JEPPIAAR INSTITUTE OF TECHNOLOGY
Self Belief | Self Discipline | Self Respect

QUESTION BANK

ACADEMIC YEAR : 2019-20

REGULATION: 2017

III YEAR – 05th SEMESTER

DEPARTMENT OF MECHANICAL ENGINEERING

BLOOM’S TAXONOMY

Definition:

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

TABLE OF CONTENT

ME8501 METROLOGY AND MEASUREMENTS L T P C
3 0 0 3

OBJECTIVES:

- To provide knowledge on various Metrological equipment available to measure the dimension of the components.
- To provide knowledge on the correct procedure to be adopted to measure the dimension of the components.

UNIT I . BASICS OF METROLOGY 5

Introduction to Metrology – Need – Elements – Work piece, Instruments – Persons – Environment – their effect on Precision and Accuracy – Errors – Errors in Measurements – Types – Control – Types of standards.

UNIT II LINEAR AND ANGULAR MEASUREMENTS 10

Linear Measuring Instruments – Evolution – Types – Classification – Limit gauges – gauge design – terminology – procedure – concepts of interchange ability and selective assembly – Angular measuring instruments – Types – Bevel protractor clinometers angle gauges, spirit levels sine bar – Angle alignment telescope – Autocollimator – Applications.

UNIT III ADVANCES IN METROLOGY 12

Basic concept of lasers Advantages of lasers – laser Interferometers – types – DC and AC Lasers interferometer – Applications – Straightness – Alignment. Basic concept of CMM – Types of CMM – Constructional features – Probes – Accessories – Software – Applications – Basic concepts of Machine Vision System – Element – Applications.

UNIT IV FORM MEASUREMENT 10

Principles and Methods of straightness – Flatness measurement – Thread measurement, gear measurement, surface finish measurement, Roundness measurement – Applications.

UNIT V MEASUREMENT OF POWER, FLOW AND TEMPERATURE 8

Force, torque, power - mechanical, Pneumatic, Hydraulic and Electrical type. Flow measurement: Venturimeter, Orifice meter, rotameter, pitot tube – Temperature: bimetallic strip, thermocouples, electrical resistance thermometer – Reliability and Calibration – Readability and Reliability.

TOTAL : 45 PERIODS

OUTCOMES:

- Upon completion of this course, the Students can demonstrate different measurement technologies and use of them in Industrial Components

TEXT BOOKS:

1. Jain R.K. "Engineering Metrology", Khanna Publishers, 2005.
2. Gupta. I.C., "Engineering Metrology", Dhanpatrai Publications, 2005.

REFERENCES:

1. Charles Reginald Shotbolt, "Metrology for Engineers", 5th edition, Cengage Learning EMEA, 1990.
2. Backwith, Marangoni, Lienhard, "Mechanical Measurements", Pearson Education, 2006.

REGULATION: 2017 **ACADEMIC YEAR: 2019-20**

Subject Code: ME8501 **Year/Semester: III /05**

Subject Name:Metrology & Measurements **Subject Handler: Mr.S.Arun/ Mr.D.Arun Kumar**

UNIT I –BASICS OF METROLOGY

Introduction to Metrology – Need – Elements – Work piece, Instruments – Persons – Environment – their effect on Precision and Accuracy – Errors – Errors in Measurements – Types – Control – Types of standards.

PART * A

Q.No.	Questions
1	**What is measurement? Give its types. (Dec 2011)** BTL2 Measurement is a process of comparing the input signal (unknown magnitude) with a pre-defined standard and giving out the result. Its types are: Direct comparison method, Indirect comparison method, Primary measurement, Secondary measurement and Tertiary measurement.
2	**Define Sensitivity. (Jun 2012, Dec 2012)** BTL1 Sensitivity may be defined as the following relation: Sensitivity = Change in the output signal / Change in the input signal
3	**Define readability. (Dec 2012)** BTL1 Readability is defined as the closeness with which the scale of an analog instrument can be read.
4	**Define tolerance and zero line. (Dec 2013)** BTL1 The basic dimension say 25 mm is the zero line. Any variation to this basic dimension is the tolerance towards upward or downward limits.
5	**Differentiate the terms reproducibility and repeatability.**BTL2 Reproducibility is the degree of closeness between measurements of the same quantity where the individual measurements are made under different conditions. Repeatability is the closeness between successive measurements of the same quantity with the same instrument by the same operator over a short time span.
6	**Define a measuring instrument. (Jun 2012)** BTL1 A measuring instrument is a device that has many components to perform a particular function. It is used to know about physical quantities such as length, weight, pressure, force etc.
7	**Differentiate static and dynamic response. (Dec2013)** BTL2 The behaviour of systems subjected to inputs that do not vary with time is termed as static response. The behaviour of systems subjected to dynamic inputs (continuously changing) is termed as dynamic response.
8	**Why instruments are to be calibrated? (June 2012)** BT2 Calibration is necessary to get meaningful results. In cases where sensing system and measuring system are different, it is then imperative to calibrate the system as an integrated whole to take into account the error producing properties of each component.
9	**Define calibration. (Dec 2014)** BTL1 Calibration is a set of operations that establish the relationship between the values that are indicated by the measuring instrument and the corresponding known value of a measurand.
10	**Define interchangeable system. (Dec2013)** BTL1 Interchangeability means ease of replacement in the event of failure. Any one component selected

at random should assemble correctly with any other mating component that too selected at random.

11 **Differentiate between sensitivity and range with suitable example. (Jun 2014)** BTL2

- Sensitivity is defined as the ratio of the change in output of the instrument to a change of input or measured variable. Units are mm/micro-ampere, counts, etc depending upon the type of input and output.
- Range is the minimum and maximum values of a quantity for which an instrument is designed to measure.

12 **What is Legal metrology? (Jun 2014)** BTL2

Legal metrology is that part of metrology which treats units of measurement, methods of measurement and measuring instruments, in relation to the statutory, technical and legal requirements. It assures security and appropriate accuracy of measurements.

13 **Write the difference between accuracy and precision. (Dec 2014)** BTL2

The closeness of the measured value with respect to the true value is called accuracy.
Precision refers to the ability of an instrument to reproduce its readings again and again in the same manner for a constant input signal.

14 **What is backlash?** BTL2

Backlash is the maximum distance through which one part of the instrument may be moved without disturbing the other part.

15 **What is hysteresis?** BTL2

Hysteresis is a phenomenon which depicts different output effects when loading and unloading whether it is a mechanical system or an electrical system and for that matter any system.

16 **What is frequency response?** BTL2

Frequency response is defined as the maximum frequency of the measured variable that the measurement system (instrument) is capable of following without error.

17 **What are analog and digital instruments?** BTL2

Signals that vary in a continuous fashion and take on an infinity of values in any given range are called analog signals and the devices which produce these signals are called analog devices. The signals which vary in discrete steps and thus take up only finite different values in a given range are called digital signals and the devices that produce such signals are called digital devices.

18 **What is meant by primary calibration?** BTL2

In primary calibration, a system is calibrated against a primary standard. While calibrating flow meter, if the flow is determined through measurement of time and volume or mass of fluid, then it termed as primary calibration.

19 **What is meant by secondary calibration?** BTL2

In Secondary calibration, a device that has been calibrated by primary calibration is used as a low meter is used as a secondary standard to calibrate other flow devices.

20 **What is a primary sensing element?** BTL2

The primary sensing element is the first element of a measurement system. This element takes energy from the measured medium and it produces an output depending on the measurand.

21 **Compare the terms range and span.** BTL4

S.No	Range	Span
1.	The region between which the instrument is to operate is called range. i.e. Range = L_c to H_c	Span is the algebraic difference between the higher calibration value and the lower calibration value. i.e. Span = H_c-L_c

2.	The range of thermometer is 0^oC to 100^oC	The span of thermometer is 100–0 = 100^oC

22 **What is traceability?** BTL2
Traceability is defined as the ability to trace the accuracy of a standard back to its ultimate source of standard.

23 **Define the term error.** BTL1
Error is the difference between the measured value (V_m) and the true value (V_t) of a physical quantity.
Error = $\pm$ (V_m-V_t), + => Positive error, - => Negative error.

24 **What is dynamic error?** BTL2
The difference between the changing value of the measured variable and the instrument reading is called dynamic error.

PART * B

1 **Give the structure of generalized measuring system and explain (13M) BTL3(Dec 2012, 2013)**
Answer: Page.1.9 -Dr.G.K.Vijayaraghavan

Block diagram (3M)

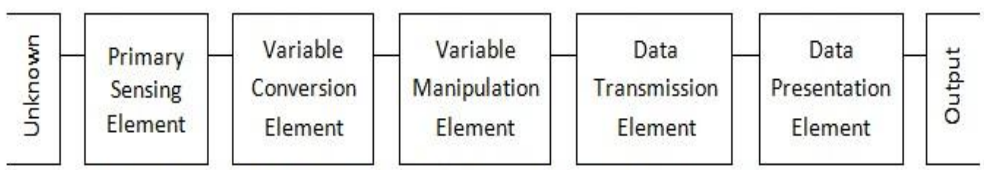


Figure: - Generalized or functional elements of an instrument system

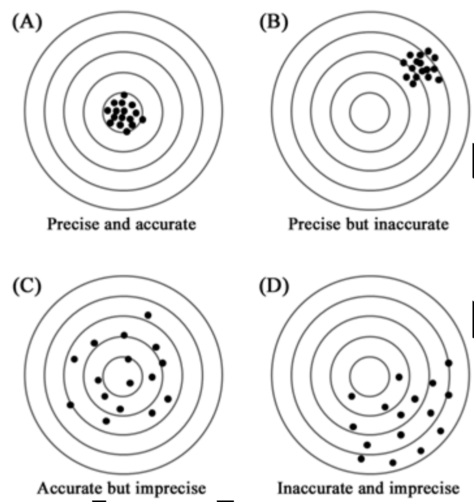
Elements of measurements (10M)
- Primary sensing element – receives - energy - measurand
- Variable conversion element – converts - one form - another form
- Variable manipulation element – amplifies – required- magnification
- Data transmission element – transmitsdata - one element - to other
- Data presentation element – communicates - information - to observer

2 **Describe briefly the different sources of errors in measurement.(13M**) BTL4 **(Jun, Dec 2013)**
Answer: Page.1.79 -Dr.G.K.Vijayaraghavan
Error = Measured value – True value (1M)
- True absolute error: Algebraic difference - result of measurement - time value of quantity measured. (2M)
- Apparent absolute error: Algebraic difference - one result- arithmetic mean. (2M)
- Relative error: algebraic difference - quotient of absolute error –apparent absolute error. (2M)

Classification of errors (6M)
- Static error
- Loading error
- Dynamic error

3 **Differentiate accuracy and precision. (13M)** BTL1**(Jun 2014)**
Answer: Page.1.27 -Dr.G.K.Vijayaraghavan
Accuracy vs precision (6M)

Precision	Accuracy
It is the repeatability of a measuring process	It is the agreement of result of a measurement with the true value of the measured quantity
It is a measure of the reproducibility of the measurement	It is the closeness with the true value of the quantity to be being measured
Precision cannot be improved	Accuracy can be improved
In measuring process importance given to Precision	Accuracy = Square root [(repeatability)^2+ (Systematic error)^2]



Pearson & Environment (5M)
- Effect of the observer
- Effect of environment

Calibration & Interchangeability definition ([illegible]M)
- Comparison – device value under test -calibration standard.
- Selection of components – assembly - random - fit - tolerances.

