineering.
- Have clear understanding on different auxiliary and transmission systems usual.

TEXT BOOKS:

1. Kirpal Singh, "Automobile Engineering", Vol 1 & 2, Seventh Edition, Standard Publishers, New Delhi, 1997.

2. Jain K.K. and Asthana .R.B, "Automobile Engineering" Tata McGraw Hill Publishers, NewDelhi, 2002.

REFERENCES:

1. Newton ,Steeds and Garet, “Motor Vehicles”, Butterworth Publishers,1989.
2. Joseph Heitner, “Automotive Mechanics,” Second Edition, East-West Press, 1999.
3. Martin W, Stockel and Martin T Stockle , “Automotive Mechanics Fundamentals,” The Goodheart – Will Cox Company Inc, USA ,1978.
4. Heinz Heisler, “Advanced Engine Technology,” SAE International Publications USA, 1998.
5. Ganesan V. “Internal Combustion Engines”, Third Edition, Tata McGraw-Hill, 2007.

REGULATION :2017 **ACADEMIC YEAR : 2019-2020**

Subject Code:ME8091 **Year/Semester: III /06**

Subject Name:Automobile Engineering

Subject Handler: Mr.M.Kalaimani & Mr.D.Arunkumar

UNIT I - VEHICLE STRUCTURE AND ENGINES

Types of automobiles, vehicle construction and different layouts, chassis, frame and body, Vehicle aerodynamics (various resistances and moments involved), IC engines –component, functions and materials, variable valve timing (VVT).

PART * A

Q.No.	Questions
1.	**What are the classification of automobile based on transmission system?(MAY/JUNE2016)(BTL1)** • Manual type • Semi-Automatic • Fully Automatic • Continuously Variable • Automated Manual
2	**What are the advantages of tubeless tyre over tubes tyre?(MAY/JUNE2016) (BTL1)** • Lower Tire Pressure • More Comfortable for Hire Speed • Easily puncture repair • Doesn’t Puncture easily
3	**What are the advantages of diesel engine in cars?(MAY/JUNE2014) (BTL1)** • Diesel engines offer significantly higher efficiency than current gasoline spark-ignition engines • Although the modern diesel engine is very clean • Fuel cost is low compared to petrol.
4	**How automobiles are classified based on capacity? Give example.(MAY/JUNE2014) (BTL1)** • Heavy Transport Vehicle – Trucks, Lorry • Light Transport vehicle – Car, Jeep
5	**Name the resistance to vehicle motion(APR/MAY 2015) (BTL1)** • Air Resistance • Gradient Resistance • Rolling Resistance
6	**Name the components of engine(APR/MAY 2015) (BTL1)** i) Cylinder ii) Piston iii) Crank case iv) Connecting rod
7	**What are the types of cross section frames used in automobile? (MAY/JUNE 2016) (BTL1)** (a)channel section,(b) tubular section (c)box section (d) hat section (e) double channel or I section
8	**What are the forces acting on running vehicle?(MAY/JUNE 2016)** i) Lift Force ii) Drag Force & iii) Cross wind force
9	**What is frameless construction? (APR/MAY 2017) (BTL2)** This type of construction has heavy side members used in conventional construction are eliminated and floor is strengthen by cross members and the body, all welded together. In some cases sub frames also used along with this type of construction.

10	**State the function of pushrod and rocker arm(APR/MAY 2017) (BTL1)** The push rod and rocker arm actuates valves according to engine stroke by the cams.
11	**List the classification of chassis name according to its control method. (NOV/DEC2016) (BTL1)** (a) Conventional control chassis (b)Semi formal Chassis (c) Full forward control Chassis
12	**Why a Gear box required in an automobile? (NOV/DEC2015) (BTL1)** • The main purpose of a gear box is to multiply the torque available in the driving wheels so that a wide range of torque is available in the same. • Gear box is basically used to shift gears. • The need for gearbox is simple that is you have a control over the reduction ratio • Transmit power from engine to wheels
13	**What is meant by dumb iron in frame work? (NOV/DEC2013) (BTL2)** A Dumb iron is a curved side piece of a chassis to which the front springs are attached, at the front of the car dumb irons project forward, providing a location to attach the front of the leaf springs.
14	**State any four function of lubricants(NOV/DEC2013) (BTL1)** • To avoid friction between moving parts • To reduce excess heat produced
15	**What are the types of engine valve? (NOV/DEC2012) (BTL2)** The valves are usually made of stainless steel. The valves used in modern passenger car engines are termed as poppet and mushroom valves.
16	**Write down the firing order of 4 and 6 cylinder engine. (BTL2)** i) For 4 cylinders engine, the firing order is 1-3-4-2 or 1-4-3-2 ii) For six cylinder engine, the firing order is 1-5-3-6-2-4 or 1-4-2-6-3-5
17	**List out the forces acting on a chassis frame (MAY/JUNE2013) (BTL1)** • Reactions from ground acting on tires and transmitting through suspensions. • Weight of different components like engine, transmission, passengers, fuel tank, seats, exhaust, etc acting at mounting points • Centrifugal force acting on the CG during turning. • Aerodynamic forces at considerable speed. • Bending moment and torsion moment along the longitudinal axis • Impact load when the vehicle passes over a hump or a pot hole
18	**What are the major functions of the chassis frame?[NOV/DEC 14] (BTL1)** • To carry load of passenger or goods carried in the body. • To support the load of the body, engine, gear box, steering system, Propeller or shaft etc. • To withstand the forces causes due to sudden breaking or acceleration and withstand the load cause due to bad road condition. • To withstand the centrifugal force by cornering
19	**Give any two advantages of frameless construction over the conventional framed construction.(MAY/JUNE2012) (BTL1)** • Reduce weight and consequent saving in fuel consumption • Lower manufacturing cost • Increase stability of automobile.
20	**Name the sources of automobile pollutants.(MAY/JUNE2012) (BTL2)**

Hydrocarbons, Carbon monoxide, Nitrogen oxides, Particulate matter, Sulphur oxide

PART * B

1

(i)What is the effect of weight of vehicle and passenger on the frame side member? Explain(MAY/JUNE2016) (7 M)(BTL5)

- Vertical bending,
- Longitudinal torsion,
- Lateral bending,
- Horizontal lozenging.7M

(ii)Write note on different types of material used for chassis frame(MAY/JUNE2016) (6 M) (BTL5)

- Steel
- Aluminium
- Magnesium
- Carbon-fibre epoxy composite
- Glass-fibre composites 6M

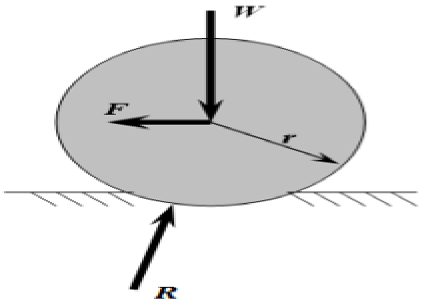
2

(i)Explain the term rolling resistance with the help of neat sketch. (MAY/JUNE 2016)

(7 M)(BTL5)

Rolling resistance, sometimes called rolling friction or rolling drag, is the force resisting the motion when a body (such as a ball, tire, or wheel) rolls on a surface. It is mainly caused by non-elastic effects; that is, not all the energy needed for deformation (or movement) of the wheel, roadbed, etc. is recovered when the pressure is removed. Two forms of this are hysteresis losses (see below), and permanent (plastic) deformation of the object or the surface.

2M



2M

The "rolling resistance coefficient" $F = C_{rr}N$

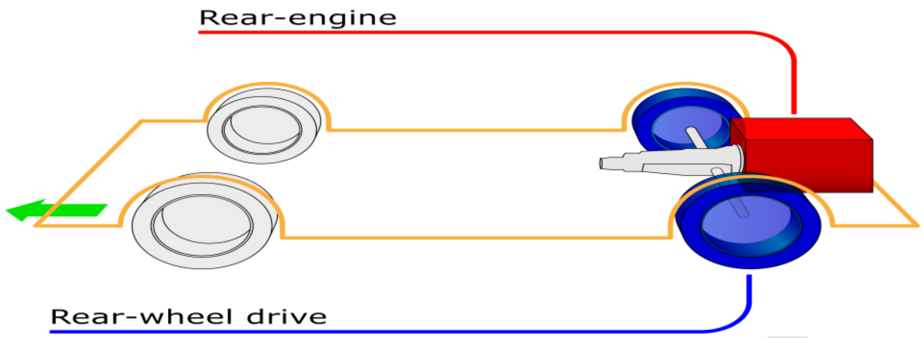
F is the rolling resistance force

C_{rr} is the dimensionless rolling resistance coefficient or coefficient of rolling friction (CRF)

Nis the normal force, the force perpendicular to the surface on which the wheel is rolling. 3M

(ii)Draw a neat labelled diagram of rear engine wheel drive type of vehicle layout (MAY/JUNE 2016)(6 M)(BTL5)

Answer: Page



6M

3 **(i)Give reasons for using single cylinder four stroke petrol engines on two wheelers (MAY/JUNE2014) (6 M)(BTL4)**

Single-cylinder engines are simple and compact, and will often deliver the maximum power possible within a given envelope. Cooling is simpler than with multiple cylinders, potentially saving further weight, especially if air cooling is used. 2M

Single-cylinder engines require more flywheel than multi-cylinder engines, and the rotating mass is relatively large, restricting acceleration and sharp changes of speed. In the basic arrangement they are prone to vibration - though in some cases it may be possible to control this with balance shafts. 2M

A variation known as the split-single makes use of two pistons which share a single combustion chamber. 2M

(ii)Give reasons for using multi cylinder diesel engines in commercial vehicles. (MAY/JUNE2014) (7 M)(BTL3)

A multicylinder engine develops more power. A commercial vehicle needs greater force to propel the vehicle because it carries greater loads. 2M

A diesel engine runs at a higher compression ratio and at this compression ratio the thermal efficiency of a multi-cylinder engine is higher than an Otto cycle petrol engine. This means that a diesel engine gives better fuel economy per kilometer. 2M

A multi cylinder engine has a greater swept volume and also its surface volume ratio is increased. This results in greater engine output and also better cooling which is essential for the protection of the engine parts like cylinder head, cylinder liner, piston, etc. The lubricating oil is also prevented from partial oxidation. 2M

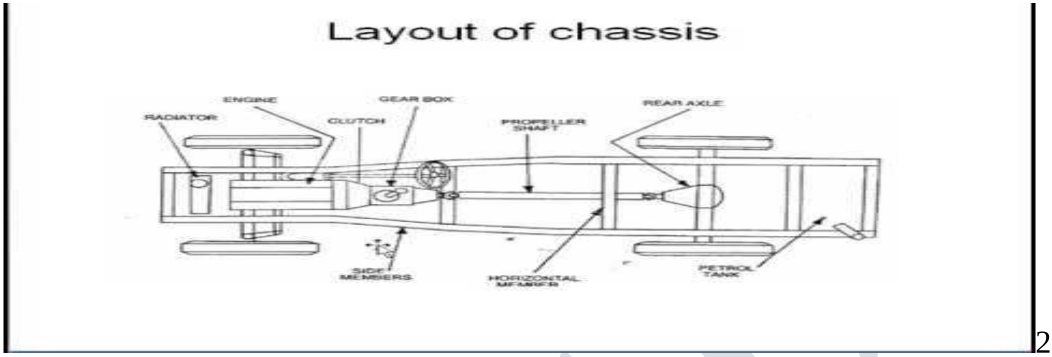
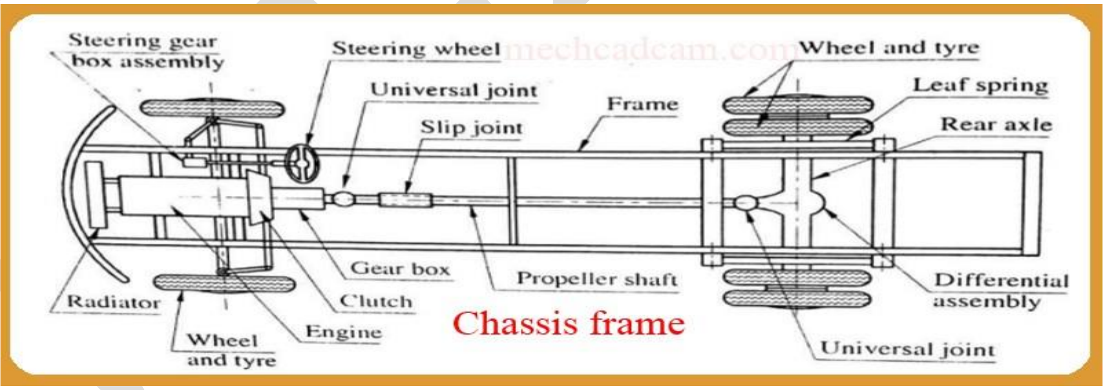
In a multi-cylinder engine, vibrations are decreased due to balancing of the crank. 1M

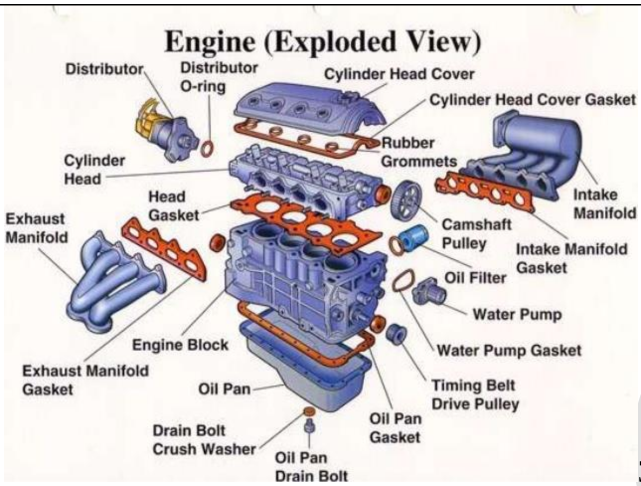
4 **(i)Write short notes on following engine parts, Piston, Cylinder Head, Piston Ring, Gudgeon Pin, Flywheel, Exhaust Valve, Lubrication Pump (MAY/JUNE 2016) (8 M)(BLT4)**

Engine parts, 1M

Piston,1M

Cylinder Head, 1M

	Piston Ring, 1M Gudgeon Pin, 1M Flywheel, 1M Exhaust Valve, 1M Lubrication Pump 1M **(ii) Draw the layout of automobile chassis and explain its significance (MAY/JUNE 2016)(5 M)(BLT4)** **Answer: Page 528-R.S KHURMI**  2M The internal framework of an artificial object, which supports the object in its construction and use. An example of a chassis is a vehicle frame, the underpart of a motor vehicle, on which the body is mounted; if the running gear such as wheels and transmission, and sometimes even the driver's seat, are included, then the assembly is described as a rolling chassis. 3M
5	**With neat diagram explain components and drive system in an automobile chassis (APR/MAY2017) (13 M)(BTL4)**
	Answer: Page 537-R.S KHURMI Diagram  5M PartsPower plant, Transmission System, Axles, Wheels and Tyres, Suspension, Controlling Systems like Braking, Steering 8M
6	**List IC engine parts its materials and functions.(APR/MAY2017) (13 M) (BTL3)**
	Answer: Page 607-R.S KHURMI



3M

Parts 3M

Materials 3M

Functions 4M

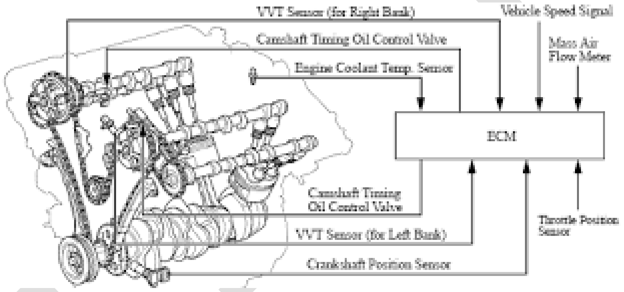
7 **Explain the construction of various chassis frames used in automobile with neat figure. (NOV/DEC2016) (13 M) (BTL4)**

Answer: Page 533-R.S KHURMI

3M

1. According to Fitting of Engine:
    - Full forward Chassis
    - Semi forward Chassis
    - Bus Chassis
    - Engine at back Chassis (Eg. Volvo Bus, Tata nano)
    - Engine at Centre Chassis (Eg. Royal tiger master bus) 5M

2. According to No of wheels fitted into vehicle:

	• 4 x 2 Drive Chassis [has 4 wheels with 2 driving wheels] • 4 x 4 Drive Chassis [has 4 wheels with 4 driving wheels] • 6 x 2 Drive Chassis [has 6 wheels with 2 driving wheels] • 6 x 4 Drive Chassis [has 6 wheels with 4 driving wheels]5M
8	**Explain with suitable sketches and valve timing diagram, the working of a variable valve timing (VVT) system used in automobiles. (NOV/DEC2016)(13 M) (BLT4)**
	Answer: Page 533-R.S KHURMI Variable valve timingIn internal combustion engines, variable valve timing (VVT) is the process of altering the timing of a valve lift event, and is often used to improve performance, fuel economy or emissions. It is increasingly being used in combination with variable valve lift systems. There are many ways in which this can be achieved, ranging from mechanical devices to electro-hydraulic and camless systems. Increasingly strict emissions regulations are causing[citation needed] many automotive manufacturers to use VVT systems. 5M  3M Typical effect of timing adjustments Late intake valve closing (LIVC) Early intake valve closing (EIVC) Early intake valve opening Early/late exhaust valve closing 5M
9	**Draw the layout of an automobile and indicate its various components(NOV/DEC2015) (13 M) (BLT4)**
	Answer: Page 533-R.S KHURMI

	 3M In automotive design, the automobile layout describes where on the vehicle the engine and drive wheels are found. Many different combinations of engine location and driven wheels are found in practice, and the location of each is dependent on the application for which the vehicle will be used. Factors influencing the design choice include cost, complexity, reliability, packaging (location and size of the passenger compartment and boot), weight distribution, and the vehicle's intendedhandling characteristics. 4M Front-wheel-drive layouts 3M Rear-wheel-drive layouts 3M
	PART * C
1	**Discuss the various resistance encountered by an automobile.(15 M)(BTL4)**
	Answer: Page 528-R.S KHURMI • Aerodynamic drag 5M • Gradient resistance 5M • Rolling resistance 5M
2	**Explain the frameless construction type vehicles with neat sketch and example.** **(15 M)(BTL4)**
	Answer: Page 528-R.S KHURMI ADVANTAGE OF FRAMELESS CONSTRUCTURE * light in weight and hence fuel efficient. * manufacturing cost is less. * safe for the passenger during collision , since the body crumbles thereby absorbing the shock due to impact. * more stable automobile can be made because of the lower body construction.