4	**Discuss about the various standards in metrology. (13M**) BTL2 **Answer: Page. 1.17 -Dr.G.K.Vijayaraghavan** ➢ International standards: Maintained - International bureau of weight - measurements - France (4M) ➢ Primary standards: National laboratories - various parts of world - maintains standard. (3M) ➢ Secondary standards:Regional laboratories - industrial measurement - standards. (3M) ➢ Working standards: Manufacturer – workers- standards.(3M)
	PART * C
1	**Define errors and explain the causes of those errors with suitable examples. (15M**) BTL4 **Answer: Page.1.79-Dr.G.K.Vijayaraghavan** Error = Measured value – True value (1M) ➢ True absolute error: Algebraic difference - result of measurement - time value of quantity measured. (2M) ➢ Apparent absolute error: Algebraic difference - one result- arithmetic mean. (2M) ➢ Relative error: algebraic difference - quotient of absolute error –apparent absolute error. (2M) **Classification of errors (8M)**

	➢ Static error ➢ Loading error ➢ Dynamic error
2	**Briefly discuss about the various static and dynamic characteristics of a measuring instruments.(15M)** BTL2 **Answer: Page. 1.43 -Dr.G.K.Vijayaraghavan** Static characteristics (8M) Characteristics – measurement - unvarying process conditions. ➢ Sensitivity ➢ Hysteresis ➢ Range ➢ Threshold ➢ Linearity ➢ Repeatability ➢ Reproducibility Dynamic characteristics (7M) Behaviors of an instrument - time varying input – output conditions. ➢ Response time ➢ Dead band ➢ Zero drift ➢ Resolution
3	**Discuss about the various methods of measurement.(15M)** BTL2 **Answer: Page. 1.5 -Dr.G.K.Vijayaraghavan** ➢ Contact & contactless methods (e.g.: projection comparator) ➢ Coincidence method (e.g.: measurement of length by Vernier caliper) ➢ Fundamental method (e.g.: base quantity define the quantity – pressure from density) ➢ Comparison method (e.g.: function of quantity – pressure: bourdon tube) ➢ Substitution method (e.g.: indicating device – temperature: thermometer) ➢ Transposition method (e.g.: measurement of mass by gauss double weighing method) ➢ Differential method (e.g.: determination of diameter with master cylinder on a comparator) ➢ Null method (e.g.: measurement of electrical resistance using Wheatstone bridge - null indicator) ➢ Deflection method (e.g.: measurement of length by dial indicator) ➢ Complementary method (e.g.: determination of volume by liquid displacement)

UNIT II–LINEAR AND ANGULAR MEASUREMENTS

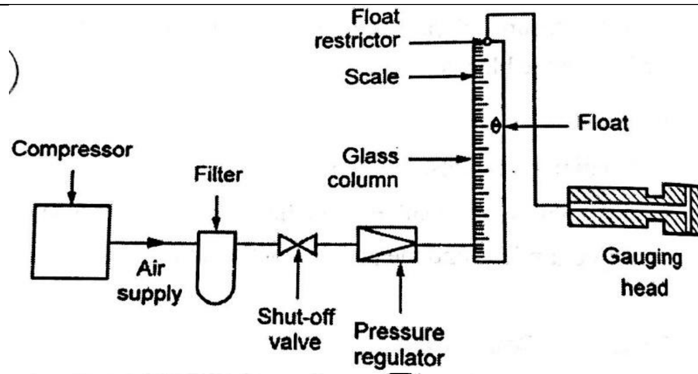
Linear Measuring Instruments – Evolution – Types – Classification – Limit gauges – gauge design – terminology – procedure – concepts of interchange ability and selective assembly – Angular measuring instruments – Types – Bevel protractor clinometers angle gauges, spirit levels sine bar – Angle alignment telescope – Autocollimator – Applications.

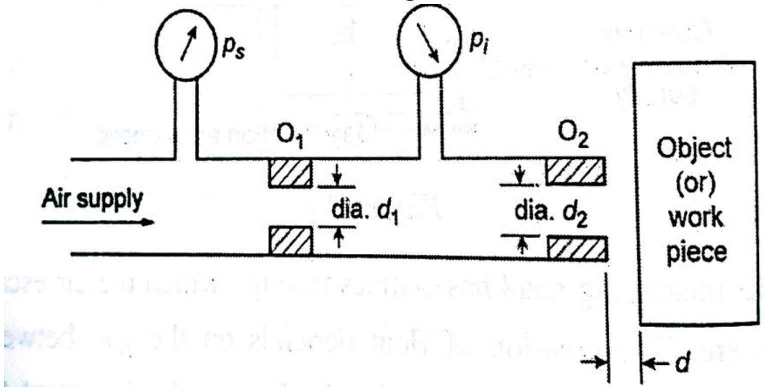
PART * A

Q.No.	Questions
1	**What are the possible sources of errors in micrometer?** BTL2 The following are some of the possible sources of errors in micrometer: ➢ Lack of flatness of the anvil

	➢ Lack of parallelism of the anvils at some, or all parts of the scale ➢ Inaccurate setting of the zero reading ➢ Inaccurate readings following the zero position and ➢ Inaccurate readings shown by the fractional divisions on the thimble.
2	**Define interferometry.** BTL1 Interferometry is a field of science used to measure the surface nature by using light wave interference.
3	**Mention the various light sources for interferometry.** BTL2 Mercury, cadmium, krypton, thallium, sodium, helium, neon and gas lasers.
4	**Define optical flat.** BTL1 An optical flat is a circular piece of optical glass or fused quartz having its two plane faces flat and parallel and the surfaces are finished to an optical degree of flatness.
5	**How will you wring two slip gauges?** BTL2 The wringing of slip gauges are accomplished by pressing their faces into contact and then imparting a small twisting motion whilst maintaining the contact pressure. The contact pressure is just sufficient to hold the two slip gauges in contact and no additional internal pressure.
6	**Mention the applications of interferometry.** BTL2 Surface flatness testing, surface contour testing, testing the parallelism of any surface with reference to a standard optically flat surface are some of the applications of interferometry.
7	**Define comparators. (Dec 12, June 13)** BTL1 Comparators are the measuring instruments which give only dimensional differences in relation to a basic dimension. It can compare the unknown dimensions of a part with some standard or master setting.
8	**Mention the various types of comparators available.** BTL2 Mechanical comparators, mechanical-optical comparators, electrical and electronic comparators, pneumatic comparators, fluid displacement comparators, projection comparators, multi-check comparators and automatic gauging machines.
9	**Mention the various applications of comparators.** BTL2 The following are some of the ways in which the comparators used: ➢ In mass production, where components are to be checked at a very fast rate. ➢ As laboratory standards from which working or inspection gauges are set and correlated. ➢ For inspecting newly purchased measuring gauges and ➢ Comparators can be used as working gauges to prevent work spoilage and to maintain required tolerances at all stages of manufacturing by attaching with the machines.
10	**Define sine principle of measuring angles.** BTL1 The sine principle of measuring angles is the angle included between two line is given by the sin^{-1} term of the ratio between the opposite side and the hypotenuse of a right triangle.
11	**Define sine bar and mention its limitation.** BTL1 Sine bar is an angular measuring device working on the sine principle. The devices operating on sine principle are capable of ‘self-generation’. So the measurement is usually limited to 45^0 from loss of accuracy point of view.
12	**Differentiate between sine bar and sine centre. (June 13)** BTL2 Sine bar is used for locating any work to a given angle and to change unknown angle. The conical work is difficult to mount on sine bars, to overcome this sine centre is used. In this two blocks are mounted on top surface of sine bar at each end, these block have centers and can be clamped at any position.

13	**Why the sine bars are impractical and inaccurate as the angle exceeds 45^0?** BTL4 The sine bars are impractical and inaccurate as the angle exceeds 45^0, because of the following reasons: ➢ The sine bar is physically clumsy to hold in position. ➢ The body of the sine bar obstructs the gauge block stack even if relieved. ➢ Slight errors of the sine bar cause large angular errors. ➢ Long gauge stacks are not nearly as accurate as when compared with shorter gauge blocks. ➢ Temperature variation affects the accuracy.
14	**Define angle decker.**BTL1 Angle decker is an optical instrument used for the measurement of small angular differences, changes or deflection, plane surface inspection etc.
15	**State the various uses of angle decker.**BTL2 The angle decker is used in the measurement of angle of a component ➢ Checking the slope angle of a V-block ➢ Measurement of angle of cone or taper gauge and ➢ Precise angular setting of machines for operations.
16	**What is the constructional difference between an autocollimator and an angle decker?**BTL2 The illuminated target used in the auto collimator is replaced by an illuminated scale on a glass screen which is set in the focal plane of the objective lens.
17	**Write the constructional requirements of the sine bar for accurate measurement. (Dec 2014)** BTL2 ➢ The rollers must have equal diameter and equal cylinders. ➢ The rollers must be placed parallel to each other and also to the upper face. ➢ The accurate center to center of rollers must be known. ➢ The top surface of the bar must be flat with high degree of accuracy.
18	**Write the difference between comparator and measuring instrument. (Dec 2014)** BTL5 Comparators are the measuring instruments which give only dimensional differences in relation to a basic dimension. It can compare the unknown dimensions of a part with some standard or master setting. E.g. Dial gauge used as mechanical comparator. Measuring instruments are measuring devices that transform the measured quantity or a related quantity into an indication or information. E.g. Equal arm balance.
19	**State the working principle of an electronic comparator. (Jun 2014)** BTL2 In an electronic comparator, transducer induction or the principle of application of frequency modulation or radio oscillation is followed.
20	**What are the advantages of electrical and electronic comparator? (Jun 2014)** BTL2 ➢ It has less number of moving parts. ➢ Magnification obtained is very high. ➢ Two or more magnifications are provided in the same instrument to use various ranges. ➢ The pointer is made very light so that it is more sensitive to vibration.
	PART * B
1	**Explain with a schematic sketch the working of pneumatic comparator. (13M)** BTL2 **Answer: Page. 2.55- Dr.G.K.Vijayaraghavan** **Diagram** (6M)





Construction & Working (7M)

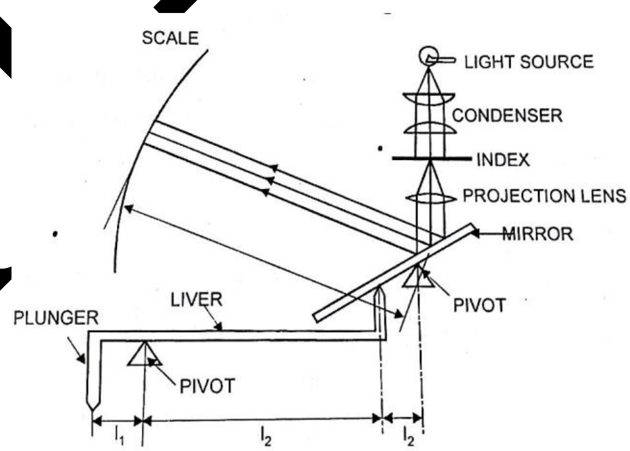
- Velocity or flow type – compressor – float – gauging head – pressure regulator.
- Back pressure type –supplied pressure – inlet pressure – orifice – distance b/w orifice & object.

2

Discuss about the construction &working of optical comparators. (13M) BTL2

Answer: Page. 2.49 - Dr.G.K.Vijayaraghavan

Diagram (6M)



Construction & working (7M)

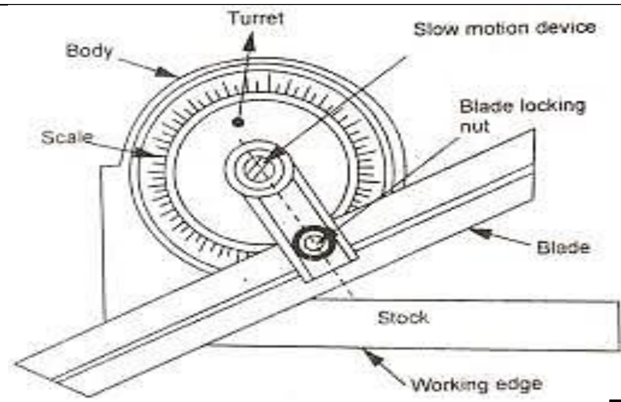
Plunger movement – mirror deflection (Ɵ) – angle of deflection (2Ɵ) – angle of reflection – light source.

3

Explain the construction and working of bevel protractor. (13M) BTL2

Answer: Page. 2.95 - Dr.G.K.Vijayaraghavan

Diagram (5M)



Working principle (6M)

Angle measuring instrument – base plate – adjustable blade – Vernier scale – main scale graduated in degrees.

Applications: flatness- parallelism – V block angle – acute angle – checking inside beveled face. (2M)

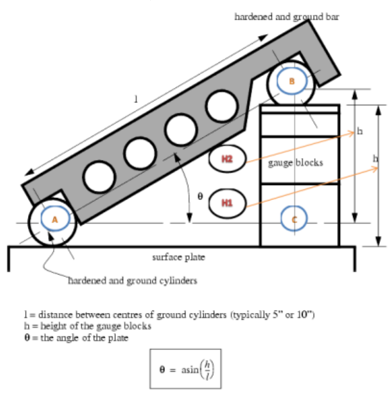
4 **Explain the use of sine bar. (13M)**BTL2

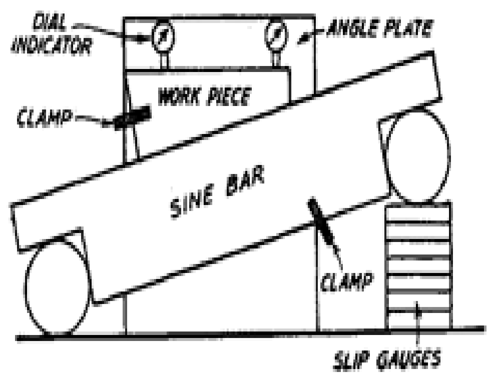
Answer: Page. 2.103 - Dr.G.K.Vijayaraghavan

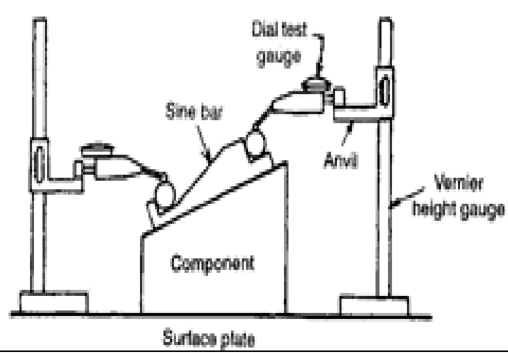
Applications (3M)

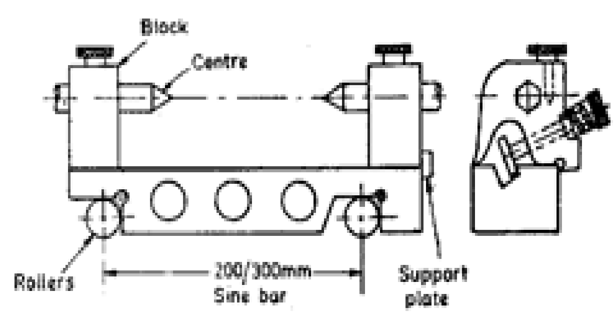
- Locating work at given angle.
- To check unknown angles.
- Measurement of unknown angle for heavier components.
- Sine centre

Diagram (3M + 3M + 4M)





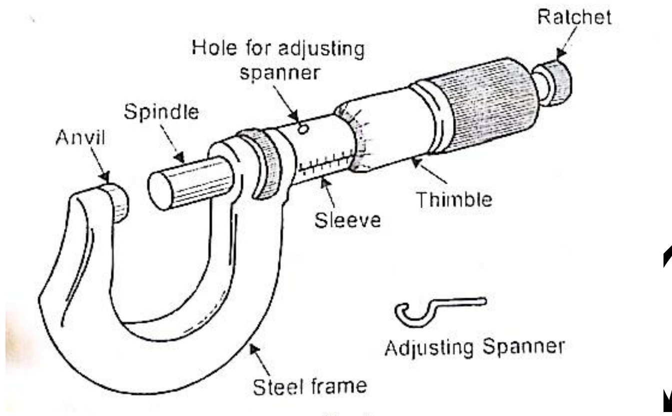


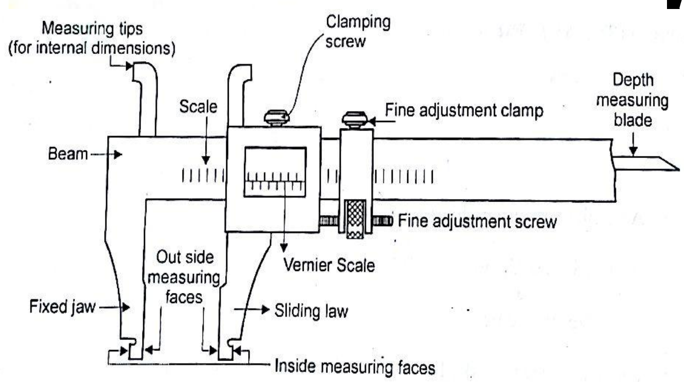


5 **Briefly discuss about the Vernier caliper and micrometer. (13M)**BTL2

Answer: Page. 2.5 & 2.15 - Dr.G.K.Vijayaraghavan

Diagram (4M + 3M)





Construction & working (3M + 3M)

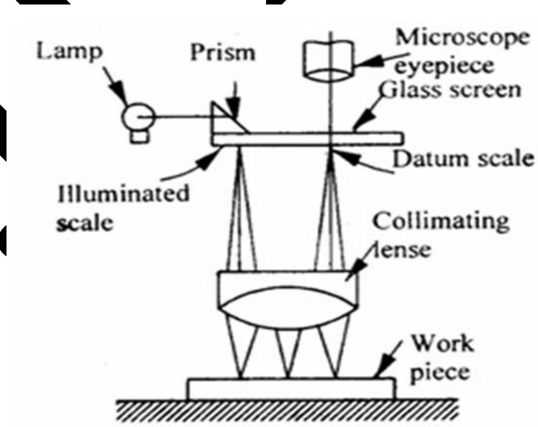
- Micrometer – least count 0.02 mm – main scale division – Vernier scale division – fixed jaw – adjustable jaw – depth measuring blade.
- Vernier Caliper – least count 0.0[illegible] mm – spindle – sleeve – ratchet – thimble.