DISADVANTAGE OF FRAME LESS CONSTRUCTION
* less strength and durability.
* cost of repair is height.
* economical only if adopted in mass production.
* car without roof are difficult to design.

APPLICATION OF FRAME LESS CONSTRUCTION

it is possible only in case of closed car, since the roof, screen pillars,door pillars and rear panel are essential load taking parts of the structure.

A third type of body construction is the space frame. it is made by steel stamping welded together this is similar to tube chassis and roll cage in a race car plastic panels fasten to the space frame to complete the body.

3 **Explain why automobile engine causes vibration when it started and stands idle. Discuss the effect. (15 M) (BTL3)**

Sometimes the vibration depends on certain speeds, not by deceleration and acceleration. Sometime when driving and braking, the steering wheel shakes heavily, and the most common reason for that is the brake rotors. Out of round brake rotors sometimes can be the reason for the car engine shaking. 5M

Causes for automobile engine vibration

- The Crankshaft Damper
- Faulty Engine Mount
- Spark Plug Issues
- Extreme Weather
- Car Axle 5M

solution for automobile engine vibration

- Step 1: Spot The Problem Source
- Step 2: Analyze The Problem
- Step 3: Replace Damaged Car Parts 5M

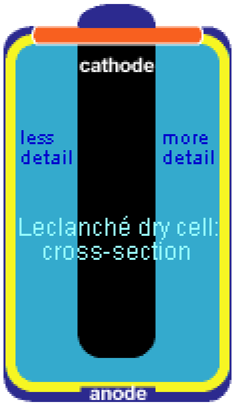
UNIT II -ENGINE AUXILIARY SYSTEMS

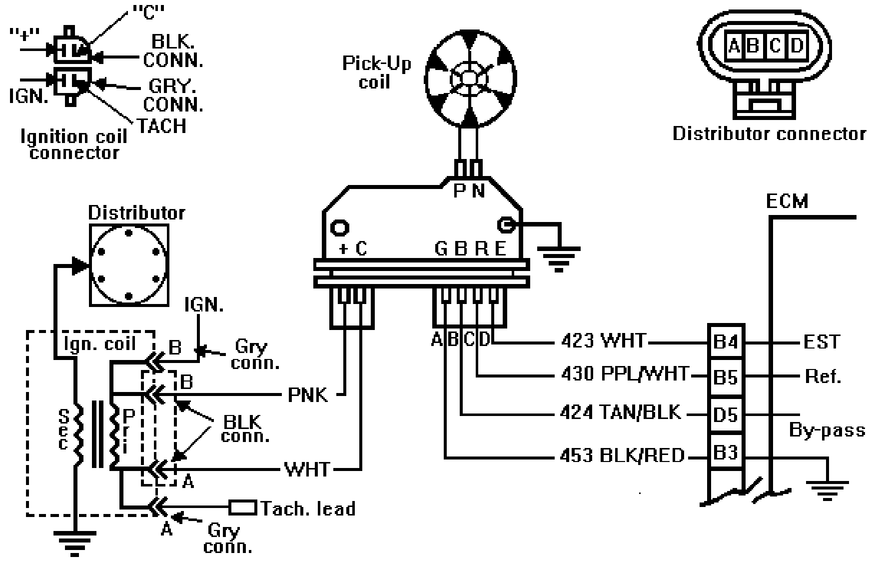
Electronically controlled gasoline injection system for SI engines, Electronically controlled diesel injection system (Unit injector system, Rotary distributor type and common rail direct injection system), Electronic ignition system (Transistorized coil ignition system, capacitive discharge ignition system), Turbo chargers (WGT, VGT), Engine emission control by three way catalytic converter system, Emission norms (Euro and BS).

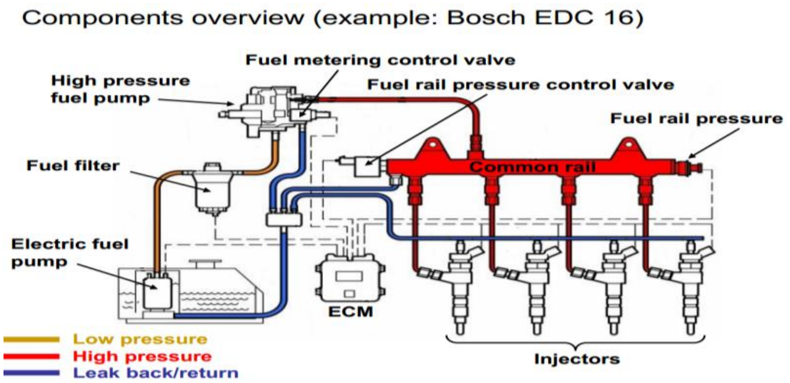
PART * A

Q.No.	Questions
1.	**Enumerate the factors which affect battery life. [NOV/DEC 13] (BTL1)** 1. Driving style 2. Extreme temperatures 3. Dirt 4. Low driving
2	**What is CRDI? [NOV/DEC 12] (BTL2)** Common rail direct fuel injection is a direct fuel injection system for diesel engines. On diesel engines, it features a high-pressure (over 1,000 bar or 100 MPa or 15,000 psi) fuel rail feeding individual solenoid valves, as opposed to a low-pressure fuel pump feeding unit injectors (or pump nozzles).
3	**What are the components of battery? [NOV/DEC 12] (BTL2)** There are three main components of a battery: two terminals made of different chemicals (typically metals), the anode and the cathode; and the electrolyte, which separates these terminals. The electrolyte is a chemical medium that allows the flow of electrical charge between the cathode and anode.
4	**Write any two benefits of CRDI system. [MAY/JUN 13] (BTL1)** • Fuel can be supplied and discharged into the cylinder at a very high pressure • Finer atomization of fuel • Produce better combustion, • Lower soot production • Multiple smaller injections per stroke
5	**Name the drawbacks of Carburetor in multi-cylinder engine. [MAY/JUN 13] (BTL1)** • At a very low speed, the mixture supplied by a carburetor is so weak that it will not ignite properly and for its enrichment, at such conditions some arrangement in the carburetor is required • The working of carburetor is affected by changes of atmospheric pressure. • It gives the proper mixture at only one engine speed and load, therefore, suitable only for engines running at constant speed increase or decrease
6	**What is exhaust gas recirculation? [MAY/JUN 13] (BTL2)** The process of re-circulating about 10% of the inert gas back into the intake manifold to reduce the combustion temperature when peak combustion temperature exceeds 19500C. It is done to avoid the formation of excessive nitrogen oxides (NO2) formation.
7	**Write the two methods of lead acid battery charging. [MAY/JUN 12] (BTL1)** Constant Current Charging, Constant Voltage Charging
8	**List out the major components in an electronic fuel injection system. [NOV/DEC 14] (BTL1)** (1)Pumping element (2)Metering Element (3) Mixing Element (4) Metering Control (5) Mixture Control (6) Distributing Element (7) Timing Element (8) Ambient Control
9	**What is the role of regulator unit in electrical systems? [NOV/DEC 14] (BTL2)** Faster the vehicle moves more voltage goes into the car's electrical system. If this weren't

	controlled the generator would damage the battery and burn out the car's lights. Also, if the generator weren't cut out from the car's circuitry when not running, the battery would discharge through its case. To avoid above two mistake a voltage regulator is used.
10	**List out the emissions that are common for both SI and CI engines. [NOV/DEC 16] (BTL1)** (a) HC (b) CO (c) NOx (d)Particulate matters
11	**What is the need of altering the ignition timing with respect to engine speed and load?(MAY/JUNE 2016) (BTL2)** • The ignition timing will need to become increasingly advanced (relative to TDC) as the engine speed increases so that the air-fuel mixture has the correct amount of time to fully burn. As the engine speed (RPM) increases, the time available to burn the mixture decreases but the burning itself proceeds at the same speed, it needs to be started increasingly earlier to complete in time. • The ignition timing is also dependent on the load of the engine with more load (larger throttle opening and therefore air: fuel ratio) requiring less advance (the mixture burns faster).
12	**What are the factors that affect the life of spark plug?(MAY/JUNE2016) (BTL1)** (a)Overheating Damage (b)Oil Contamination (c)Carbon
13	**Enlist the limitation of turbo charging(MAY/JUNE2014) (BTL2)** The main limitation of turbo charging is Turbo Lag. Turbo lag is the time it takes for a turbocharger to “light up” or produce positive manifold pressure drastically changing the power output of a motor.
14	**Write the main requirements of an injector nozzle(MAY/JUNE2014) (BTL1)** • To inject fuel at a sufficiently high – pressure so that the fuel enters the cylinder with a high velocity. • The penetration should not be high. • The fuel supply and cut off should be rapid.
15	**What is gasoline injection system(APR/MAY2015) (BTL2)** The gasoline is highly pressurized, and injected via a common rail fuel line directly into the combustion chamber of each cylinder, as opposed to conventional multipoint fuel injection that injects fuel into the intake tract or cylinder port. Directly injecting fuel into the combustion chamber requires high-pressure injection, whereas low pressure is used injecting into the intake tract or cylinder port.
16	**What are the function of turbocharger(APR/MAY2015) (BTL2)** The function of a turbocharger is to improve an engine's volumetric efficiency by increasing density of the intake gas (usually air) allowing more power per engine cycle. The turbocharger's compressor draws in ambient air and compresses it before it enters into the intake manifold at increased pressure.
17	**Define continuous injection of petrol engine(MAY/JUNE2016) (BTL2)** In a continuous injection system, fuel flows at all times from the fuel injectors, but at a variable flow rate. This is in contrast to most fuel injection systems, which provide fuel during short pulses of varying duration, with a constant rate of flow during each pulse. Continuous injection systems can be multi-point or single-point, but not direct.
18	**Which is most commonly used supercharger in automobile? why petrol engines are rarely supercharged?(APR/MAY2017) (BTL2)** Commonly used supercharger is Positive Displacement supercharger. There are two main types of superchargers defined according to the method of gas transfer positive displacement and dynamic compressors. Positive displacement blowers and compressors deliver an almost constant level of pressure increase at all engine speeds (RPM). Dynamic compressors do not deliver

	pressure at low speeds; above a threshold speed, pressure increases with engine speed
19	**Give short note on unit injector system. (APR/MAY2017) (BTL1)** Unit injector is an integrated direct fuel injection system for diesel engines, combining the injectornozzle and the injection pump in a single component. The plunger pump used is usually driven by a shared camshaft. In a unit injector, the device is usually lubricated and cooled by the fuel itself.
20	**Define intermittent injection of petrol engine(NOV/DEC2016) (BTL2)** Intermittent fuel injection systems provide fuel during short pulses of varying duration, with a constant rate of flow during each pulse.
	PART * B
1	**What are primary and secondary batteries? Give the details about the major components, Working principles and energy storage in secondary battery. [NOV/DEC 14] (13 M) (BTL4)** A flashlight battery, or dry cell, is constructed with a zinc shell that serves as the anode; a graphite rod which serves as the cathode; and a moist mixture of ammonium chloride {NH_4Cl}, zinc chloride {$ZnCl_2$}, and manganese dioxide {MnO_2}. A schematic representation of a dry cell is shown on the right. The half-reaction that occurs on the anode when the battery delivers current is the oxidation of zinc atoms: $Zn(s, shell) \longrightarrow Zn_2^+(aq) + 2e^-$ The half-reaction that occurs simultaneously on the cathode is the reduction of ammonium ions: $2\ e^- + 2\ NH_4^+(aq, moist\ paste) \longrightarrow 2\ NH_3(g) + H_2(g)$  A porous graphite electrode is embedded in the moist paste and readily conducts electrons from the external circuit to the aqueous ammonium ions. Take another look at the products of the reduction that occurs at the graphitic cathode. Two gases are being produced in a sealed container! Not to fear, our battery will not explode as additional reactions essentially fix the two gases:

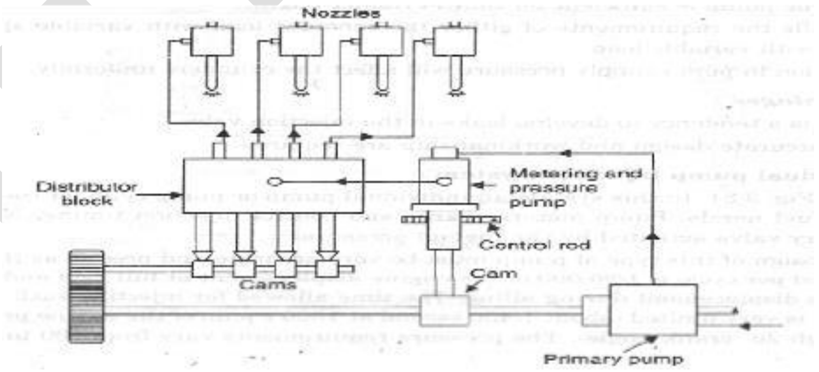
	$2\ NH_{3(g)} + Zn^{+2}\ (aq) \longrightarrow [Zn(NH_3)_2]^{2+}(aq)$ In this reaction, zinc ion, primarily from $ZnCl_2$, is acting as a Lewis acid; the complex formed solubilizes the gas.
2	**(i)Explain electronic spark timing control with a circuit diagram. [MAY/JUN 16] (BTL3)**
	The spark-Optimizer is a closed-loop type electronic control device that continuously corrects the ignition timing; in effect it re-tunes the engine some ten times every second. In contrast to the better known pre-programmed controls, the Optimizer is an adaptive type system, in which the output influences the input. By providing the correct spark timing all the time, the Optimizer reduces fuel consumption considerably. 
	(ii)Discuss the various methods to reduce the level of pollutants in the exhaust gases. [MAY/JUN 16](13 M)(BTL4) **Humid Air Method** **Exhaust Gas Re circulation (EGR)** **Water Injection and Water emulsion** **High Scavenge Pressure and Compression Ratio** **Selective Catalytic Reduction** **Two Stage Turbocharger** **Engine Component Modification**
3	**(i)Discuss about CRDI system[APR/MAY2015] (BTL4)**



The System is divided into 3 basic circuits

1. High Pressure Delivery Circuit
2. Low Pressure Supply Circuit
3. Fuel Leak back and return

(ii)Discuss the construction and working principle of rotary distributor type diesel injection system[APR/MAY2015](13 M) (BTL4)



The main components of a fuel injection system

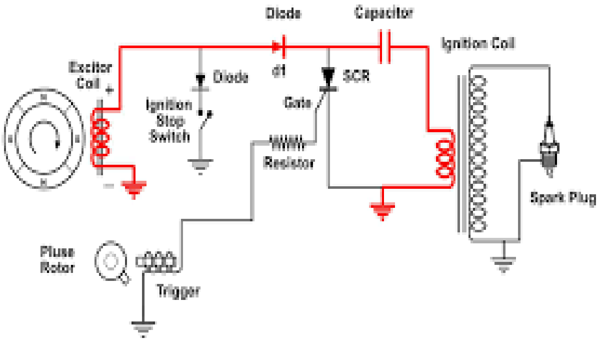
(i) Fuel tank.