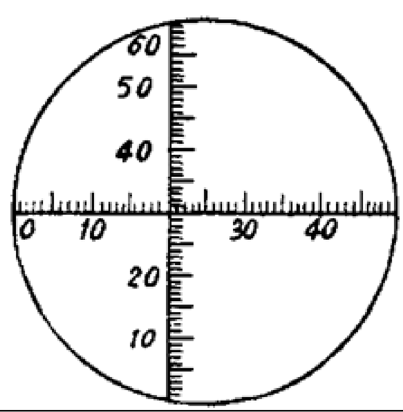
PART * C

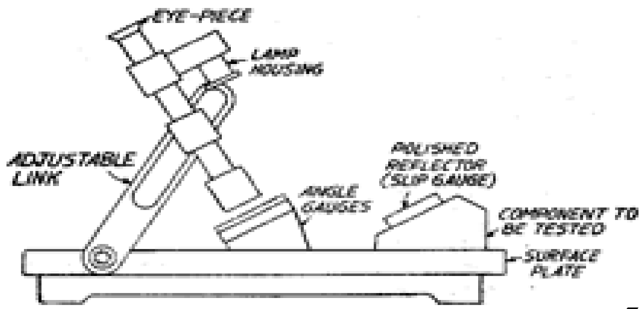
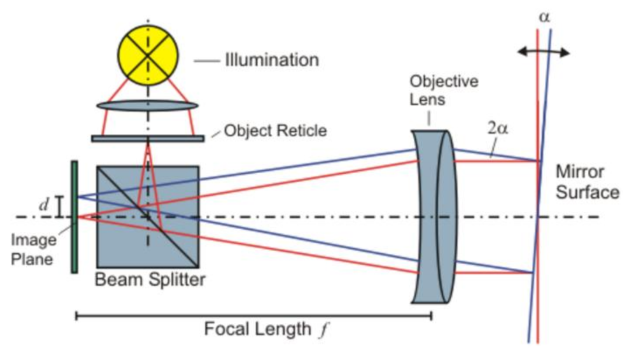
1 **Explain the working principle of Angle Dekkor and how the job of angle $43^0 24'12''$ is checked.(15M)** BTL5

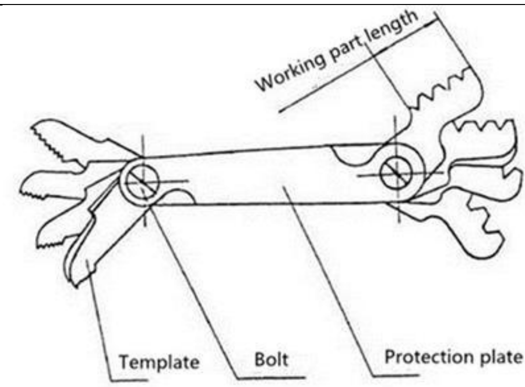
Answer: Page. 2.118 - Dr.G[illegible] Vijayaraghavan

Diagram (8M)

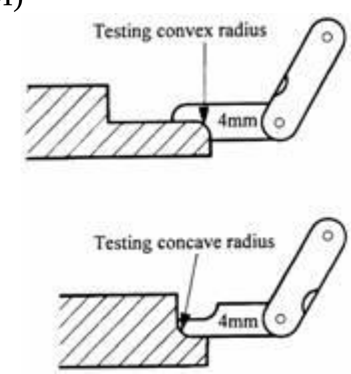




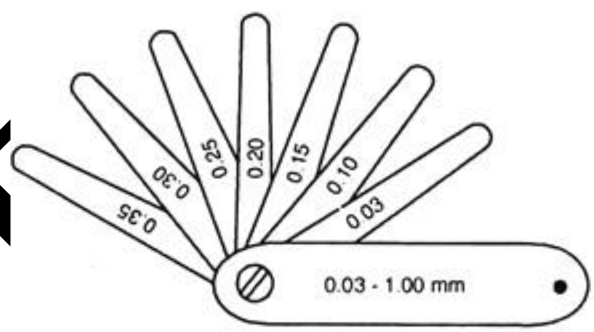
	 **Working principle** (5M) Illuminated scale – focal plane – parallel beams – angular errors – adjustable brackets. **Applications:** slope angle of V-block – angle of a component – angle of cone – taper gauge. (2M)
2	**Briefly discuss about the working principle of autocollimator with a neat sketch. (15M)**BTL3 **Answer: Page. 2.115 - Dr.G.K.Vijayaraghavan** **Working principle** (2M) $x = 2\theta f$ where, f = focal length of the lens Θ = fitted angle of reflecting mirror **Diagram** (6M)  **Construction & working** (5M) Micrometer microscope – lighting unit – collimating lens – calibrating polygons – checking angular index – small linear displacements – sensitive, accurate approach. **Applications:** angular difference – small displacements – plane surface inspection. (2M)
3	**Briefly discuss about the various applications of limit gauges. (15M)**BTL4 **Answer: Page. 2.86 - Dr.G.K.Vijayaraghavan** Purpose of limit gauge: inspecting gauges – plug gauge – ring gauge – snap gauge. (2M) **Applications with diagrams** ➢ Thread gauge& screw pitch gauge (3M)



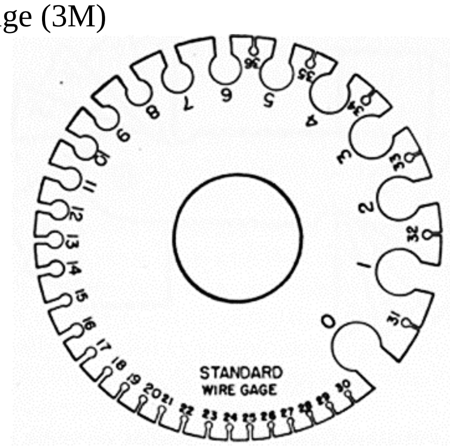
- Radius and fillet gauge (2M)



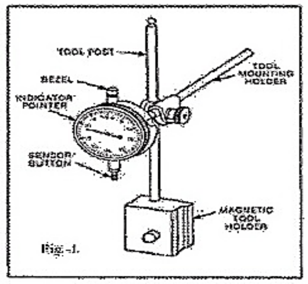
- Feeler gauge (2M)

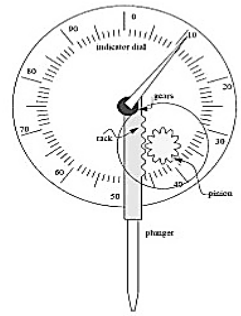


- Plate gauge [illegible] wire gauge (3M)



- Indicating gauge (3M)





UNIT III–ADVANCES IN METROLOGY

Basic concept of lasers Advantages of lasers – laser Interferometers – types – DC and AC Lasers interferometer – Applications – Straightness – Alignment. Basic concept of CMM – Types of CMM – Constructional features – Probes – Accessories – Software – Applications – Basic concepts of Machine Vision System – Element – Applications.

PART * A

Q.No.	Questions
1	**Define laser and laser instrument.** BTL1 Laser is the acronym of Light Amplification by Stimulated Emission of Radiation. Laser instrument is a device which produces powerful, monochromatic, collimated beam of light. The waves in the beam of light are coherent.
2	**Name the various optical elements used in laser interferometry.** BTL2 The following are some of the optical elements used in laser interferometry: ➢ Beam splitter ➢ Beam benders ➢ Retro reflectors.
3	**State the principle of laser.** BTL1 When the photon comes from higher energy level to lower energy level, it releases another photon. The sequence of triggered identical photon from stimulated atom is known as stimulated emission. This multiplication of photon through stimulated emission leads to coherent, powerful, monochromatic, collimated beam of light emission. This light emission is called laser.
4	**State the advantages of coherent light.** BTL2 The advantage of coherent light is that whole of the energy appears to be emanating from a very small sharp point and the beam can be focused into either a parallel beam or onto a very small point by using lenses.
5	**Mention the various components present in the laser interferometry.** BTL2 The various components present in the laser interferometry are two frequency laser source, optical elements, laser head's measurement receiver and measurement display.
6	**Briefly explain two frequency laser source.** BTL2 Normally He-Ne type generates stable coherent light beam of two frequencies with one polarized vertically and another horizontally relative to the plane of the mounting feet. This laser oscillates at two slightly different frequencies by a permanent magnet of cylindrical shape around the cavity. The two components of frequencies are distinguishable by their opposite circular

	polarization.
7	**Mention the applications of two frequency laser interferometer.** BTL3 Two frequency laser interferometer is used to measure displacement, high precision measurements of length, angle, speed and refractive indicies as well as derived static and dynamic quantities.
8	**Define concentricity.** BTL1 Concentricity is defined as the matching of components like hollow shafts and spindles in a same line of operation or in a single centre.
9	**Define axial slip of a machine tool.** BTL1 Axial slip of a machine tool is defined as the axial movement of the spindle which follows the same pattern and is due to the manufacturing error.
10	**Distinguish between coordinate and conventional metrology.** BTL4 In coordinate metrology, the linear dimensions in three coordinates are carried out by using the machines. In conventional metrology, it is not possible to carry out the linear measurements in three coordinates.
11	**What do you mean by the alignment test on a machine tool?** BTL2 The alignment test on a machine tool is carried out to check the grade of manufacturing accuracy of the machine tool.
12	**Mention the various geometrical checks made on machine tools. (Jun 2014)** BTL2 The geometrical checks made on machine tools are : ➢ Straightness and flatness of guide ways and slide ways of machine tool. ➢ Flatness of machine tables ➢ Parallelism, equidistance and alignment of the slide ways. ➢ True running and alignment of shaft and spindle. ➢ Lead of lead screw or error in pitch.
13	**Differentiate geometrical test and practical test on a machine tool.** BTL4 ➢ The geometrical test is carried out to check the grade of manufacturing accuracy of the machine tool. ➢ Practical test is carried out to check the accuracy of the finished component. ➢ Geometrical test consists of checking the relationship between various machine elements when the machine tool is idle. ➢ Practical test consists of preparing the actual test jobs on the machine and checking the accuracy of the jobs produced.
14	**Mention the various types of measuring machines.** BTL2 Measuring machines are classified as: ➢ Length bar measuring machine ➢ Newall measuring machine ➢ Universal measuring machine ➢ Coordinate measuring machine and ➢ Computer controlled coordinate measuring machine.
15	**What is CMM?** BTL2 CMM stands for Coordinate Measuring Machine and it measures the linear dimensions in three coordinates for various components. These machines have precise movement in X, Y and Z coordinates which can be easily controlled and measured. Slide in each direction is equipped with a precision linear measurement transducer which gives digital display and senses positive and negative directions.

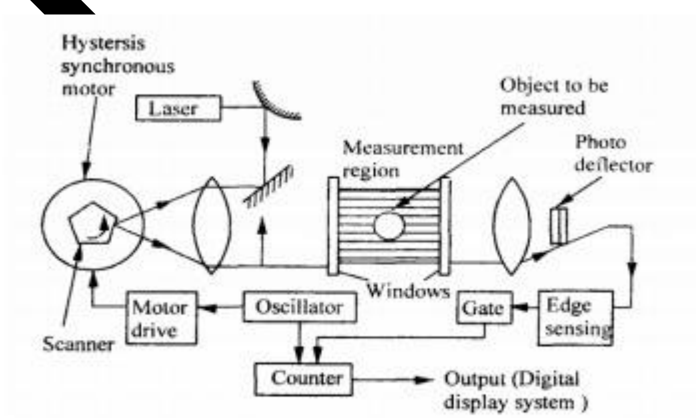
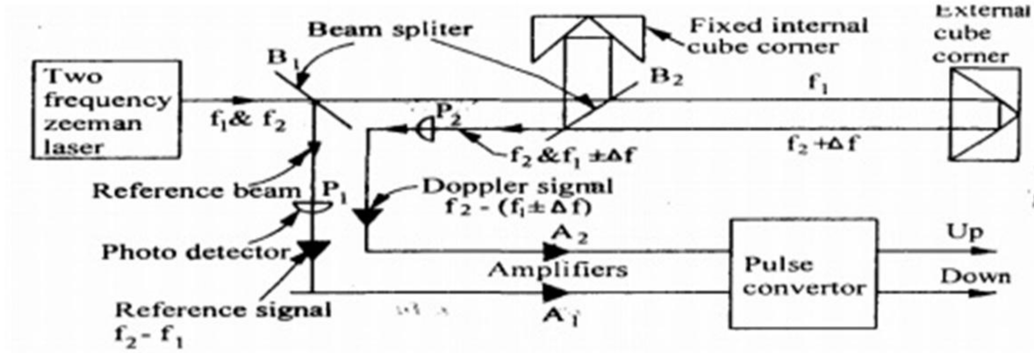
16	**Define position accuracy. (Dec 2012)** BTL1 Position accuracy is defined as the difference between the positions read out of machine along an individual axis and value of a reference length measuring system. Position accuracies in X, Y and Z axis are measured and these three are needed for position accuracy.
17	**Define machine vision (Computer vision or Intelligent vision). (Dec 2012, Jun 2014)** BTL1 Machine vision is defined as the means simulating the image recognition and analyse the capabilities of the human system with electronic and electromechanical techniques.
18	**What are the advantages of machine vision system?** BTL2 The advantages of machine vision system are: ➢ Reduction of tooling and fixture cash ➢ Elimination of precise part location ➢ Detection of defect ➢ Dimensional verification of integrated automation.
19	**What are the advantages of Laser in interferometry? (Dec 2014)** BTL2 Laser provides a source of coherence and truly monochromatic light. The property of clearance enables it to be projected in a narrow pencil of beam without any scatter.
20	**Write the features of CMM. (Dec 2014)** BTL2 ➢ In faster machines with higher accuracies, the stiffness to weight ratio has to be high in order to reduce dynamic forces. ➢ All the moving members, the bridge structure Z-axis carriage and Z-column are made of hollow box construction. ➢ Errors in machine are built up and fed into the computer system so that error compensation is built up into the software. ➢ All machines are provided with their own computers and the CMM is able to measure three-dimensional object from the variable datums.
	PART * B
1	**Explain the construction and measuring principle of Laser Telemetric System.(13M)** BTL2 **Answer: Page. 3.3[illegible] - Dr.G.K.Vijayaraghavan** Diagram (6M)  Construction & working (7M) Transmitter – receiver – processor electronics – collimating lens – helium neon gas – reflector prism – synchronous motor.
2	**With a neat sketch explain the working of AC laser interferometer. (13M)** BTL2 **Answer: Page. 3.17 - Dr.G.K.Vijayaraghavan**

Diagram (6M)



Construction & working (7M)

Two frequency Zeeman laser – beam splitter – internal cube corner – external cube corner – photo detector – amplifier – pulse converter.

3

State the possible sources of errors in CMM. (13M) BTL

Answer: Page. 3.47 - Dr.G.K.Vijayaraghavan

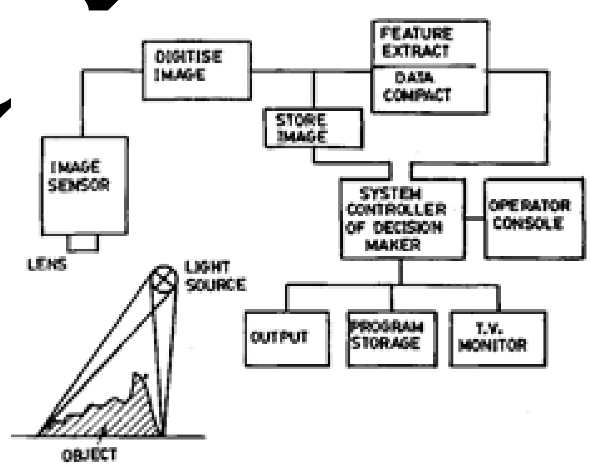
- Perfect geometrics (1M)
- Probes – degree run out (1M)
- Perpendicularity error (1M)
- Dimensional error – scale division – probe structure – strainghtness – interpolation – data feeding – environment. (3M)
- Smoke particle – finger print – dust particle – human hair. (1M)
- Temperature variation. (1M)
- Translational error. (1M)
- Specimen weight. (1M)
- Surface finish. (1M)
- Measuring software. (1M)
- Probe deflection (1M)

4

Explain in detail the operation of a machine vision system. (13M) BTL2

Answer: Page. 3.65 - Dr.G.K.Vijayaraghavan

Block Diagram (6M)



Elements of machine vision (4M)

Image formation – processing of image – analyzing image – interpretation of image.

Applications (3M)

- Inspection – recognize pattern – raw materials – parts – assemblies.
- Part identification – decision making – part recognition.
- Guidance control – feedback – time – industrial robots – geometric off set.

5

Explain the various geometrical tests that are to be done to get a better accuracy in the machine tool.(13M) BTL3

Answer: Page. 3.27-Dr.G.K.Vijayaraghavan

- Geometrical test: static – dynamic – dimension – position – displacement. (3M)
- Practical test – fundamental purpose (2M)
- Straightness, flatness, parallelism, squareness of straight line, movement of all working components (5M)
- Rotations – out of round – eccentricity – runout - camming, spindle test – concentricity – axial slip – axis position. (3M)

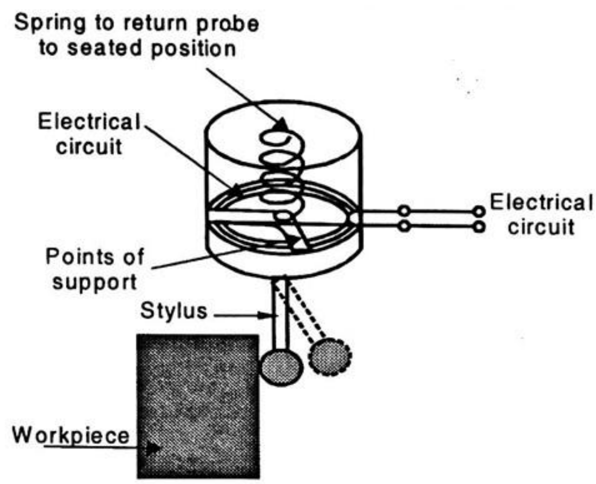
PART * C

1

List out the various probes used in CMM and explain the working principle of touch trigger probe. (15M) BTL2

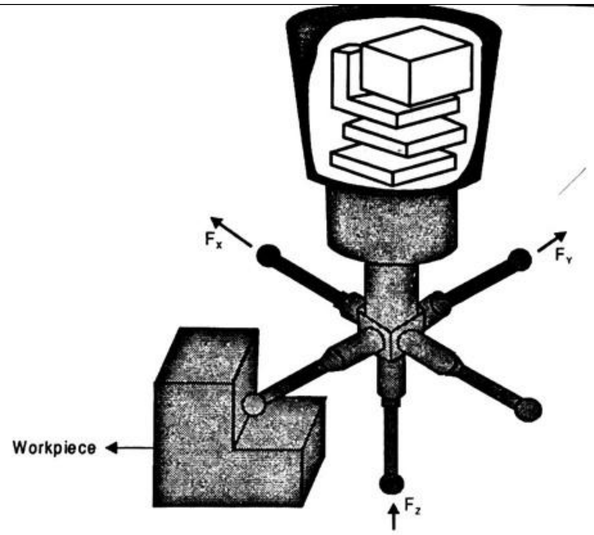
Answer: Page. 3.55 - Dr.G.K.Vijayaraghavan

Trigger type probe system (4M)



Buckling mechanism – electrical micro switches – pulse generation – point bearing – prestressed force (4M)

Measuring type probe system (4M)



Parallel guide – spring parallelograms – parallel displacement – electronic position – error correction (3M)

2

With neat sketch explain the various types of CMM based on its construction. (15M) BTL2

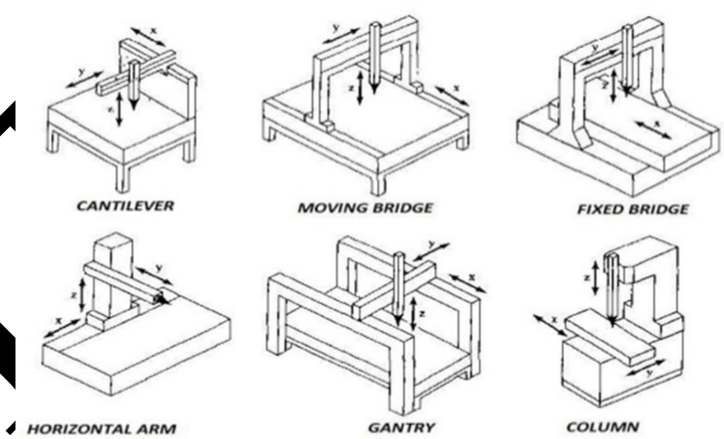
Answer: Page. 3.44 - Dr.G.K.Vijayaraghavan

Cantilever type – easy to load – unload – deflection in y axis. (1M)

Bridge type – difficult to load – floating bridge – y direction slide – fixed type – moving type. (2M)

Boring mill type – heavy work pieces – horizontal type – vertical type – automatic recording – data processing unit.(4M)

Diagram (8M)



3

Describe the use of Lasers as a means of alignment testing (or) Discuss the testing of machine tools using interferometer. (15M) BTL3

Answer: Page. 3.28 - Dr.G.K.Vijayaraghavan

Alignment tests on lathe (8M)

- ➢ Levelling.
- ➢ True running - main spindle – head stock.
- ➢ Parallelism of main spindle to saddle movement.
- ➢ True running of taper socket in main spindle.
- ➢ Movement of upper slide parallel with main spindle.
- ➢ Parallelism of tailstock guide ways with movement of carriage.