(ii) Fuel feed pump to supply the fuel from the main fuel tank to the injection pump.

(iii) Fuel filters to prevent dust and abrasive particles from entering the pump and injectors.

(iv) Injection pumps to meter and pressurize the fuel for injection.

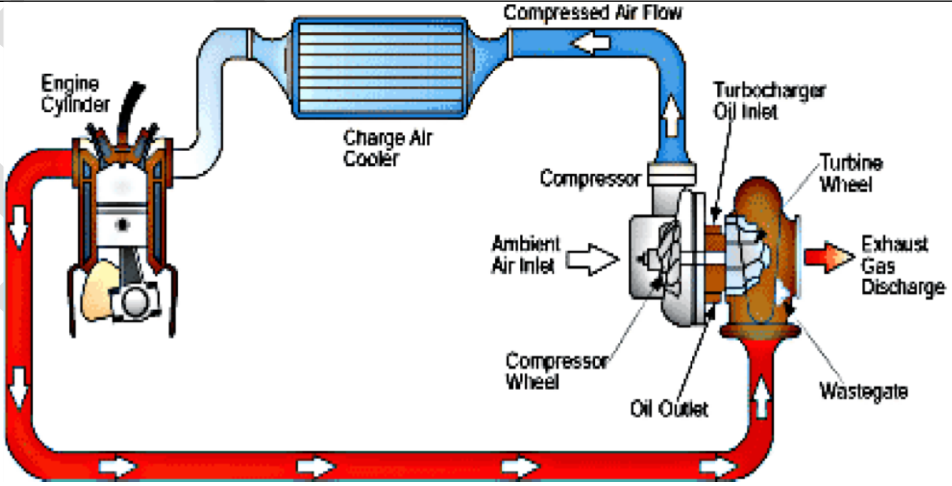
	(v) Governor to ensure that the amount of fuel is in accordance with variation in load. (vi) Fuel piping and injectors to take the fuel from the pump and distribute it in the combination chamber by atomizing it in fine droplets. (vii) Fuel atomizer or injector to inject the fuel
4	**(i)What are the advantages of transistorized coil ignition (TCI) System? [MAY/JUN 16] (BTL4)**
	• A CDI system has a short charging time, a fast voltage rise (between 3 ~ 10 kV/μs) compared to typical inductive systems (300 ~ 500 V/μs) and a short spark duration limited to about 50-80 μs. The fast voltage rise makes CDI systems insensitive to shunt resistance, but the limited spark duration can for some applications be too short to provide reliable ignition. The insensitivity to shunt resistance and the ability to fire multiple sparks can provide improved cold starting ability. • Since the CDI system only provides a short spark, it's also possible to combine this ignition system with ionization measurement. This is done by connecting a low voltage (about 80 V) to the spark plug, except when fired. The current flow over the spark plug can then be used to calculate the temperature and pressure inside the cylinder. **(ii)Sketch and explain the capacitive discharge ignition system[MAY/JUN 16](13 M) (BLT4)** **Answer: Page 528-R.S KHURMI** Most ignition systems used in cars are inductive discharge ignition (IDI) systems, which are solely relying on the electric inductance at the coil to produce high-voltageelectricity to the spark plugs as the magnetic field collapses when the current to the primary coil winding is disconnected (disruptive discharge). In a CDI system, a charging circuit charges a high voltage capacitor, and at the instant of ignition the system stops charging the capacitor, allowing the capacitor to discharge its output to the ignition coil before reaching the spark plug.



Advantages and Disadvantages of CDI

- A CDI system has a short charging time, a fast voltage rise (between 3 ~ 10 kV/μs) compared to typical inductive systems (300 ~ 500 V/μs) and a short spark duration limited to about 50-80 μs. The fast voltage rise makes CDI systems insensitive to shunt resistance, but the limited spark duration can for some applications be too short to provide reliable ignition. The insensitivity to shunt resistance and the ability to fire multiple sparks can provide improved cold starting ability.
- Since the CDI system only provides a short spark, it's also possible to combine this ignition system with ionization measurement. This is done by connecting a low voltage (about 80 V) to the spark plug, except when fired. The current flow over the spark plug can then be used to calculate the temperature and pressure inside the cylinder.

5 **With neat sketch explain the working of turbocharger and state how it differs from supercharger[APR/MAY2017] [NOV/DEC2015](13 M) (BTL4)**



An Engine may not produce same power output when it is operated at different location and altitudes. Super charging & turbo charging is used to overcome this effect. Super charging is the process of supplying the fuel (or air-fuel mixture) above the atmospheric pressure by boosting the pressure. When the supercharger is driven by gas turbine which derives gas from engine exhaust, it is called TURBO CHARGER. The turbocharger is bolted to the exhaust manifold of the engine. The exhaust from the cylinders spins the turbine, which works like agas turbine engine. The turbine is connected by a shaft to the compressor, which is located between the air filter and the intake manifold. The compressor pressurizes the air going into the pistons.

6 **What are the main function of ECU?[NOV/DEC2016] (13 M)(BTL4)**

ELECTRONIC CONTROL UNIT:

- Electronic Control Unit acts as a Central Processing Unit which
- receives the signals from various sensors and automatically
- monitors and regulates the system. Various parts controlled by ECU are represented in picture
- In modern vehicles, which uses fuel injection for petrol engine operates in the sequence as shown below. Vehicle which uses direct fuel injection are
- MAZDA, AUDI, VOLKSWAGEN, BMW, ALFA

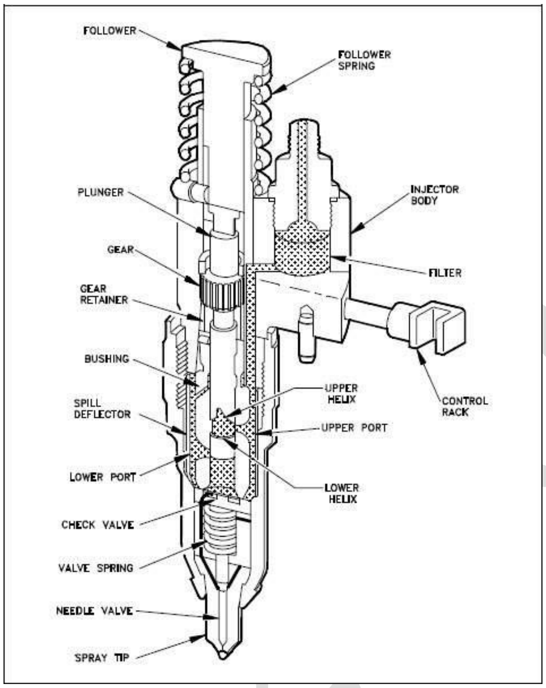
7 **Describe the construction details of distributor type diesel fuel injection pump with sketch. [NOV/DEC2016] [MAY/JUN 16](13 M) (BTL4)**

Answer: Page 533-R.S KHURMI

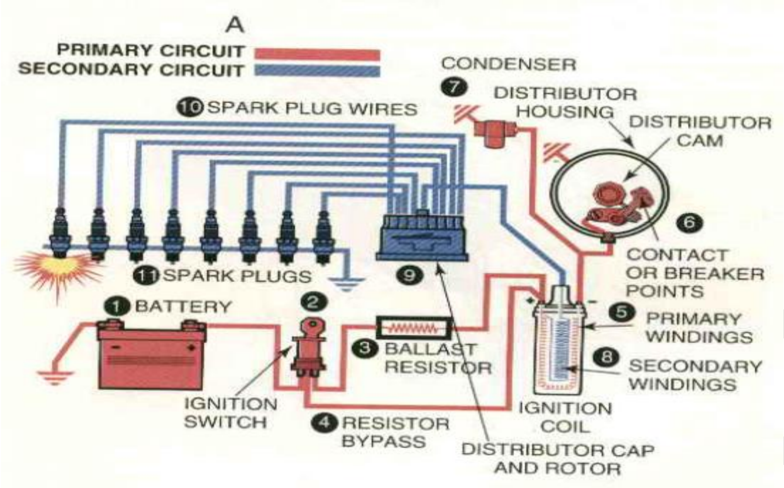
Each injector operates in the following manner. fuel under pressure enters the injector through the injector's filter cap and filter element. From the filter element the fuel travels down into the supply chamber (that area between the plunger bushing and the spill deflector). The plunger operates up and down in the bushing, the bore of which is open to the fuel supply in the supply chamber by two funnel-shaped ports in the plunger bushing.

he motion of the injector rocker arm (not shown) is transmitted to the plunger by the injector follower which bears against the follower spring. As the plunger moves downward under pressure of the injector rocker arm, a portion of the fuel trapped under the plunger is displaced into the supply chamber through the lower port until the port is closed off by the lower end of the plunger. The fuel trapped below the plunger is then forced up through the central bore of the plunger and back out the upper port until the upper port is closed off by the downward motion of the plunger. With the upper and lower ports both closed off, the remaining fuel under the plunger is subjected to an increase in pressure by the downward motion of the plunger.

When sufficient pressure has built up, the injector valve is lifted off its seat and the fuel is forced through small orifices in the spray tip and atomized into the combustion chamber. A check valve, mounted in the spray tip, prevents air in the combustion chamber from flowing back into the fuel injector. The plunger is then returned back to its original position by the injector follower spring. On the return upward movement of the plunger, the high pressure cylinder within the bushing is again filled with fresh fuel oil through the ports. The constant circulation of fresh, cool fuel through the injector renews the fuel supply in the chamber and helps cool the injector. The fuel flow also effectively removes all traces of air that might otherwise accumulate in the system.

	The fuel injector outlet opening, through which the excess fuel returns to the fuel return manifold and then back to the fuel tank, is adjacent to the inlet opening and contains a filter element exactly the same as the one on the fuel inlet side 
8	**(i)What are the types of electronic ignition system used in S I engine? [NOV/DEC2016] (BLT4)**
	• Capacitance Discharge Ignition system • Transistorized system • Piezo-electric Ignition system • The Texaco Ignition system

(ii)Draw and explain the circuit diagram of electronic ignition system using a magnetic pick up method. [NOV/DEC2016](13 M) (BLT5)



Answer: Page 533-R.S KHURMI

To understand the working of the electronic ignition system let’s consider above figure in which all the components mentioned above are connected in their working order.

When the driver switch ON the ignition switch in order to start a vehicle the current starts flowing from the battery through the ignition switch to the coil primary winding, which in turn starts the armature pickup coil to receives and send the voltage signals from the armature to the ignition module.

When the tooth of the rotating reluctor comes in front of the pickup coil as shown in the fig the voltage signal from pickup coil is sent to the electronic module which in turn senses the signal and stops the current to flow from primary coil.

When the tooth of the rotating reluctor goes away from the pickup coil, the change in voltage signal is sent by pickup coil to the ignition module and a timing circuit inside ignition module turns ON the current flow.

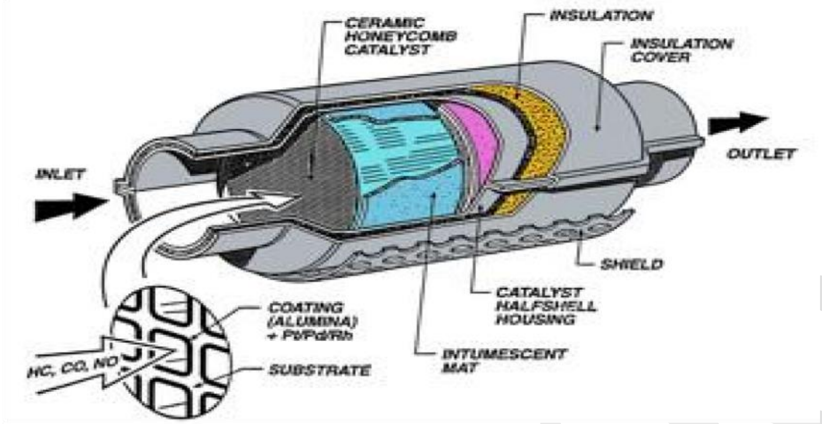
A magnetic field is generated in the ignition coil due to this continuous make and break of the circuit which induced an EMF in secondary winding which increases the voltage upto 50000 Volts.

This high voltage is then sent to distributor,which has the rotating rotor and distributor points which is set according to the ignition timing.

When the rotor comes in front of any of those distributor points the jumping of voltage through the air gap from the rotor to the distributor point takes place which is then sent to the adjacent spark plug terminal through the high tension cable and a voltage difference is generated between the central electrode and ground electrode which is responsible for generating a spark at the tip of the spark plug and finally the combustion takes place.

PART * C

1 **Draw a sketch of three way catalytic converter and explain its principle of operation. [NOV/DEC2015] [APR/MAY2015] (15 M)(BTL4)**

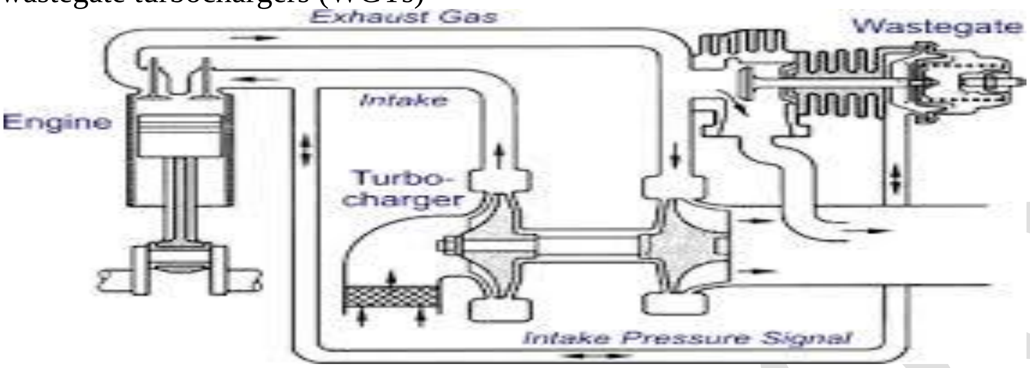


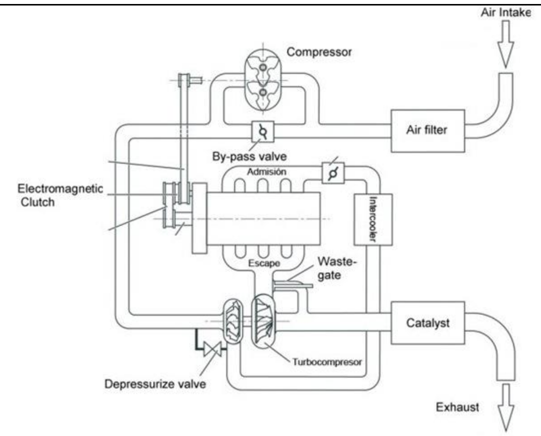
- The Catalytic Convertor Converts the toxic gases like HC, CO, NOx into harmless gases.
- It contains ceramic or metallic base with active coating incorporating alumina and other oxides with combination of precious metals like platinum, palladium and rhodium.
- Inside the passage way of catalytic convertor is a honey comb set passage way or ceramic bead coated with catalyst. It makes chemical reaction without being part of the reaction.
- Convertors may TWO WAY or THREE WAY Catalytic convertor.
- Two Way convertors are Oxidation catalytic convertor.
- Three ways Convertor are Oxidation as well as Reduction Catalytic Convertor.
- In 3 Way Convertors, 3 refer to emission control of CO, HC and Volatile Organic Compounds (VOC).
- It uses 2 types of Catalyst >> Oxidation Catalyst & Reduction Catalyst both structure coated with a catalyst such as Platinum, Rhodium & Palladium.
- REDUCTION CATALYST is the first stage of catalytic convertor which uses platinum & rhodium to help reduce NOx emissions.

2 **Compare BS Standard and Euro Standard emission norms for a diesel engine and petrol engine vehicle.(15 M) (BTL4)**

Bharat stage emission standards (BSES) are emission standards instituted by the Government of India to regulate the output of air pollutants from internal combustion enginesand Spark-ignition engines equipment, including motor vehicles. The standards and the timeline for implementation are set by the Central Pollution Control Board under the Ministry of Environment & Forests and climate change

European emission standards define the acceptable limits for exhaust emissions of new vehicles

	sold in the European Union and EEAmember states. The emission standards are defined in a series of European Union directives staging the progressive introduction of increasingly stringent standards.
3	**What is the purpose of WGT & VGT and explain its working principle in detail.(15 M) (BTL3)**
	wastegate turbochargers (WGTs)  • A wastegate is a valve that diverts exhaust gases away from the turbine wheel in a turbocharged engine system. • Diversion of exhaust gases regulates the turbine speed, which in turn regulates the rotating speed of the compressor. The primary function of the wastegate is to regulate the maximum boost pressure in turbocharger systems, to protect the engine and the turbocharger. One advantage of installing a remote mount wastegate to a free-float (or non-WG) turbo includes allowance for a smaller A/R turbine housing, resulting in less lag time before the turbo begins to spool and create boost. Variable-geometry turbochargers (VGTs) • Variable-geometry turbochargers (VGTs), (also known as variable nozzle turbines/VNTs), are a family ofturbochargers, usually designed to allow the effective aspect ratio (A:R) of the turbo to be altered as conditions change. This is done because optimum aspect ratio at low engine speeds is very different from that at high engine speeds. If the aspect ratio is too large, the turbo will fail to create boost at low speeds; if the aspect ratio is too small, the turbo will choke the engine at high speeds, leading to high exhaust manifold pressures, high pumping losses, and ultimately lower power output. By altering the geometry of the turbine housing as the engine accelerates, the turbo's aspect ratio can be maintained at its optimum. Because of this, VGTs have a minimal amount of lag, have a low boost threshold, and are very efficient at higher engine speeds. VGTs do not require a waste gate.


Air Intake
Compressor
Air filter
By-pass valve
Admision
Electromagnetic
Clutch
Intercooler
Escape
Waste-
gate
Catalyst
Turbocompresor
Depressurize valve
Exhaust

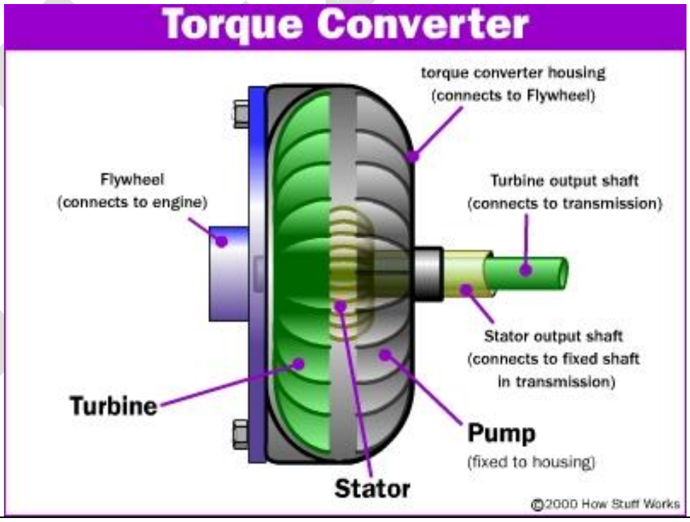
UNIT III -TRANSMISSION SYSTEMS

types and construction, gear boxes- manual and automatic, gear shift mechanisms, Over drive, transfer box, fluid flywheel, torque converter, propeller shaft, slip joints, universal joints ,Differential and rear axle, Hotchkiss Drive and Torque Tube Drive

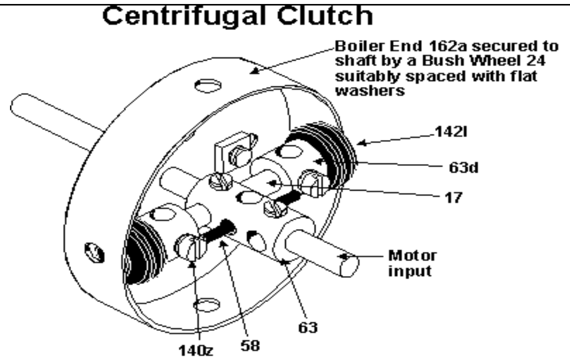
PART * A

<table>
<tr><th>Q.No.</th><th>Questions</th></tr>
<tr><td>1.</td><td>Differentiate between live and a dead axle. [NOV/DEC 13] (BTL2)
<table>
<tr><td>LIVE AXLE</td><td>DEAD AXLE</td></tr>
<tr><td>An axle that is driven by the engine or prime mover is called a drive axle.
Modern front-wheel drive cars typically combine the transmission (gearbox and differential) and front axle into a single unit called a transaxle.</td><td>A dead axle, also called a lazy axle, is not part of the drive train, but is instead free-rotating. The rear axle of a front-wheel drive car is usually a dead axle.</td></tr>
</table></td></tr>
<tr><td>2</td><td>How is drive from propeller shaft turned at right angle? [NOV/DEC 13] (BTL1)
Slip joint and Universal joint used at end of propeller shaft is reason for converting te drive at right angle.</td></tr>
<tr><td>3</td><td>State the functions of a clutch. [NOV/DEC 12] (BTL2)
To engage or disengage the rest of the transmission as required.
To transmit the engine power to rear wheels without shock.
To enable the gear to get engaged when the vehicle is in motion.</td></tr>
<tr><td>4</td><td>What is synchromesh Device? [NOV/DEC 12] (BTL2)
This type of gear box is similar to the constant mesh type. The provision of synchromesh device avoids the necessity of double declutching. The parts which ultimately are to be engaged are first brought into frictional contact which equalizes their speed, after which these may be engaged smoothly.</td></tr>
<tr><td>5</td><td>List the disadvantages of floor mounted gear shifting mechanism. [MAY/JUN 13] (BTL1)
(a) Complexity (b) Shifting Speed (c) Ease of Use (d) Stopping on hills</td></tr>
<tr><td>6</td><td>Define the term 'double declutching' used in sliding mesh gear box. [MAY/JUN 13] (BTL2)
The clutch pedal is used twice during a gear change, therefore disengaging the transmission twice- hence the name.
1. Clutch pedal depressed and accelerator released, gear stick shifted to neutral position.
2. Using the throttle, the engine speed is matched as closely as possible to the gear speed.
3. The clutch pedal is depressed again and the required gear is selected and throttle pedal is used to accelerate the vehicle.</td></tr>
<tr><td>7</td><td>Name the possible causes for the propeller shaft to develop noise while running[MAY/JUN 12] (BTL1)
Grinding and squeaking from the drive shaft is frequently caused by worn universal joints.
A clunking sound, when going from acceleration to deceleration or deceleration to acceleration, may be caused by slip yoke problems.
A whining sound from the drive shaft is sometimes caused by a dry, worn center</td></tr>
</table>

<table>
<tr><td></td><td>support bearing.</td></tr>
<tr><td>8</td><td>**Where and why do we use the multiple clutch system? [NOV/DEC 14] (BTL1)**
A multi-plate clutch has more than one driven plate. Multi-plate type of clutch finds a use in automatic gearboxes. In these gearboxes, a number of clutches hold the various gear elements, and as the clutch diameter in these units is limited, a multi-plate clutch is suitable.</td></tr>
<tr><td>9</td><td>**Distinguish between transfer box and over drive. [NOV/DEC 14] (BTL2)**
<table>
<tr><td>TRANSFER BOX</td><td>OVERDRIVE</td></tr>
<tr><td>Transfer case is a part of four wheel drive system used in four wheel drive and all wheel drive vehicles which provides a two speed transmission to obtain low gear and direct gear in vehicles.</td><td>Gear in a motor vehicle providing a gear ratio higher than that of direct drive (the usual top gear), so that the engine speed can be reduced at high road speeds to lessen fuel consumption or to allow further acceleration.</td></tr>
</table>
</td></tr>
<tr><td>10</td><td>**Why do we provide slip joint in the propeller shaft? [NOV/DEC 16] (R08,R13) (APR/MAY2015) (BTL1)**
Slip joint serves to adjust the length of the propeller shaft when demanded by the rear axle movements.</td></tr>
<tr><td>11</td><td>**What is the function of differential? [NOV/DEC 16] (MAY/JUNE2016) (BTL1)**
A vehicle with two drive wheels has the problem that when it turns a corner the drive wheels must rotate at different speeds to maintain traction. The automotive differential is designed to drive a pair of wheels while allowing them to rotate at different speeds.</td></tr>
<tr><td>12</td><td>**State the function of main shaft and lay shaft of a gear box?(MAY/JUNE2016) (BTL2)**
MAIN SHAFT
It is the shaft which runs at the vehicle speed. It carries power form the counter shaft by use of gears and according to the gear ratio, it runs at different speed and torque compares to counter shaft. One end of this shaft is connects with the universal shaft
LAY SHAFT
A lay shaft is an intermediate shaft within a gearbox that carries gears, but does not transfer the primary drive of the gearbox either in or out of the gearbox</td></tr>
<tr><td>13</td><td>**What do you meant by overdrive?(MAY/JUNE2016) (BTL1)**
Gear in a motor vehicle providing a gear ratio higher than that of direct drive (the usual top gear), so that the engine speed can be reduced at high road speeds to lessen fuel consumption or to allow further acceleration.</td></tr>
<tr><td>14</td><td>**What is known as one way clutch?(MAY/JUNE2014) (BTL2)**
One way Clutch is also called as freewheel, it transmit torque in one direction and disengages or freewheels in another direction.</td></tr>
<tr><td>15</td><td>**Mention few important causes of axle failure(MAY/JUNE2014) (BTL2)**
Any of the two half shaft may be broken
Splines on the axle shaft may be stripped
The teeth of some gear in the rear axle drive may be stripped
The taper key at the hub be fracture.</td></tr>
<tr><td>16</td><td>**Name the types of clutches(APR/MAY2015) (NOV/DEC2016) (NOV/DEC2015) (BTL1)**
i)Wet clutch ii)Dry clutch iii)Cone clutch
iv)Centrifugal clutch v)Positive clutch vi)Vacuum clutch</td></tr>
<tr><td>17</td><td>**What are the functions of gear box?(MAY/JUNE2016) (BTL1)**
A gearbox converts the rotational energy of the engine to a rotational speed appropriate for the wheels. Mechanical gearboxes do so with simple gears. Automatic gearboxes use more complicated planetary gear sets</td></tr>
</table>

18	**What is a free wheel? What is the importance of the free wheel in the transmission of an automobile?(APR/MAY2017) (BTL2)** Free wheel is a device which is installed between propeller shaft and the gear box. (Also there is overdrive between propeller shaft and gearbox.) Free wheel makes the wheel to rotate wheel freely when propeller shaft is disengaged from the engine or gear box. To reduce the wear on transmission system To reduce the fuel consumption on sloping downward Using this, at low speed gear changing is simplified
19	**Write short note on panhard rod(APR/MAY2017) (BTL1)** A Panhard rod (also called Panhard bar or track bar) is a suspension link that provides lateral location of the axle.
20	**Define Tractive Force (BTL1)** The torque available on the wheel produces a driving force which is parallel to road known as tractive effort.
	PART * B
1	**Explain the working of a torque converter with neat sketch.[NOV/DEC 13] [MAY/JUN 13] (13 M) (BTL3)** The parts of a torque converter (left to right): turbine, stator, pump The pump section of the torque converter is attached to the housing. The torque converter turbine: Note the spline in the middle. This is where it connects to the transmission. The stator sends the fluid returning from the turbine to the pump. This improves the efficiency of the torque converter. Note the spline, which is connected to a one-way clutch inside the stator. 
2	**With a neat sketch, explain the working of simple floor mounted gear shifting mechanism.[MAY/JUN 13] [MAY/JUN 12] (MAY/JUNE2016)(13 M) (BTL5)**
	The mechanism that transmits engine four to the rear wheel (in case of rear wheel drive vehicle) or to the front wheel. (In front wheel drive vehicle) or to all the four wheel (in four wheel drive vehicles) is known as a transmission system.

	The gear box and its associated units perform the following function on A gear box assists in variation of torque (or tractates effort) produced by the engine in accordance with the driving conditions. A large torque is required at the start of the vehicle and a low torque at higher speeds. oIt helps in smooth running of the vehicle at different speed since variation a torque induces. **Answer: Page**
3	**What is the need of clutch system in automotive vehicle? Classify the types of clutch. Explain the working of centrifugal clutch with neat schematic[NOV/DEC 14] (MAY/JUNE2016)(13 M) (BTL5)**
	Clutch is a machine member used to connect the driving shaft to a driven shaft, so that the driven shaft may be started or stopped at will, without stopping the driving shaft. A clutch thus provides an interruptible connection between two rotating shafts. Clutches allow a high inertia load to be stated with a small power. Clutches are used whenever the ability to limit the transmission of power or motion needs to be controlled either in amount or over time (e.g. electric screwdrivers limit how much torque is transmitted through use of a clutch; clutches control whether automobiles transmit engine power to the wheels). Types of clutch Single plate clutch Multi plate clutch Cone clutch Centrifugal clutch Centrifugal Clutch It consists of two members one is fitted to the driving shaft and other to the driven member. It is a drum which encloses the driving member. The driving member consists of a spider, shoes having friction linings at outer end. The springs exert a radially inward force.



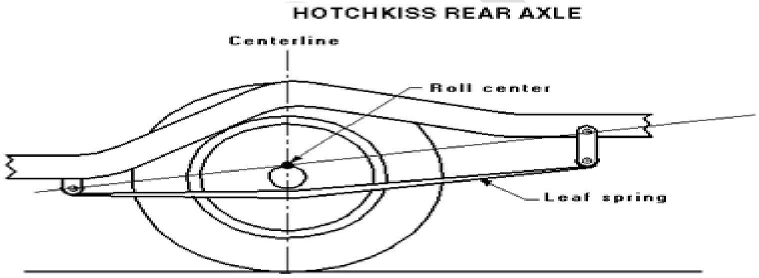
4 **Explain the construction details of Hotchkiss and torque tube drive rear axle drive system.[NOV/DEC 14] [NOV/DEC 12] [APR/MAY2017] [MAY/JUNE2016](13 M) (BLT4)**

Hotchkiss Drive

It consists of two longitudinal leaf spring and propeller shaft. The propeller shaft has slip joint.

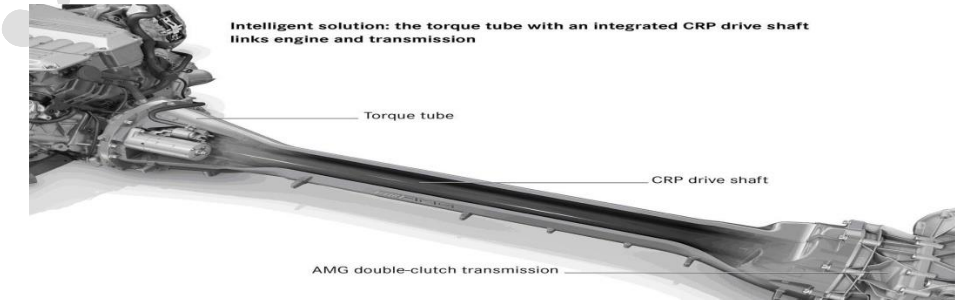
* The front end of the leaf springs is hinged to the frame and the rear end is connected with the frame by swinging shackles.

* The driving force is transferred from the axle casing to the front end of the spring and then to the frame. Hence, both rear end torque and driving thrust are opposed by the springs.



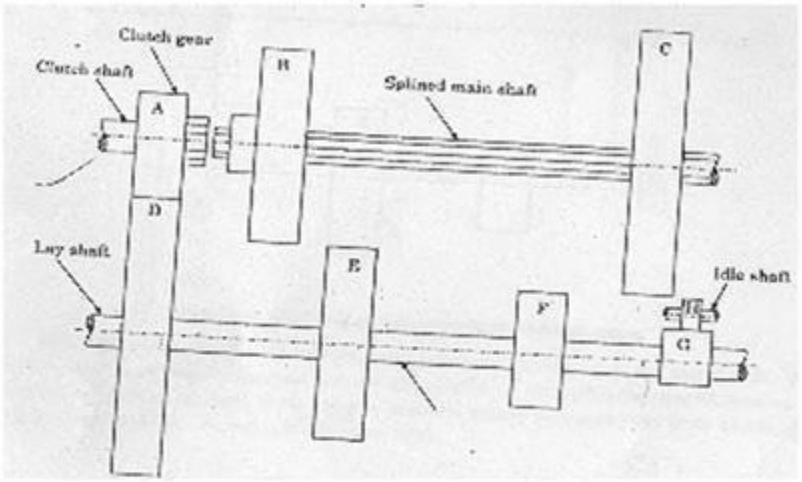
TORQUE TUBE DRIVE

It is similar to Hotch kiss drive but uses a hollow tube which encloses the propeller shaft. The tube is rigidly connected to the differential housing at one end. The other end of the tube is connected to the gearbox casing by a flexible ball and socket arrangement. The driving thrust and rear end torque are carried by a hollow tube.