	➢ Parallelism of tailstock sleeve taper socket to saddle movement. ➢ Pitch accuracy of lead screw. Alignment test on milling machine (7M) ➢ Cutter spindle axial slip. ➢ Eccentricity of external diameter. ➢ True running of internal taper. ➢ Surface parallel with longitudinal movement. ➢ Traverse movement parallel with spindle axis. ➢ Centre T-slot square with arbor. ➢ Tests on column.

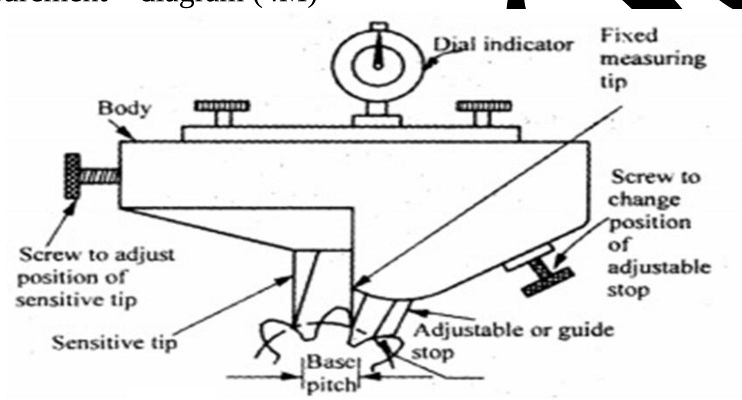
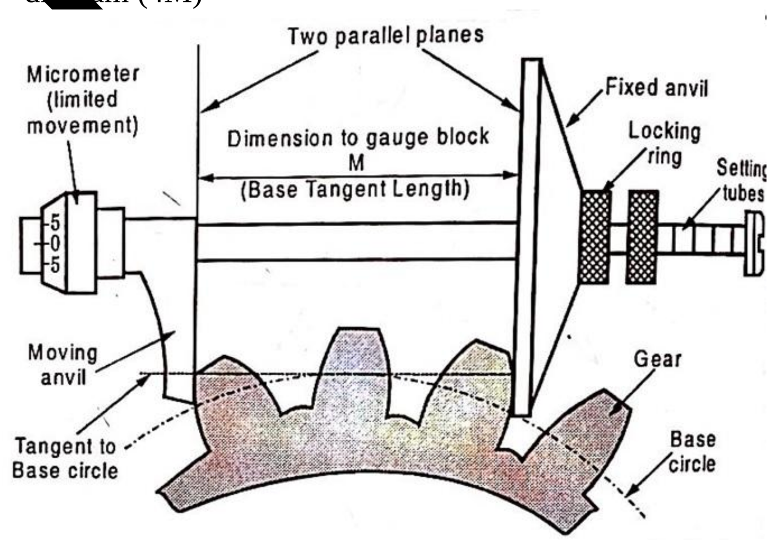
UNIT IV–FORM MEASUREMENTS

Principles and Methods of straightness – Flatness measurement – Thread measurement, gear measurement, surface finish measurement, Roundness measurement – Applications.

PART * A

Q.No.	Questions
1	**Mention the various terminologies of a screw thread.** BTL2 Screw thread, crest, flank, root, lead, pitch, helix angle, flank angle, depth of thread, included angle, major diameter, minor diameter, addendum and dedendum are some of the screw thread terminologies.
2	**List out the various forms of thread gauges.** BTL2 Thread gauges are classified as: ➢ Plug screw gauge ➢ Ring screw gauge and ➢ Caliper gauge
3	**What do you mean by lead angle? (Dec 2013)** BTL2 Lead angle is the angle between the tangent to the helix and the plane perpendicular to the axis of cylinder.
4	**Mention the various methods used for measuring the gear tooth thickness. (Jun 2014)** BTL2 To measure the gear tooth thickness, the methods used are: ➢ Gear tooth vernier ➢ Base tangent method ➢ Constant chord method and ➢ Measurement over pins or balls.
5	**Define backlash.** BTL1 Backlash is the distance through which a gear can be rotated to bring its non-working flank in contact with the teeth of mating gear.
6	**A spur gear of 4 mm module has 60 teeth. Calculate the pitch circle diameter and base pitch for pressure angle of 20^0.** BTL5 Pitch circle diameter = Module x number of teeth = 4 x 60 = 240 mm. Base pitch = Module x π cos(pressure angle) = 4πcos(20) = 11.7 mm
7	**Write the formula used for measuring the radius of the circle.** BTL3 Radius of the circle $R = [(l - d)^2] / 8d$ Where, R = Radius of the circle; l = Distance between the balls; d = diameter of pins.

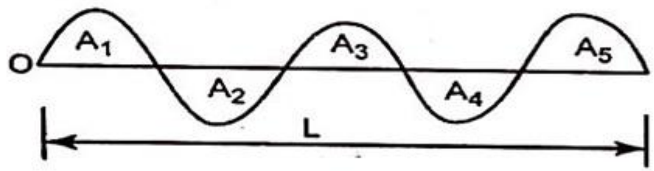
8	**Define constant chord.**BTL1 Constant chord is defined as the chord joining the points which are on the opposite faces of the tooth.
9	**What are the various factors affecting surface roughness?**BTL4 The surface roughness is affected by: ➢ Work piece material ➢ Vibrations of the work and machine ➢ Method of machining and ➢ Type of tool and fixtures used.
10	**How will you measure the pitch diameter of a screw thread?**BTL4 The pitch diameter of a screw thread can be measured by using the following methods: ➢ Pitch measuring machine ➢ Tool makers microscope and ➢ Screw pitch gauge.
11	**What is best size of wire?**BTL2 Best size of wire is the diameter of the wire in such a way that it makes contact with the flanks of the thread on the pitch line.
12	**State the applications of tool maker's microscope.**BTL2 Tool maker's microscope is used to ➢ Measure the linear dimension ➢ Measure the pitch of a screw ➢ Measure the thread angle ➢ Compare the thread forms ➢ Measure the centre to centre distance.
13	**Define Drunken thread error.**BTL1 In any screw thread if the thread is not cut to the true helix then the Drunken thread error will form. The thread is having erratic pitch in which the advance of helix is not regular in one complete turn of the thread.
14	**Define degree of fullness in form factor.**BTL1 Degree of fullness is defined as the ratio between the area of metal present and the area of the enveloping portion.
15	**Define degree of emptiness in form factor. (Dec 2013)**BTL1 Degree of emptiness is defined as the ratio between the area of empty space and the total area of the enveloping portion.
16	**Name the various devices used for the measurement of roundness.**BTL2 The roundness is measured by, ➢ Diametral gauge, ➢ Circumferential conferring gauge ➢ Rotating on centre, ➢ Three point probe and ➢ Accurate spindle.
17	**Name the four reference circles used in measurement of roundness. (Dec 2014)**BTL2 ➢ Least squares circle ➢ Minimum zone or minimum radial separation circles ➢ Maximum inscribed circle and ➢ Minimum circumscribed circle

18	**What do you mean by roundness?** BTL2 Roundness is defined as a condition of a surface of revolution where all the surfaces intersected by any plane perpendicular to a common axis in case of cylinder and cone.
19	**What is straightness of a line in two planes? (Jun 2014)**BTL2 A line is said to be straight over a given length if the variation of the distance between the two points on the two planes perpendicular to each other and parallel to the direction of a line remaining within the specified tolerance limits.
20	**What is the effect of flank angle error?**BTL4 Flank angle error causes a virtual increase in the effective diameter of a bolt and decrease in the effective diameter of the nut.
	PART * B
1	**Discuss about tooth to tooth measurement and base tangent methods of gears. (13M)**BTL2 **Answer: Page. 4.54& 4.57-Dr.G.K.Vijayaraghavan** Tooth to tooth measurement – diagram (4M)  Working: fixed tip – sensitive tip – guide stop – dial indicator – base pitch. (3M) Gear tooth Vernier – diagram (4M)  Working: micrometer – fixed anvil – moving anvil – adjusting locking – setting tubes. (3M)
2	**Discuss in detail about comparison methods used for measuring surface finish. (13M)**BTL4

Answer: Page. 4.76 - Dr.G.K.Vijayaraghavan

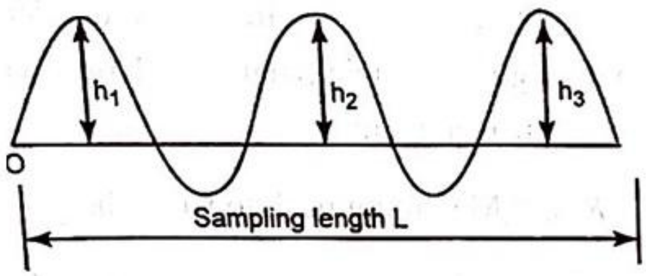
Average roughness method:

- Centre line average method (2M)



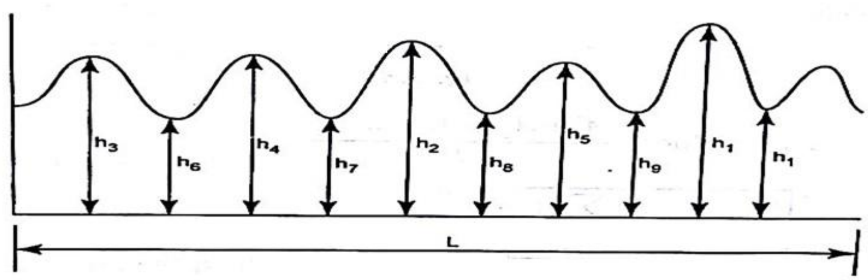
- Root mean square method (2M)

$$C.L.A = \frac{\sum A}{L}$$



$$R.M.S.\,average = \sqrt{\frac{h_1^2 + h_2^2 + h_3^2 + \cdots + h_n^2}{n}}$$

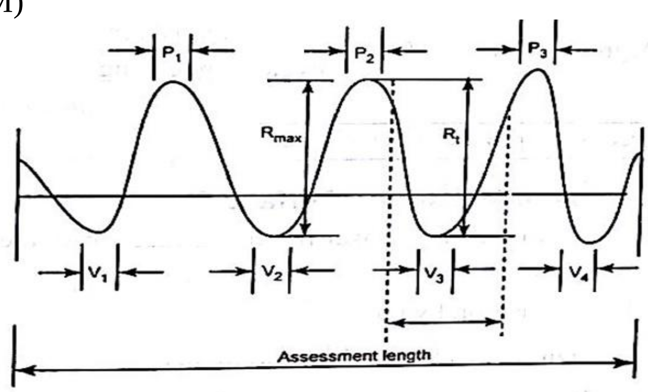
- Ten point method (2M)