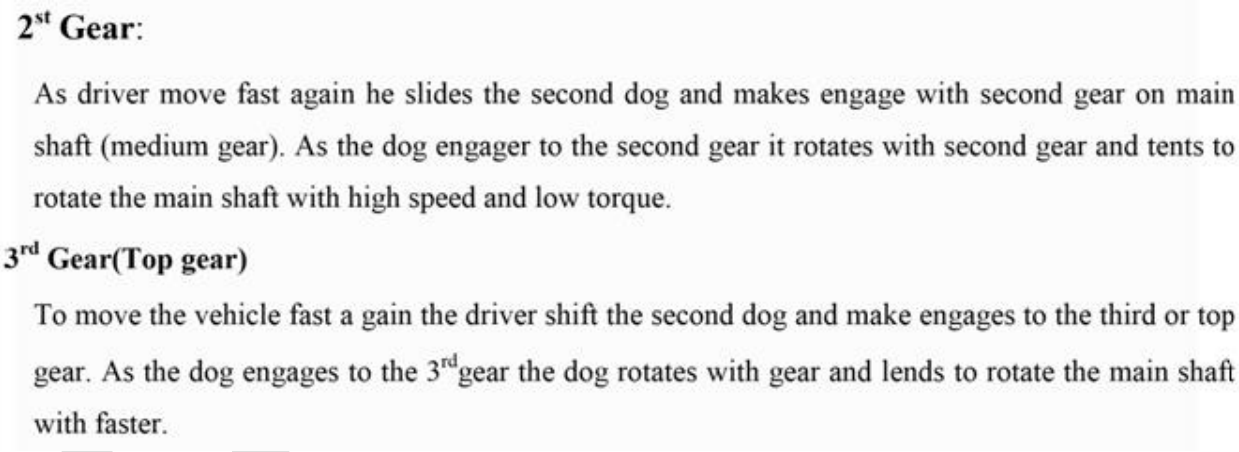
5 **With the help of neat sketch, explain the construction and operation of a sliding mesh gear**

box.[NOV/DEC 16] (13 M)(BTL4)



1st Gear:

When driver wand's to move the vehicle he engage the 1st dog to the with the help of gear shifting levees as the dog slides on engage to the 1st gear it starts rotate with 1st gear and tends to rotate the main shaft like 1st gear operates.



2st Gear:

As driver move fast again he slides the second dog and makes engage with second gear on main shaft (medium gear). As the dog engager to the second gear it rotates with second gear and tents to rotate the main shaft with high speed and low torque.

3rd Gear(Top gear)

To move the vehicle fast a gain the driver shift the second dog and make engages to the third or top gear. As the dog engages to the 3rdgear the dog rotates with gear and lends to rotate the main shaft with faster.

6 **Explain types of gear boxes in detail with neat sketches(MAY/JUNE2016)(13 M)**(BTL4)

Answer: Page 607-R.S KHURMI

MANUALGEARBOX

1) Sliding mesh gearbox.
2) Constant mesh gearbox.
3) Synchromesh gearbox.

4) Synchromesh gear box with over drive.

SEMI- AUTOMATIC GEARBOX

1)Electric controlled with a avid drive.

2) Electric controlled with over drive.

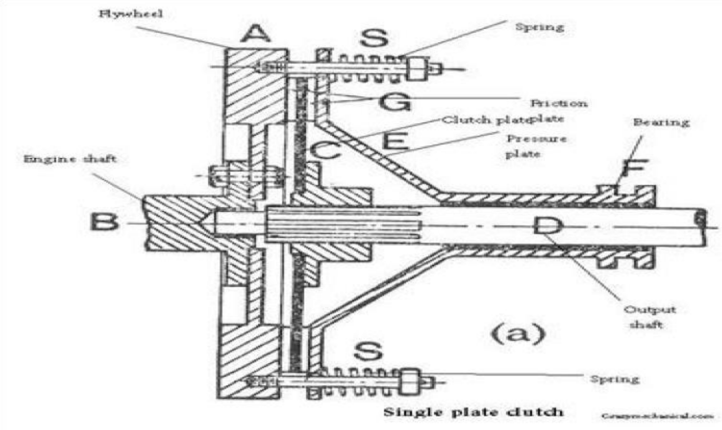
3) Fluid – torque drive.

AUTOMATIC GEARBOX

1) Hydromantic drive.

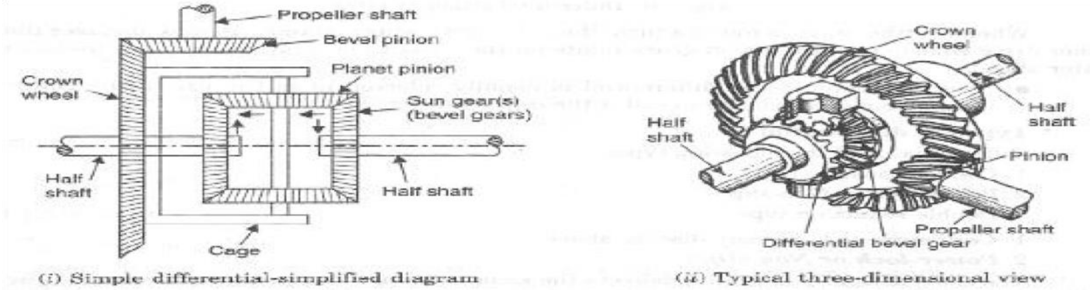
2) Torque converter drive.

7 **(i)Discuss about the working principle of single plate clutch[APR/MAY2015] (BTL4)**



It is when drivers want to shift the gear or to stop the vehicle. He depress clutch pedal so that the fork pushed the forward and pushes the clutch bearing and finger. The finger are pivoted so that they pulls the pressure plate back hence the clutch plate will get free so the flywheel radiate but the clutch plate will not get rotate. This is the disengage position on clutch.

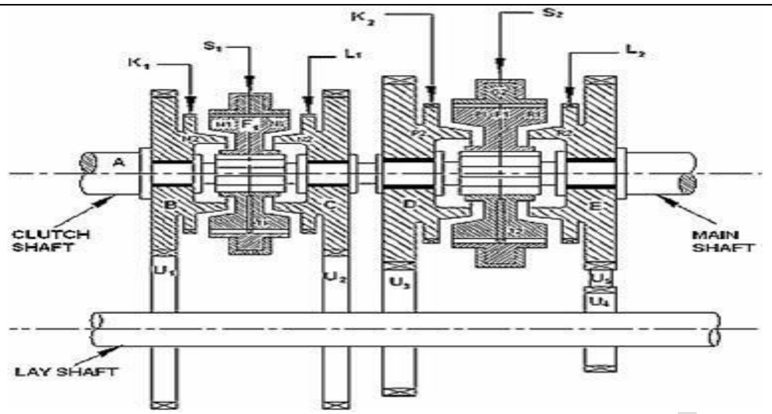
(ii)Discuss about the working principle of differential with neat diagram [APR/MAY2015](13 M)(BTL4)



(i) Simple differential-simplified diagram (ii) Typical three-dimensional view

When the car is on a straight road, the ring gear, differential case, differential pinion gears, and two differential side gears all turn 38 a unit. The two differential pinion gears do not rotate on

	the pinion shaft. This is because they exert equal force on the two differential gears. As a result, the side gears turn at the same speed as the ring gear, which causes both drive wheels to turn at the same speed also. However, when the car begins to round a curve, the differential pinion gears rotate on the pinion shaft. This permits the outer wheel to turn faster than the inner wheel.
8	
	(i)What are the types of rear axle casing?[MAY/JUNE2016] (BLT3) **Following are the three different types of axles** • Rear Axles • Front Axle • Stub Axle **(ii)What are the rear axle drive? and explain with neat sketch[MAY/JUNE2016]** **(13 M) (BLT5)** **Rear Axle** In between the differential and the driving wheels is the rear axle to transmit power from the differential to the driving wheels. It is clear from the construction of the differential, that the rear axle is not a single piece, but it is in two halves connected by the differential, one part is known as the half shaft. The inner end of the half shaft is connected to the sun gear of the differential. and the outer end of the driving wheel. In rear-wheel-drive vehicles, the rear wheels are the driving wheels. Whereas, in front-wheel drive vehicles, the front wheels are the driving wheels. Almost all rear axles on modern passenger cars are live axles, that is, they revolve with the wheels. Dead axles simply remain stationary, do not move with the wheels. A housing completely encloses the rear axles and the differential, protecting them from water, dust and injury, in addition to mounting their inner bearings and providing a container of the lubricant. **Answer: Page 533-R.S KHURMI**
9	
	(i)Explain construction and working principle of constant mesh gear box with neat sketch.[APR/MAY2017] (BLT3)

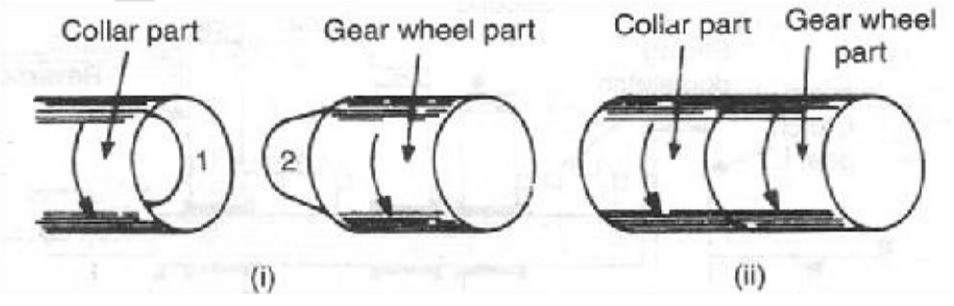


This type of gears is fixed to their positions. They are meshed. It is a type of manual transmission. It is this gear box that we use in today's automobiles, right? Synchromesh is absent here. It shows a simple constant mesh gear box though from it you will not be able to understand its simulation. I would suggest that you try to analyze how the power is transmitted through main shaft to the wheels through clutch and gear system. We use various gear ratios to control the vehicle speed. It is that gear box in which sliding synchronizing units are provided in place of sliding Clutches as in case of constant mesh gear box. With the help of synchronizing unit, the speed of both the driving and driven shafts is synchronized before they are clutched together through train gears. The arrangement of power flow for the various gears remains the same as in the constant mesh gear box.

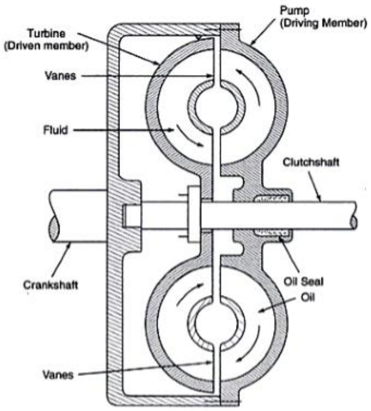
(ii)Describe the line diagram of synchromesh unit and mention the component (spring with ball type system)[NOV/DEC2016](13 M) (BLT5)

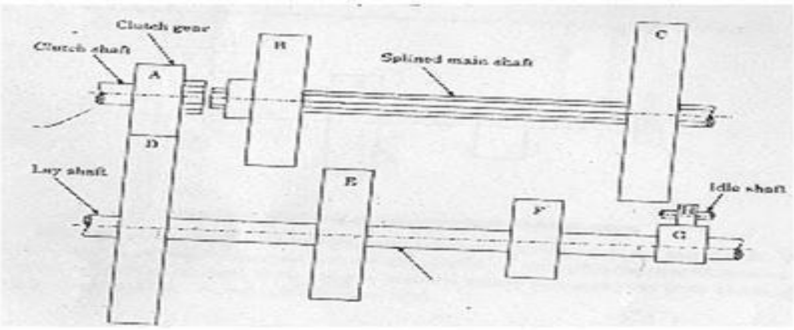
Answer: Page 533-R.S KHURMI

Synchromesh gear devices work on the principle that two gears to be engaged are first Brought into frictional contact which equalizes their speed after which they are engaged readily and smoothly.

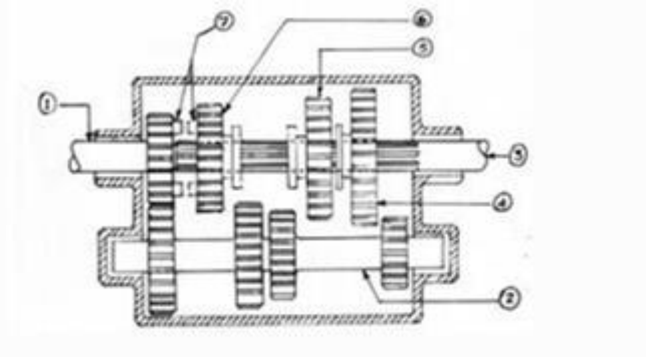


Advantages

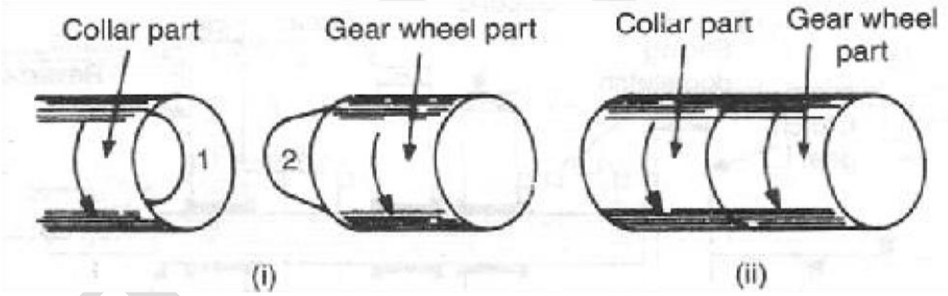
	The synchromesh type of transmission has the big advantage of allowing smooth type and quick shifting of gears without danger of damaging the gears and without necessity for double clutching. The synchromesh gear box is considered the most advanced and has been adopted in most cars.
	PART * C
1	
	(i)What are the functions of transmission systems? [NOV/DEC2016] **(ii)Sketch and explain the working method of fluid flywheel [NOV/DEC2016] (15 M)(**BTL4) • The fluid flywheel is used in cars with automatic transmission. • It consists of two members; the driving member is attached to the engine flywheel and the driven member to the transmission shaft. • There is no direct contact between the two members. The two rotors are always filled with fluid of suitable viscosity. • A simplified diagram representing the fluid flywheel is shown. At start tube X is rotating say at N rpm and Y tube is stationary. • With the movement of fluid in X and Y, Y also starts rotating but at a lower speed. • The speed goes on increasing till the speed equals to N rpm, then the coupling is fully engaged.  Fluid flywheel **Answer: Page 528-R.S KHURMI**
2	**Compare the applications of sliding mesh, constant mesh and synchromesh gear box. (15 M) (BTL4)**
	Answer: Page 528-R.S KHURMI Sliding Mesh



Constant Mesh



synchromesh gear box

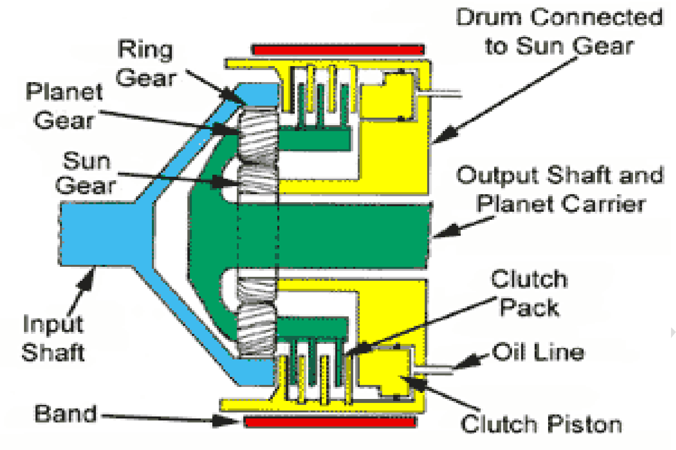


3 **Explain EPICYCLIC GEARBOX and AUTOMATIC GEAR BOX. (15 M) (BTL5)**

Answer: Page 528-R.S KHURMI

EPICYCLIC GEARBOX:

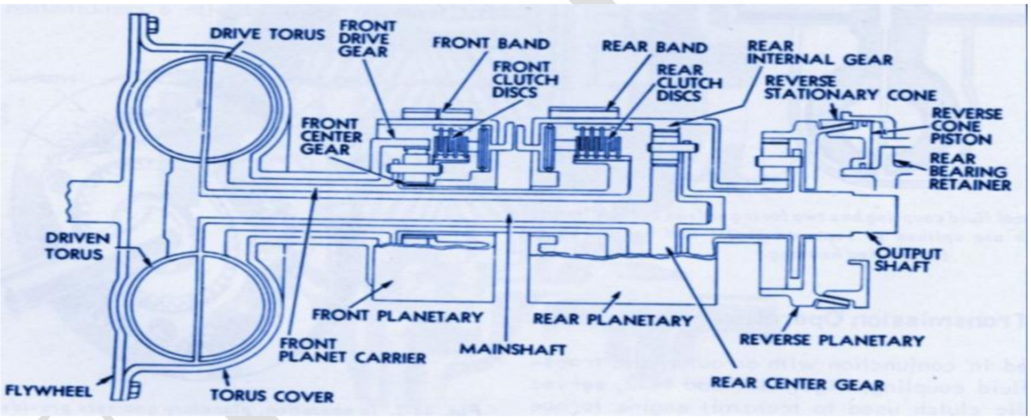
In epicyclic gear box at least one of the gear not only rotates about its own axis but also revolves bodily about the some other axis. Here speed can be changed automatically by tightening the band (mechatronic control).



PLANETARY GEAR SYSTEM
Side View

AUTOMATIC GEAR BOX

It consists of a set of epicyclic gears with fluid flywheel & changes the speed automatically (hydraulic control).



UNIT IV -STEERING, BRAKES AND SUSPENSION SYSTEMS

Steering geometry and types of steering gear box-Power Steering, Types of Front Axle,Types of Suspension Systems, Pneumatic and Hydraulic Braking Systems, Antilock Braking System(ABS), electronic brake force distribution (EBD) and Traction Control.

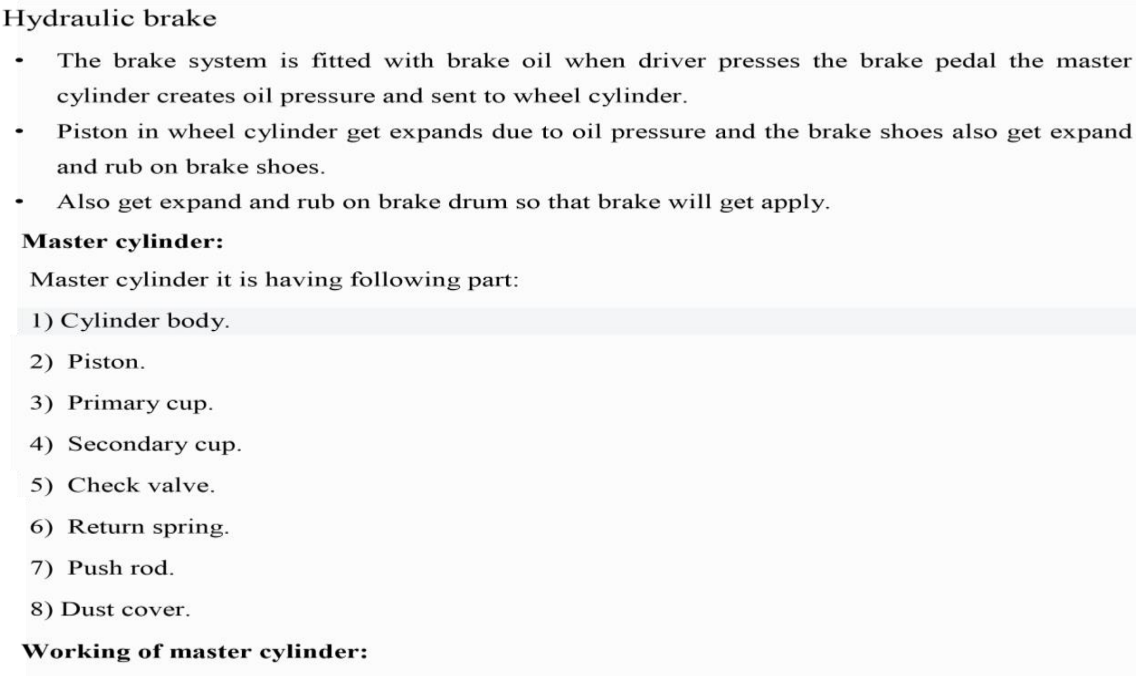
PART * A

Q.No.	Questions
1.	**Define the term 'braking efficiency'. [NOV/DEC 2013] (BTL12)** The brake efficiency, which is expressed as a percentage, calculates how effective your brakes are when you lightly and heavily tap on them. The brakes efficiency is dependent on the weight of your vehicle and the force of your brakes.
2	**State functions of steering gears. [NOV/DEC 2013] (BTL2)** A function of steering wheel, the rotary motion of the steering wheel is converted into straight line motion of the linkage by the steering gears. The gear which is used for steering arrangement is worm gear. Steering gear is the device used for controlling the direction of a vehicle.
3	**What is steering geometry? [NOV/DEC 2012] (BTL1)** Steering geometry is a geometric arrangement of linkages in the steering of a car or other vehicle designed to solve the problem of wheels on the inside and outside of a turn needing to trace out circles of different radii.
4	**What is the use of stub axle? [NOV/DEC 2012] (BTL2)** A stub axle is one of the two front axles that carry a wheel in a rear wheel drivevehicle. The axle is capable of limited angular movement about the kingpin for steering the vehicle. The stub axle consists of wheel bearings which support the wheel hub.
5	**Define 'camber' and 'castor'. [MAY/JUN 2013] (BTL2)** Camber angle is the angle made by the wheels of a vehicle; specifically, it is the angle between the vertical axis of the wheels used for steering and the vertical axis of the vehicle when viewed from the front or rear Caster angle or Castor angle is the angular displacement of the steering axis from the vertical axis of a steered wheel in a car, motorcycle, bicycle or other vehicle, measured in the longitudinal direction
6	**Define 'King pin inclination'. [MAY/JUN 2012] (BTL2)** The kingpin angle is set relative to the true vertical line, as viewed from the front or back of the vehicle.
7	**Write the functions of automobile suspension system. [MAY/JUN 2012] (BTL1)** To safeguard the passengers and goods against road shocks. To pressure the stability of the vehicles while in motion. To maintain proper steering geometry. To bear the torque and braking reaction.
8	**What is bleeding of hydraulic brakes? [NOV/DEC 2014] (BTL2)** Brake bleeding is the procedure performed on hydraulic brake systems whereby the brake lines (the pipes and hoses containing the brake fluid) are purged of any air bubbles. This is necessary because, while the brake fluid is an incompressibleliquid, air bubbles are compressiblegas and their presence in the brake system greatly reduces the hydraulic pressure that can be developed within the system.

9	**What do you mean by telescopic steering wheel? [NOV/DEC 2016] (BTL2)** Between the wheel and the dash on the steering column is found a metal tab that is the adjusting collar. This collar is attached to a threaded insert that when loosened screws out away from a metal rod that actuates the locking device. It is a fairly simple device.
10	**What is self-energizing brake?(MAY/JUNE2016) (BTL1)** Self – Energizing brake uses the force (typically torque) generated by friction to increase the clamping force of the brake shoes.
11	**Why synchronizer is required in the automotive transmission system?(MAY/JUNE2016) (BTL1)** Synchronizer is required in the automotive transmission system is to avoid double clutching and smooth engagement of gears.
12	**What is the advantage of having rigid axle suspension?(MAY/JUNE2014) (BTL2)** Simplicity Space efficient, durable in high load environment Cheap to manufacture Better vehicle articulation
13	**With regard to steering what is Toe-in and Toe-out?(MAY/JUNE2014) (BTL2)** Toe-in The front wheels are usually turned in slightly in front so that the distance between the front ends A is slightly less than the distance between the back ends B, when viewed from the top. The difference between these distances is called toe-in. The amount of toe-in is usually 3 to 5 mm. Toe-out The inner front wheel turns a larger angle than the outer while turning. So the wheels are made toe-out on turns due to the difference in their turning angles and thereby avoiding tyre scrub.
14	**Name the types of front axles.(APR/MAY2015) (BTL1)** i) Live front axle ii) Dead front axle
15	**What is meant by traction control(APR/MAY2015) (BTL2)** Traction control is an active vehicle safety feature designed to help vehicles make effective use of all the traction available on the road when accelerating on low-friction road surfaces.
16	**What is the function of the tension spring in the clutch plate?(MAY/JUNE2016) (BTL2)** Clutch springs can be found in use on most motorcycle clutch assemblies. The function of these short coil springs is to continuously hold the friction and driven plates together through spring tension, preventing slippage except when the clutch lever is engaged. Most often, five or more clutch springs are used per motorcycle clutch assembly.
17	**Name the classification brake system(MAY/JUNE2016) (BTL1)** (a) Mechanical brakes (b) Hydraulic brakes (c) Air brakes (d) Vacuum brakes (e) Electric brakes.
18	**Give types of stub axle(APR/MAY2017) (BTL2)** i) Elliot type stub axle ii) Reversed Elliot stub axle iii) Lamoine stub axle iii) Reversed Lamoine stub axle
19	**Name any four types of suspension spring(NOV/DEC2016) (BTL2)** (a)Leaf Spring (b)Semi Elliptical Spring (c)Torsion Beam (d)Coil Spring
20	**List down any two types of steering gear.(NOV/DEC2015) (BTL1)** (a)Worm and Sector Steering Gear (b)Worm and roller Steering Gear (c)Cam and double lever steering gear (d)Worm and Ball bearing nut steering gear (e)Cam and roller steering gear (f)Cam and peg steering gear (g)Rack and pinion steering gear
	PART * B
1	**Discuss the working of diagonal braking system with a layout. Also explain the working of master cylinder in a hydraulic brakes.[MAY/JUN 2013]**

(13 M) (BTL5)

- In this system the brake is operated with the help of oil pressure in this system master cylinder and wheel cylinder is most important part.
- This system is very popular on four wheeler vehicle basically light and medium vehicle.



Hydraulic brake

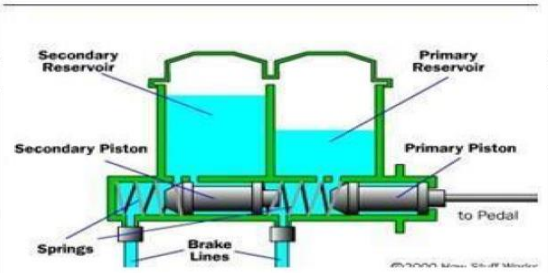
- The brake system is fitted with brake oil when driver presses the brake pedal the master cylinder creates oil pressure and sent to wheel cylinder.
- Piston in wheel cylinder get expands due to oil pressure and the brake shoes also get expand and rub on brake shoes.
- Also get expand and rub on brake drum so that brake will get apply.

Master cylinder:

Master cylinder it is having following part:

1) Cylinder body.
2) Piston.
3) Primary cup.
4) Secondary cup.
5) Check valve.
6) Return spring.
7) Push rod.
8) Dust cover.

Working of master cylinder:



2 **Explain the various types of suspension and types offered for automobile with neat schematic.[NOV/DEC 2014](BTL5)**

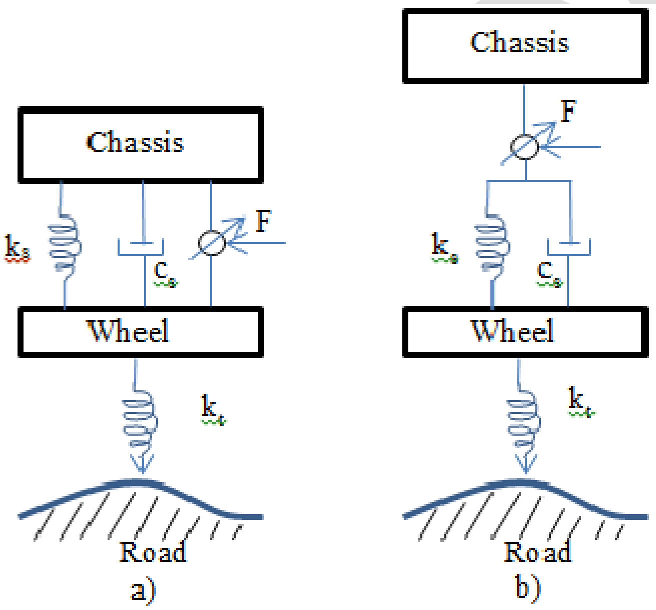
Answer: Page

Suspension system is responsible for smoothing out the ride and keeping the car in control. Specifically, the suspension system maximizes the friction between the tires and the road to provide steering stability and good handling. The suspension system also provides comfort for passengers to limiting the impact of particular road conditions to not only the car, but the passengers riding inside.

The suspension system is made up of several components, including the chassis, which holds the cab of the car. The springs support the vehicle weight and absorb and reduce excess energy from road shocks, along with the shock absorbers and struts. Finally, the anti-sway bar shifts the movement of the wheels and stabilizes the car.

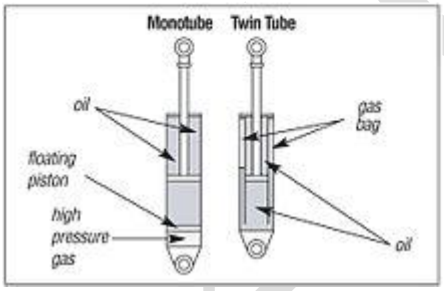
Your car's suspension system must be in good condition. Worn suspension components may reduce the stability of the vehicle and reduce driver control, as well as accelerate wear on other suspension system components. Replacing worn or inadequate shocks and struts will help maintain good ride control, as they:

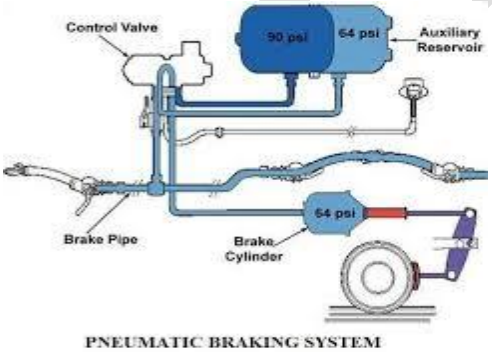
- Control spring and suspension movement
- Provide consistent handling and braking
- Prevent premature tire wear
- Help keep the tires in contact with the road
- Maintain dynamic wheel alignment
- Control vehicle bounce, roll, sway, drive, and acceleration squat
- Reduce wear on other vehicle systems
- Promote even and balanced tire and brake wear

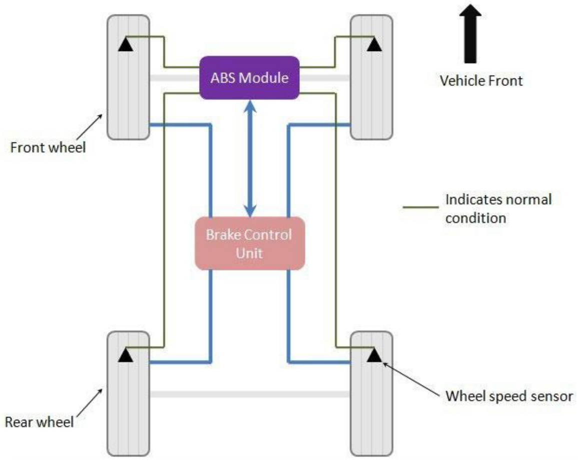
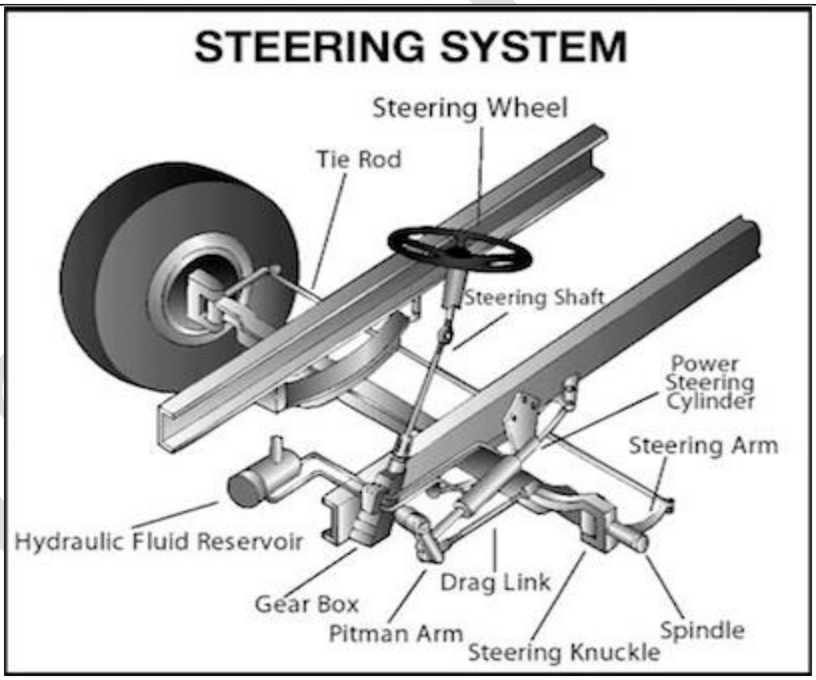


3 **(i)Write short notes on power steering.[NOV/DEC 2016] [NOV/DEC2015] (BTL5)**

The increased use of large section low-pressure balloon tyres has aggravated the steering problem due to the greater contact area between the tyre and ground. The driver requires a greater force to be exe11ed on the steering wheel for steering the heavy vehicle or heavily loaded commercial vehicle, especially when the vehicle has to take a sharp turn. Power steering makes it easier to turn sharp corners. It is fitted not only to heavy commercial vehicles but also to heavy and medium weight cars. It is usually arranged to be operative when the effort at the steering wheel exceeds a pre-determined value. When this effort is excluded, a valve directs the working fluid to the appropriate side of the power cylinder, and this result in the steered wheels being turned in the desired direction. The working fluid is high quality lubricating oil having a viscosity rating equivalent to ASE low for normal

	conditions. The actual amount of assistance given depends upon the resistance offered to movement *of* the road wheels. Types of power steering systems: 1. Integral power steering, in which the power operating assembly is part of the steering gear. 2. Linkage power steering, in which the power opening assembly is part of the linkage. **(ii)What is the 'Under steering' and Over steering'?[NOV/DEC 2013] (13 M)**(BTL5)
4	**(i)With neat sketch explain the construction and operation of a shock absorber[MAY/JUNE2016] (BTL4)|**
	A shock absorber (in reality, a shock "damper") is a mechanical or hydraulic device designed to absorb and damp shock impulses. It does this by converting the kinetic energy of the shock into another form of energy (typically heat) which is then dissipated. Most shock absorbers are a form of dashpot (a damper which resists motion via viscous friction).  **(ii)What are the requirements of good braking system?[NOV/DEC2015](13 M)** (BLT5) The brake must be strong enough to stop the vehicle within minimum distance. It is inversely proportional to brake efficiency and proportional to square of speed. Provide good control over vehicle during emergency braking and vehicle must not skid After prolonged period of application of brakes, the coefficient of friction drops and property of brake material changes which leads to less braking effect. This is called Brake Fade and hence brakes must have antifade characteristics. Cooling of the brakes must be very efficient The maximum retarding force F applied by the brakes at the wheels must be close to F=μN The brake torque depends upon effective axle height and braking force between road surface and tyre. Hence anchor pin supporting brake shoes must have enough strength to withstand high braking load.
5	**Explain any one of the front independent suspension system with neat diagram[APR/MAY2017] (13 M) (BTL5)**
	Independent suspension is any automobile suspension system that allows each wheel on the same axle to move vertically (i.e. reacting to a bump in the road) independently of the others. This is contrasted with a beam axle or deDion axle system in which the wheels are linked – movement on one side affects the wheel on the other side. "Independent" refers to the motion or path of movement of the wheels or suspension. It is common for the left and right sides of the suspension to be connected with anti-roll bars or other such mechanisms. The anti-roll bar ties the left and right suspension spring rates together but does not tie their motion together.