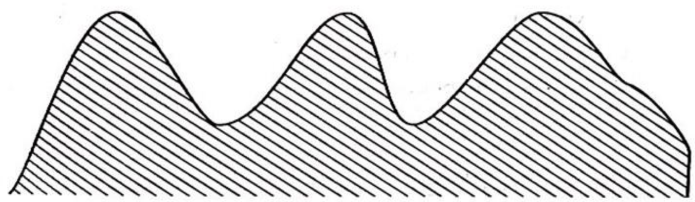
$$S_2 = \frac{1}{5}(h_1 + h_2 + h_3 + h_4 + h_5) - (h_6 + h_7 + h_8 + h_9 + h_{10})$$

Where S_2 = Ten point height of irregularities

Peak valley method (4M)



Rmax = Maximum peak to valley height in one sampling lengths,
Rt = maximum peak to valley height, V = valley, P = peak
Form factor (3M)

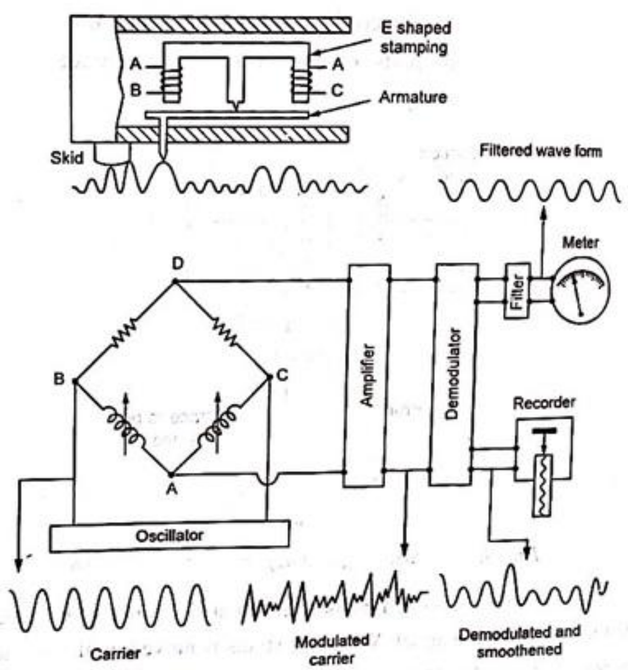


$$Degree\ of\ fullness\ (F) = \frac{Metal\ Area}{Enveloping\ rectangle\ area}$$

$$Degree\ of\ emptiness,\ (E_1) = 1 - F$$

3

Explain with sketch the working of Talysurf instrument for surface finish measurement. (13M)BTL2
Answer: Page. 4.86 - Dr.G.K.Vijayaraghavan
Diagram (7M)



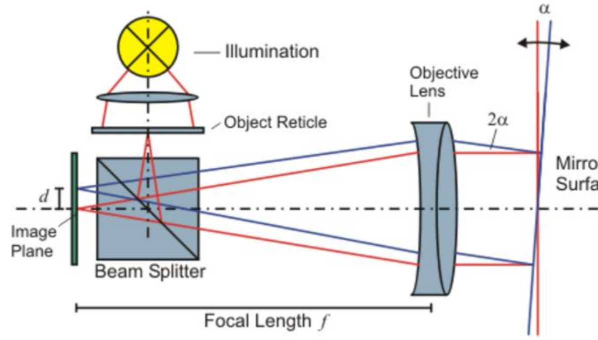
Working: E shaped stamping – oscillator – armature – stylus movement – modulation – pen recorder – numerical assessment. (6M)

4

Describe the methods of measuring straightness of a surface. (13M)BTL2
Answer: Page. 4.2 - Dr.G.K.Vijayaraghavan
Working principle (2M)

$$x = 2\theta f$$

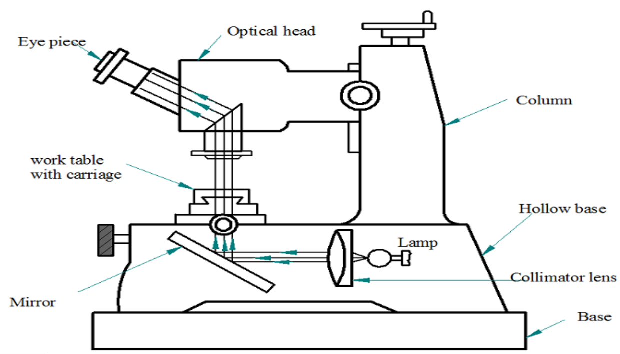
where, f = focal length of the lens
θ = fitted angle of reflecting mirror
Diagram (4M)



Construction & working (5M)
Micrometer microscope – lighting unit – collimating lens – calibrating polygons – checking angular index – small linear displacements – sensitive, accurate approach.
Applications: angular difference – small displacements – plane surface inspection. (2M)

5

How to measure the pitch of a screw thread by using the Tool maker's Microscope? Discuss in detail. (13M)BTL4
Answer: Page. 4.32 - Dr.G.K.Vijayaraghavan
Diagram (6M)

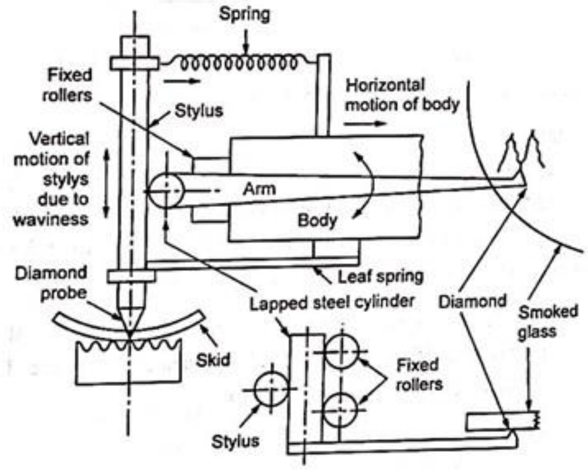


Working: optical head – horizontal beam – contour – three prisms – cross lines – graduated screens. (5M)
Applications: linear – screw pitch – pitch diameter – thread angle – thread forms – centre to centre. (2M)

PART * C

1

Explain Tomlinson surface meter with neat sketch. (15M)BTL2
Answer: Page. 4.84 - Dr.G.K.Vijayaraghavan
Diagram (7M)



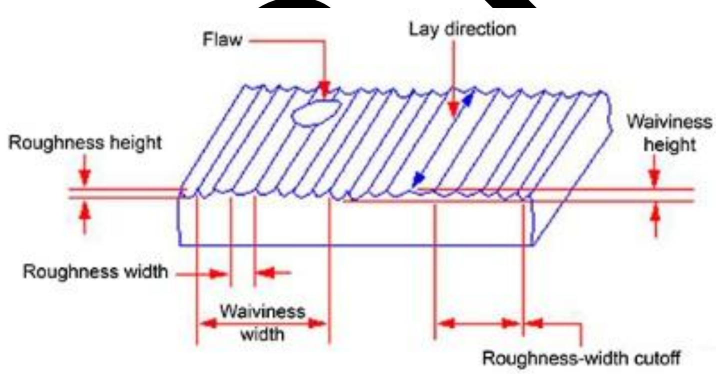
Working: screw rotation – vertical movement – lapped cylinder roll – arm movement – diamond scriber – smoked glass – magnified optical projector. (8M)

2

What is the symbol for fully defining surface roughness and explain each term? Explain the following terms in brief: Flaws, Primary texture (Roughness), secondary texture (waviness), lay, and centerline. (Jun 2014) (15M)BTL1

Answer: Page 4.75 - Dr.G.K.Vijayaraghavan

Diagram (5M)



Surface characteristics (Courtesy, ANSI B46.1 - 1962)

Lay: direction of predominate surface pattern. (2M)

Centerline: divides effective profile area. (2M)

Waviness: surface irregularities – greater spacing than roughness. (2M)

Roughness: spaced irregularities – primary texture. (2M)

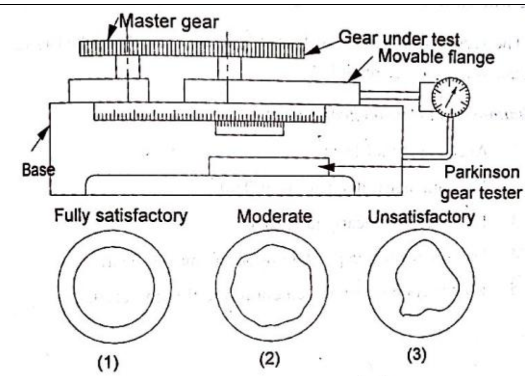
Flaws: surface irregularities – frequent intervals (2M)

3

How to check the composite errors of the gear by using Parkinson gear testing machine? Explain it in detail. (15M)BTL2

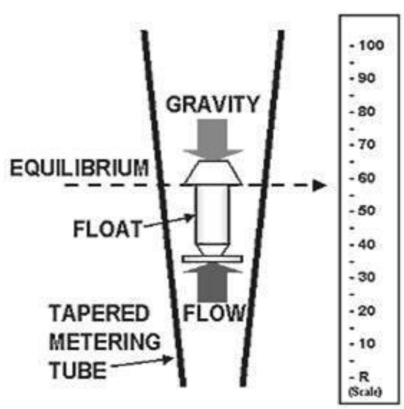
Answer: Page. 4.62 - Dr.G.K.Vijayaraghavan

Diagram (7M)