	Types - Double wishbone suspension - Multi-link suspension - MacPherson strut - Transverse leaf-spring Transverse leaf-spring 
6	**Draw the schematic diagram of pneumatic braking system and explain it. [MAY/JUNE2016] [APR/MAY2015] (13 M) (BTL5)**
	An pneumatic brake system or a compressed air brake system is a type of friction brake for vehicles in which compressed air pressing on a piston is used to apply the pressure to the brake pad needed to stop the vehicle. 
7	**With the aid of neat sketch explain the working principle of antilock braking system[APR/MAY2015] [MAY/JUNE2016] [NOV/DEC2015] (13 M) (BLT5)**

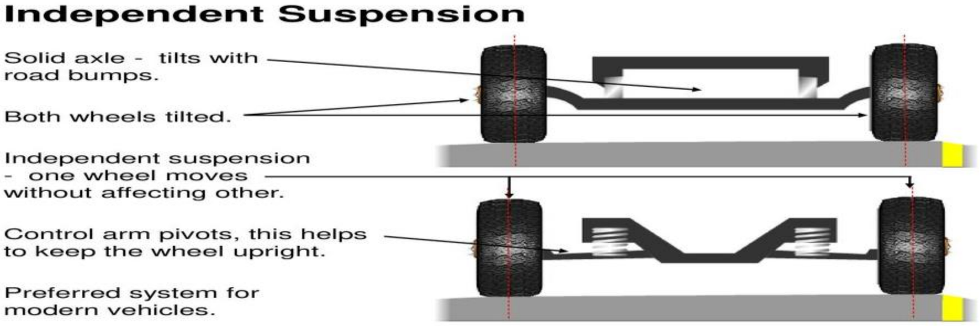
	 Parts Working principle
8	**Explain the steering principle, its need, functions in detail with proper sketches and mention the parts of steering system.[MAY/JUNE2014] [MAY/JUNE2016] [APR/MAY2017](13 M) (BLT5)**
	 Parts Working principle
	PART * C
1	**Compare the suspension system of four wheeler and two wheeler.** **(15 M) (BTL5)**
	A motorcycle's suspension serves a dual purpose: contributing to the vehicle's handling and braking, and providing safety and comfort by keeping the vehicle's passengers comfortably isolated from road noise, bumps and vibrations.

The typical motorcycle has a pair of fork tubes for the front suspension, and a swingarm with one or two shock absorbers for the rear suspension.

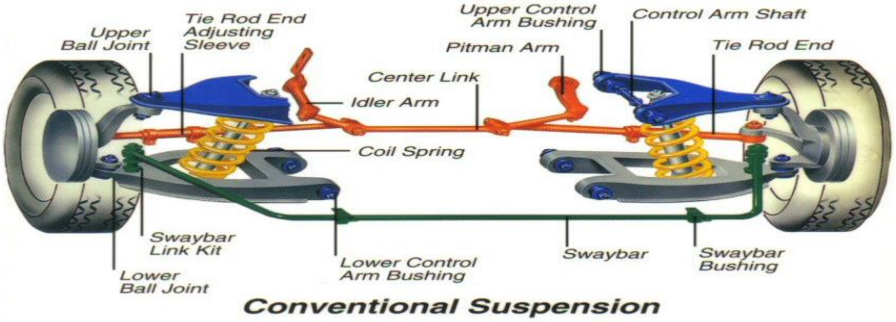
Suspension is the system of tires, tire air, springs, shock absorbers and linkages that connects a vehicle to its wheels and allows relative motion between the two. Suspension systems must support both roadholding/handling and ride quality, which are at odds with each other. The tuning of suspensions involves finding the right compromise. It is important for the suspension to keep the road wheel in contact with the road surface as much as possible, because all the road or ground forces acting on the vehicle do so through the contact patches of the tires. The suspension also protects the vehicle itself and any cargo or luggage from damage and wear. The design of front and rear suspension of a car may be different.

2 **(i)Distinguish between independent suspension and conventional suspension system. [MAY/JUNE2016] [MAY/JUNE2014] (BTL5)**

Independent suspension is any automobile suspension system that allows each wheel on the same axle to move vertically (i.e. reacting to a bump in the road) independently of the others. This is contrasted with a beam axle or deDion axle system in which the wheels are linked – movement on one side affects the wheel on the other side. "Independent" refers to the motion or path of movement of the wheels or suspension. It is common for the left and right sides of the suspension to be connected with anti-roll bars or other such mechanisms. The anti-roll bar ties the left and right suspension spring rates together but does not tie their motion together.



The suspension system of an automobile helps to support the car body, engine and passengers, and at the same time absorbs shocks received from the ground while vehicle moves on rough roads.



(ii)List the types of suspension spring used in automobile [MAY/JUNE2016] (15 M) (BTL5)

Leaf Spring: Semi elliptic leaf springs are used in almost all commercial vehicles. ...

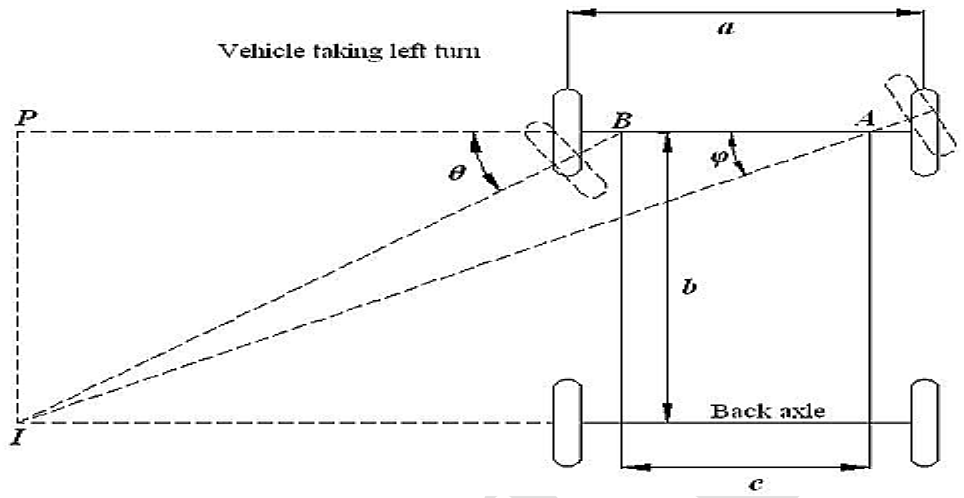
Helical Spring or Coil Spring: We all have seen coil springs many times. ...

Torsion Bar: It is simply a rod which acting under the torsion and taking shear stresses. ...

Rubber Springs:The rubber springs are also used in suspension because it store greater energy per unit weight than the steel. So it is more compact than other springs. It has also excellent vibration damping property. One more advantage of using rubber is that it is not suddenly fail like steel so there is less risk.

3 **Derive an expression for condition of correct steering.**
(15 M) (BTL5)

Answer: Page 528-R.S KHURMI



The steering gear mechanism is used to change the direction of two or more of the wheel axle's with reference to the chassis, so as to move the automobile in the desired path. The steering is done by front wheels and back wheels remain straight and do not turn.

The condition for correct steering is that all the four wheels must rotate about the same instantaneous centre which lies on the axis of the back wheels.

Let the axis of the inner wheels makes a larger angle θ than the angle φ subtended by the axis of outer wheel.

Let a = wheel track, b = wheel base
c= distance between the pivots A and B of the front axle

From triangle IBP

$$\cot\theta = \frac{BP}{IP}$$

From triangle IAP

$$\cot\phi = \frac{AP}{IP} = \frac{AB+BP}{IP} = \frac{AB}{IP} + \frac{BP}{IP} = \frac{c}{b} + \cot\theta$$

$$\cot\phi - \cot\theta = \frac{c}{b}$$

This is the fundamental equation for correct steering.

UNIT V - ALTERNATIVE ENERGY SOURCES

Use of Natural Gas, Liquefied Petroleum Gas, Bio-diesel, Bio-ethanol, Gasohol and Hydrogen in Automobiles-Engine modifications required –Performance, Combustion and Emission Characteristics of SI and CI engines with these alternate fuels - Electric and Hybrid Vehicles, Fuel Cell

Note: Practical Training in dismantling and assembling of Engine parts and Transmission Systems should be given to the students.

PART * A

Q.No.	Questions
1.	**Mention the various methods of storing hydrogen. [NOV/DEC 2013](BTL2)** (a)Compressed storage (b)Liquid Storage (c)Solid State Storage
2	**Write down the parts of a fuel cell. [NOV/DEC 2013] (BTL2)** Oxidizer.
3	**State the advantages of natural gas. [NOV/DEC 2012](BTL3)** Low engine emission. Less aldehyde than withmethanol Natural Gas is abundant worldwide. It can be made from coal. Octane number is 110 and make suitable for SI engine fuel.
4	**What is fuel cell? [NOV/DEC 2012] (BTL1)** A fuel cell is electrochemical energy conversion device that continuously converts chemical energy of a conventional fuel is converted directly and efficiently into electrical energy.
5	**What is meant by reformulated and oxygenated gasoline? (BTL1)** Reformulated gasoline is gasoline blended to burn more clearly than conventional gasoline and to reduce smog-forming and toxic pollutants in the air. Gasoline additives are added to increase oxygen content in the fuel in order to reduce carbon monoxide and soot produced during burning of fuel.
6	**Define the term 'Esterification'. [MAY/JUN 2012] (BTL2)** Esterification is the process of converting Carboxylic acids to ester using acid and alcohol.
7	**How a fuel cell differs from lead acid battery? [NOV/DEC 2014] (BTL1)** The biggest difference between the two is that a battery stores energy, while a fuel cell generates energy by converting available fuel. A fuel cell can have a battery as a system component to store the electricity its generating.
8	**State functions of stabilizers. [NOV/DEC 2014] (BTL3)** The main function of stabilizer is to make the output voltage that fees the equipment connected to it as much as possible equivalent to the ideal electrical power supply, ensuring that the oscillation in electrical power are offset, and its output maintain a stable value, preventing them from being experienced by equipment and thereby avoiding their damage.
9	**What are the advantages of Hybrid vehicle? [NOV/DEC 2016] (BTL3)** Environmental Friendly It runs cleaner and better mileage Regenerative braking system. Less dependent of fossil fuels Built from lighter material Higher resale value.

10	**Mention the advantages of LPG usage in automobiles. [NOV/DEC 2016] (BTL3)** Higher heating value Does not contain sulphur, so burnt cleaner. Releases only 70% of Carbon dioxide
11	**What is the need to switch over to alternate source of energy?(MAY/JUNE2016) (BTL3)** To reduce pollution To protect against Global warming To save money & can be produced frequently.
12	**Write the reaction takes place during discharging and charging of nickel metal hydride cell(MAY/JUNE2016) (BTL1)** When NiMH cell is discharged, the chemical reaction is the reverse of what occurs when charged. Hydrogen stored in the metal alloy of the negative electrodes is release into the electrolyte to form water. This water the releases a hydrogen ion that is absorbed into the positive electrode to form nickel hydroxide.
13	**Define energy intensity(MAY/JUNE2014) (BTL1)** consumption per work unit, often is used.
14	**Why is hydrogen called as secondary energy source?(MAY/JUNE2014) (BTL1)** Hydrogen is called as secondary energy source commonly referred to as energy carrier. Energy carrier are used to move store and deliver energy in the form that can be easily used.
15	**Define Hybrid Vehicle. (NOV/DEC2016) (BTL1)** The vehicle which is using more than one source of energy to run is called hybrid vehicle. Hybrid means something that is mixed together from to things.
16	**Write short notes on LPG(MAY/JUNE2016) (BTL2)** It is the by product of fractional distillation of petrol, consisting mainly of butane and propane and used as engine fuel. It is formed naturally, interspersed with deposits of petroleum and natural gas.
17	**Why alcohol is an alternate fuel for S I engine?(MAY/JUNE2016) (BTL1)** Alcohol has good calorific value, good volatility, not much higher ignition energy, average autoignition temperature; Viscosity also not much higher, easy burning, easy availability and easy storing makes it suitable as alternate fuel for SI engine.
18	**What are the merits and demerits of supercritical methanol (SCM) transesterification process?(APR/MAY2017) (BTL1)** Super critical methanol is any substance at a temperature and pressure above its critical point, where distinct liquid and gas phase do not exist. It can effuse through solids like gas and dissolve materials like liquids.
19	**Mention any four types of fuel cells(APR/MAY2017) (BTL2)** 1. Alkaline fuel cells 2. Solid oxide fuel cells 3. Molten carbonate fuel cells 4. Direct methanol fuel cells.
20	**List down any two types of steering gear.(NOV/DEC2015) (BTL2)** (a)Worm and Sector Steering Gear (b)Worm and roller Steering Gear (c)Cam and double lever steering gear (d)Worm and Ball bearing nut steering gear (e)Cam and roller steering gear (f)Cam and peg steering gear (g)Rack and pinion steering gear

	PART * B
1	**Explain the various properties of alternative fuels. (13M) [MAY/JUNE2016] (BTL3)**
	Measuring a fuel's relative potential energy can easily be done by defining that fuel's Btu content. A Btu is defined as the amount of heat necessary to raise one (1) pound of water, one (1) degree Fahrenheit.Gasoline and LPG are derived from oil or from natural gas production while CNG comes fromnatural gas. Both oil and natural gas are fossil fuels. The finite reserves of oil are far less than those of natural gas. Farm crops and waste-by-products are the usual sources for methanol and ethanol. The primary CNG component, methane, also may be produced from these sources. From an environmental standpoint, the sulphur content affects the level of tailpipe acids produced as an exhaust by-product. These acids significantly contribute to "acid rain." Acid rain affects plant life, animals, and humans. Environmentalists are deeply concerned over increased exposure and concentrations of automobile-produced, exhaust-oriented, tailpipe emissions. An engine fuel's "antiknock" or octane rating is important to an engine's performance and to the power yield curve. Gasoline has a relatively low octane number, thus compression ratios must be moderated resulting in a lower power yield per cubic inch displacement. Gasoline may be refined to higher octane levels; however, more fuel stocks are needed. Greater waste by-products result as a part of this refining process. Other additives such as tetraethyl lead, phosphorus, and boron were formally used to raise octane ratings. They are no longer used as they damage catalytic converters and are environmentally detrimental. Additionally, exhaust by-products that contain lead are thought to cause some forms of retardation in small children. Tailpipe emissions produced from gasoline yield significant amounts of benzene, a known carcinogen. Other additives, such as MTBE, are being studied to determine if they are carcinogenic. (13M)
2	**Explain LPG is an alternate fuel for petrol engine with diagram. Also explain its performance and emission characteristics. (13 M) [APR/MAY2017] BTL3** An alternative fuel vehicle is a vehicle that runs on a fuel other than traditional petroleum fuels (petrol or Diesel fuel); and also refers to any technology of powering an engine that does not involve solely petroleum (e.g. electric car, hybrid electric vehicles, solar powered). Because of a combination of factors, such as environmental concerns, high oil prices and the potential for peak oil, development of cleaner alternative fuels and advanced power systems for vehicles has become a high priority for many governments and vehicle manufacturers around the world. The mixture of liquefied hydrocarbon gases C3-C4 (propane and butane), called colloquially liquefied gas or LPG, is a particular energy carrier, counted among the group of alternative fuels. LPG has more than 1000 different uses, including applications in industry, civil engineering, communal economy, agriculture, households, and transport. Because of simplified logistics of transport ensuring supply diversification, availability of sources, and most of all environmental aspects, LPG exhibits high dynamics of production and consumption; the global production of this fuel comes close to 280 million tonnes. (13M)

Explain construction and working principle of hybrid vehicle with neat sketch. (13M) [APR/MAY2017] [APR/MAY2015] (BLT3)

Temperature fuel cell to be used to drive a gas turbine. Initially the researchers are developing small systems ranging from 250 kW to 1 MW, for use by business and light industry for co- generation. (2M)

3 **Explain construction and working principle of hybrid vehicle with neat sketch. (13M) [APR/MAY2017] [APR/MAY2015]** BLT3

Temperature fuel cell to be used to drive a gas turbine. Initially the researchers are developing small systems ranging from 250 kW to 1 MW, for use by business and light industry for co-generation. (2M)

the word hybrid refers to anything that has a combination of two different ideas. When a car uses two different ideas to move, it is called a hybrid car. Usually our cars run on petrol, diesel or gas. But their inefficiency, as explained earlier, led to the invention of electric cars. But, since electric cars also had disadvantages of frequent battery charging and inefficient long drives, there evolved a combination of both. When gas and electricity were used in the combined mode, a better solution was made to the inefficiency and mileage.

A user of a car always asks for some minimum requirements while using a car. They are

For long distances, the car must run for at least 450 kilometres before refuelling.
The drive should be smooth and easy.
The car should maintain a good speed so as to cope up with other cars in traffic.
Easy and fast refuelling of cars.
A good mileage
Less pollution

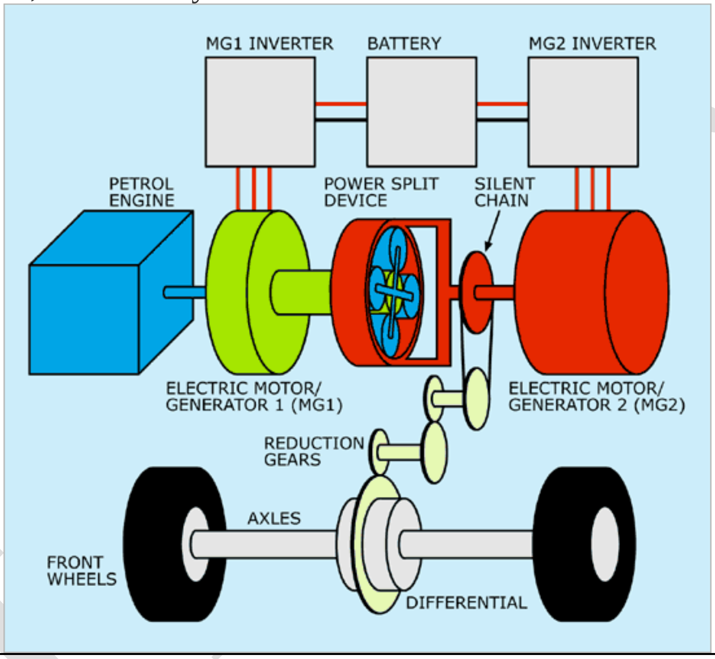
Though most of the conventional cars can provide the first four requirements correctly, they are very much backwards in the case of mileage and pollution. Electric cars, on the other hand can provide a very good mileage and very less pollution. But, the first four requirements will be let down. A combined use of both electric and gas energy will clearly find all these requirements satisfactory.

As Hybrid cars use two energy sources, a lot of energy consumption was reduced for travel (As both the gas and electricity share their energy.) As explained in my article about electric cars, there would not be a disadvantage of recharging the battery frequently. They will be spontaneously charged, while the car is running. Apart from the mileage, the car has also proved to give a performance almost adequate to a conventional car. Due to its improved mileage and reduced pollution, the governments in most countries have been pleased and have helped in its promotion.

Parts Of a Hybrid Car

There are mainly 5 essentials for a hybrid car. They are

Conventional car engine – It can be a gasoline engine or also petrol or diesel respectively. But whatever engine is used, will be more advanced than the usual ones, as they have to work together with the electrical system. They will be smaller with greater efficiency and lesser emissions.
Fuel Tank – For storing the fuel needed to rum the car engine.
Batteries – Batteries are needed to store and release energy as required by the car. The energy from the battery is taken by the motor.
Electric Motor and generator – Though motors can act as generators, both of them are needed for this car. A motor will be needed to take energy from the batteries and accelerate the car. Generators, on the other hand, are needed to produce the electrical power.
Transmission System – The entire transmissions that were performed in a conventional car will be done here as well, but in the hybrid manner.



Working (4M)

4 **What are the engine modification to be undertaken in the SI engine for Alcohol or Ethanol as alternate fuel? (13 M)[NOV/DEC2016]**(BTL5)

Octane Number (4M)
Air Fuel Mix (3M)
Fuel Filters (3M)
Cold Starting (3M)

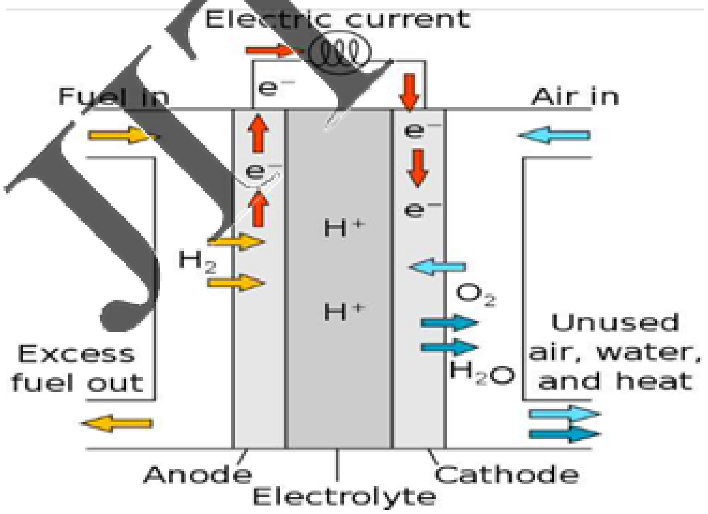
5 **(i) What are the advantages of hybrid electric vehicle?(5M) [NOV/DEC2016]** BTL3

advantages of hybrid electric vehicle
Good For The Environment
Fuel Efficient
Financial Benefits
Disadvantages of hybrid electric vehicle
Hybrid Cars Can Be Expensive
Different Driving Experience
Less Power (5M)

(ii) Explain the construction and working of the PEM fuel cell with sketch. [NOV/DEC2016]

(8M) BTL3

Proton-exchange membrane fuel cells, also known as polymer electrolyte membrane (PEM) fuel cells (PEMFC), are a type of fuel cell being developed mainly for transport applications, as well as for stationary fuel-cell applications and portable fuel-cell applications. Their distinguishing features include lower temperature/pressure ranges (50 to 100 °C) and a special proton-conducting polymer electrolyte membrane. PEMFCs generate electricity and operate on the opposite principle to PEM electrolysis, which consumes electricity. They are a leading candidate to replace the aging alkaline fuel-cell technology, which was used in the Space Shuttle (4M)



(4M)

6 **(i)Discuss the advantages and disadvantages of using LPG as an alternate fuel in engines.**

	(6M) [NOV/DEC2015] [MAY/JUNE2016] BTL3 Advantages: 1. Compared to petrol, running the vehicle engine on LPG results in around a 10% increase in consumption. 2. Due to higher octane rating, the combustion of LPG is smoother and knocking is eliminated and the engine runs smoothly. 3. When LPG leaks past the rings into the crankcase, it does not wash oil from cylinder walls and does not generate black carbon. Hence, the lubricating layer is not washed away. Thereby, the engine life is increased by 50%. 4. Due to the absence of carbon deposits on the electrodes of the spark plugs, the life of the spark plugs is increased. Disadvantages: 1. LPG reduces the volumetric efficiency due to its high heat of vaporization. 2. Handling has to be done under pressure of about 18 bars. 3. Its characteristics odor is faint, so leakage cannot be easily detected. 4. Response to blending is feeble. (6M) **(ii)Explain the performance and emission characteristics of using biodiesel in IC engine. (7M) [NOV/DEC2015]** BTL3 Engine performance with LPG: LPG (Di-tertiary-butyl peroxide) Higher thermal efficiency Better fuel economy Nox and smoke level reduced Engine performance with Bio diesel:2-8% of engine power losses measured with B-20 blends Diesel engine Co2 emission main reason for instigating the use of biodiesel Heating value of biodiesel < fossil fuel Engine performance with Ethanol: Alcohol fuel High quality and high engine performance Reduced emission Higher performance fuel and keeps high compression engines running smoothly Prevent anti freeze in winter (7M)
7	**Explain the principle of operation of an electrical vehicle with a neat sketch indicating its merits and demerits. (13M) [NOV/DEC2015] [APR/MAY2015] [MAY/JUNE2016]**BLT3 An electric vehicle, also called an EV, uses one or more electric motors or traction motors for propulsion. An electric vehicle may be powered through a collector system by electricity from off-vehicle sources, or may be self-contained with a battery, solar panels or an electric generator to convert fuel to electricity. EVs include, but are not limited to, road and rail vehicles, surface and underwater vessels, electric aircraft and electric spacecraft. EVs saw a resurgence due to technological developments, and an increased focus on renewable energy. A great deal of demand for electric vehicles developed and a small core of do-it-yourself (DIY) engineers began sharing technical details for doing electric vehicle conversions. Government incentives to increase adoptions were introduced, including in the United States and the European Union. (2M)

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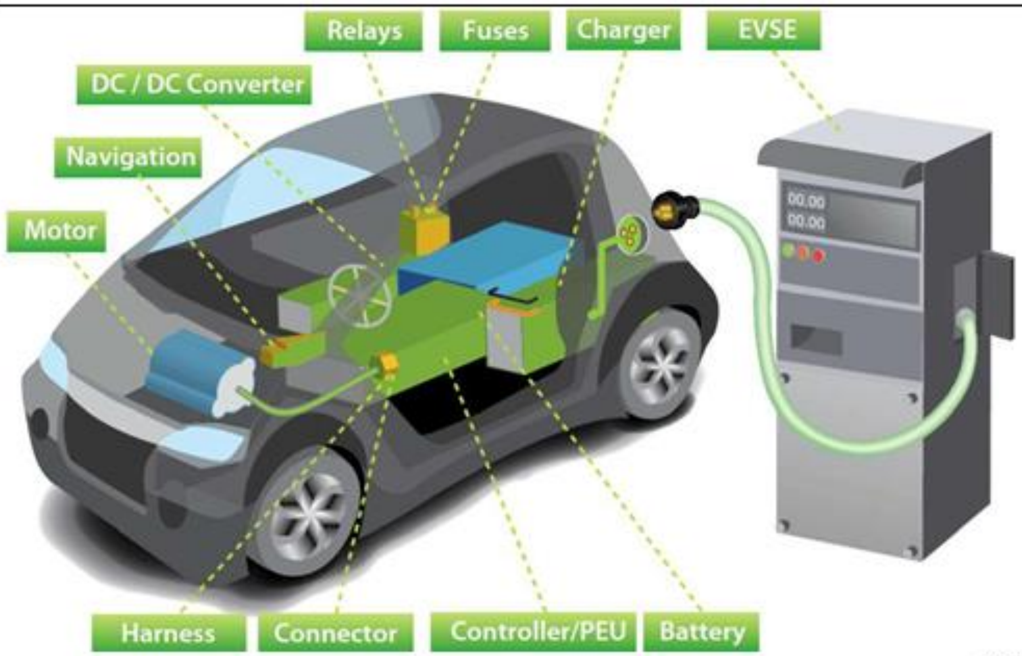

(2M)
Construction (2M)
Working (3M)
Merits (2M)
Demerits (2M)
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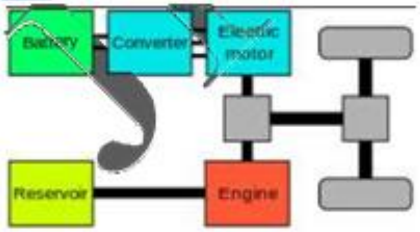
Explain the major components construction details and working of series and parallel types hybrid vehicles. (13 M) [NOV/DEC 14] [MAY/JUN 12] BLT3

Parallel hybrid systems have both an internal combustion engine and an electric motor that can both individually drive the car or both coupled up jointly giving drive.
Parallel hybrid systems have both an internal combustion engine and an electric motor that can both individually drive the car or both coupled up jointly giving drive. This is the most common hybrid system as of 2016.
If they are joined at an axis (in parallel), the speeds at this axis must be identical and the supplied torques add together. (Most electric bicycles are of this type.) When only one of the two sources is in use, the other must either also rotate (idle), be connected by a one-way clutch or freewheel. (3M)


(3M)
Construction (3M)
Working (4M)
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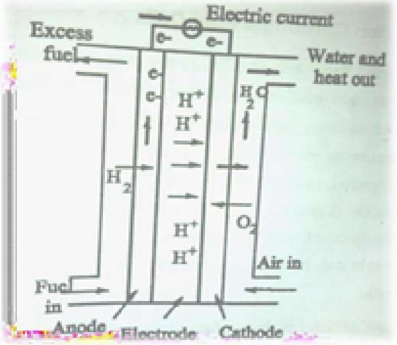
1	**With the simple sketch explain the construction and working principle of fuel cell. (15M) [NOV/DEC 13] [APR/MAY2015] [NOV/DEC 16] [NOV/DEC2015]**BTL3 - A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction of positively charged hydrogen irons with oxygen or another oxidizing agent. - Fuel cells are different from batteries in that they require a continuous source of fuel and oxygen or air to sustain the chemical reaction, whereas in a battery the chemicals present in the battery react with each other to generate an electromotive force (emf). - Fuel cells can produce electricity continuously for as long as these inputs are supplied. (2M)  (3M) Construction (5M) Working (5M)
2	**What is scope of green automobile in future? (15M)** (BTL5) - A green vehicle, or clean vehicle, or eco-friendly vehicle or environmentally friendly vehicle is a road motor vehicle that produces less harmful impacts to the environment than comparable conventional internal combustion engine vehicles running on gasoline or diesel, or one that uses certain alternative fuels. - Green vehicles can be powered by alternative fuels and advanced vehicle technologies and include hybrid electric vehicles, plug-in hybrid electric vehicles, battery electric vehicles, compressed-air vehicles, hydrogen and fuel-cell vehicles, neat ethanol vehicles, flexible-fuel vehicles, natural gas vehicles, clean diesel vehicles, and some sources also include vehicles using blends of biodieseland ethanol fuel or gasohol.(15M)
3	**Whether cryogenic engine can be used in automobile? Discuss about its advantages and disadvantages. (15 M)** BTL3 - Yes it's possible but no one is going to use that. In just basic sense the working of cryogenic engine and conventional engine is the same. The difference is that the fuel is

stored in cryogenic form that is oxygen and the fuel are stored in liquid form. The complexity of a cryogenic engine comes at handling this fuel and managing it till it reaches its combustion chamber.

- Now coming to engines used in roads as well as jet engines use oxygen from air so no need to store that(space programs doesn't have this luxury). Next is the fuel why do we need to store it in cryogenic form, space programs does this to reduce the volume of fuel stored in turn reduce the size. We have fuel stations along all the roads. So we can refuel anytime. So storing more in less space is irrelevant. If a time comes where the energy density of fuel is so low that we need so much of that fuel to run engines there is a chance we might use that. Actually what we do in case of CNG or LPG is theoretically the same but it doesn't reaches cryogenic temperature so no cryogenic engine. We store the LPG/CNG in liquified form to reduce the volume. If some cleaner fuels which needed to be stored cryogenically to use in vehicles come to exist, sure cryogenic engines will come to road.

Advantages

- Fuel density
- Cooling
- Power density
- Disadvantages
- Storage
- Production
- Health (15M)