	Working: master gear – carriage – spring pressure – dial indicator variation – waxed circular chart – centre distance. (6M) Limitations: Accuracy ± 0.001mm – max dia 300mm – dependent on master gear – low friction – error not identified. (2M)
UNIT V – MEASUREMENT OF POWER, FLOW AND TEMPERATURE	
Force, torque, power - mechanical, Pneumatic, Hydraulic and Electrical type. Flow measurement: Venturimeter, Orifice meter, rotameter, pitot tube – Temperature: bimetallic strip, thermocouples, electrical resistance thermometer – Reliability and Calibration – Readability and Reliability.	
PART * A	
Q.No.	**Questions**
1	**What is a load cell? (Dec 2012)** BTL2 When the strain gauge – elastic member combination is used for weighing it is called a load cell. Load cells utilize an elastic member as the primary transducer and strain gauge as secondary transducer.
2	**How force is measured using a Hydraulic load cell?** BTL4 When a force is applied on a liquid (oil) medium contained in a confined space, the pressure of the liquid increases which is proportional to the applied force. Hence a measure of the increase in pressure of the liquid becomes a measure of the applied force when calibrated.
3	**What is the working principle of unequal arm balance?** BTL2 An unequal arm balance works on the principle of moment comparison. The beam of the unequal arm balance is in equilibrium position when: Clockwise rotating moment = Anticlockwise rotating moment
4	**How force is measured using an elastic force meter (Proving ring)?** BTL4 When the Proving ring is subjected to a force (tensile or compressive) across its diameter, it deflects. The deflection (relative displacement) which is proportional to the applied force is measured using a precision micrometer or dial gauge or displacement transducer. Hence a measure of this relative displacement becomes a measure of the applied force when calibrated.
5	**How torque is measured using Mechanical torsion meter?** BTL4 When a torque is applied to the shaft of the torsion meter, it causes displacement of pointer relative to scale on account of angular twist of the length of the shaft between the two flanges. This angular twist is measured and calibrated in terms of torque.
6	**How torque is measured using Electrical torsion meter?(Dec 2012)** BTL4

	When a torque is applied to the shaft of the torsion meter, there is a relative displacement between the two slotted discs. This produces a phase shift between the pulses generated in the inductive pickups. When these pulses are compared with the help of an electronic timer, it will show a time interval between the two pulses. This time interval is proportional to the twist of the shaft and hence is proportional to torque.
7	**How flow is measured using Orifice meter?** BTL4 When an orifice plate is placed in a pipe carrying the fluid whose flow rate is to be measured, the orifice plate causes a pressure drop, between the converging of the fluid and diverging of the fluid, which varies with the flow rate. This pressure drop is measured using a differential pressure sensor and when calculated this pressure drop becomes a measure of flow rate.
8	**How is flow measured using Venturimeter?** BTL4 When a venturimeter is placed in a pipe carrying the fluid whose flow rate is to be measured, a pressure drop occurs between the entrance and throat of the venturimeter. This pressure drop is measured using a differential pressure sensor and when calculated this pressure drop becomes a measure of flow rate.
9	**How flow is measured using Pitot tube (Total pressure probe)?** BTL4 The pitot tube is introduced in the fluid flow area. The differential pressure (Impact pressure – Static pressure) is measured using a differential pressure sensor. This differential pressure becomes a measure of flow rate at that point where the pitot tube is present in the flowing fluid.
10	**How is flow measured using Rotameter (Variable-area meter)?** BTL4 The increase in flow rate will make the float to rise higher and vice versa. That is, the position of the float becomes a direct indication of flow rate. (By noting the position of the float with respect to the graduations on the tapered tube).
11	**What is the working principle of pendulum scale? (Dec 2012)** BTL2 The unknown force is converted into a torque which is then balanced by the torque of a fixed standard mass arranged as a pendulum.
12	**What is a bimetallic strip? Name its types. (Dec 2012)** BTL2 A bimetallic strip is made of two thin strips of metal which have different thermal co-efficient of expansion. The two metal strips are joined together by brazing, welding or riveting so that the relative motion between them is arrested. Different common forms of bimetallic sensors are: ➢ Helix type ➢ Spiral type ➢ Cantilever type ➢ Flat type.
13	**What are the important properties a material should have to be selected for bimetallic thermometers?** BTL2 The following properties should be high: ➢ Co-efficient of expansion ➢ Modulus of elasticity ➢ Elastic limit after cold rolling ➢ Electrical conductivity ➢ Ductility and ➢ Metallurgical ability.
14	**State the two principles on which Bimetallic thermometers work.** BTL1 ➢ All metals change in dimension, i.e. expand or contract when there is a change in temperature.

	➢ The rate at which this expansion or contraction takes place depend on the thermal co-efficient of expansion of the metal and this thermal co-efficient of expansion is different for different metals. Hence the difference in thermal expansion rates is used to produce deflections which are proportional to temperature changes.
15	**How temperature is measured using pressure thermometer?** BTL1 When a liquid, gas or vapour filled system is subjected to a temperature change, the volume of the liquid, gas or vapour changes causing a pressure difference in the filled system. This pressure difference becomes an indication of temperature changes when calibrated.
16	**State "Law of intermediate temperatures" in thermocouples.** BTL1 The thermal emf produced when a circuit of two homogeneous metals exists between a first temperature and a second and thermal emf produced when the same circuit exists between the second temperature and a third are algebraically equal to the thermal emf produced when the circuit exists between first and third temperatures.
17	**What is the principle involved in fluid expansion thermometer? (Jun 2014)** BTL1 In fluid expansion thermometer, the change in pressure in the bulb is taken as an indication of the temperature.
18	**Give the principle of hot wire anemometer. (Jun 2014)** BTL1 When a fluid flows over a heated surface, heat is transferred from the surface, and so its temperature reduces. The rate of reduction of temperature is related to flow rate.
19	**What is the principle used in thermocouples? (or) What is "Principle of thermo electricity"? (or) What is seeback effect? (Dec 2014)** BTL1 The principle states that "When two conductors of two different metals A and B are joined together at one end to form a junction, and this junction is heated to a higher temperature with respect to the free ends, a voltage is developed at the free ends and if these two conductors of metals at the free ends are connected, then the emf setup will establish a flow of current".
20	**What are the physical characteristics of temperature measuring sensor? (Dec 2014)** BTL2 Resistance Temperature Detectors are the sensors used to measure the temperature by correlating the resistance of the RTD element with temperature.
	PART * B
1	**Explain the rotameter with neat sketch. (13M) (Dec 2014)** BTL2 **Answer: Page: 5.66 – Dr.G.K.Vijayaraghavan** **Diagram** (6M)  **Working**(7M) Variable area type – tapered tube – float – constant pressure drop meter – buoyant effect – float position – flow rate.

$$Q = CEA_2\sqrt{\frac{2gp_d}{\rho}}$$

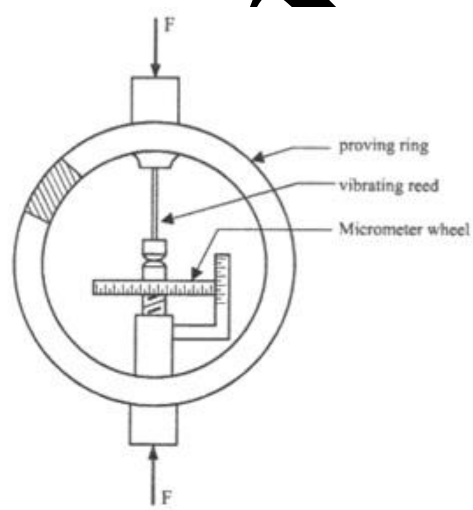
where , P_d = Pressure difference
E = Approach factor
A_2 = Orifice area
ρ = density of fluid
C = coefficient of discharge.

2

With a neat sketch explain Proving ring for force measurement. (13M) (Dec 2014) BTL2
Answer: Page: 5.16 – Dr.G.K.Vijayaraghavan
Working(7M)
Steel rings – dead weight standards – rectangular cross section – tensile force – compressive force – deflection – micrometer – damping.

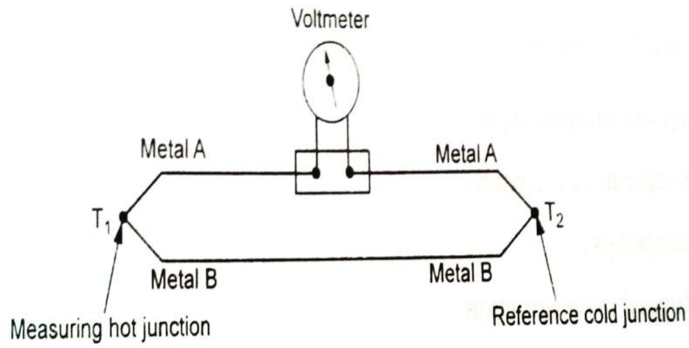
$$\delta = \frac{K}{16}\left(\frac{\pi}{2} - \frac{4}{\pi}\right)\frac{Fd^3}{EI}$$

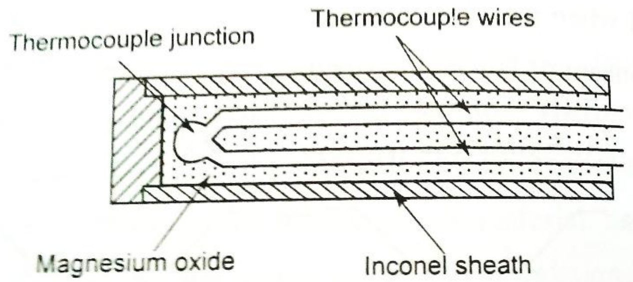
where, d = outer diameter of ring,
K = stiffness.
Diagram(6M)



3

What are thermocouples? State its applications. (13M) (May 2014) BTL2
Answer: Page:5.103 – Dr.G.K.Vijayaraghavan
Diagram ([illegible])



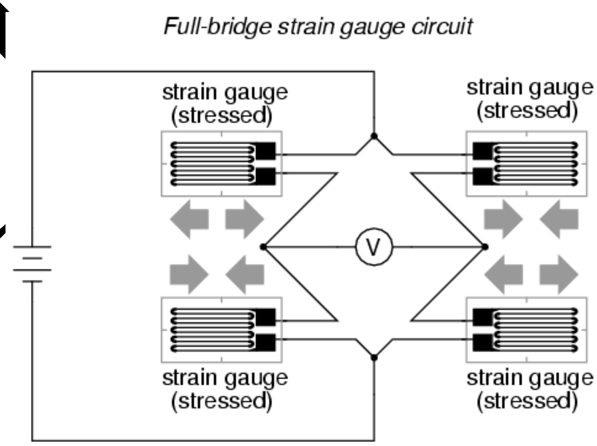


Working (7M)
Seaback effect – hot junction – cold junction – reference temperature – electromotive force – intermediate temperature – millivoltmeter.

$$(E) = AT + \frac{1}{2}BT^2 + \frac{1}{3}CT^3$$

4

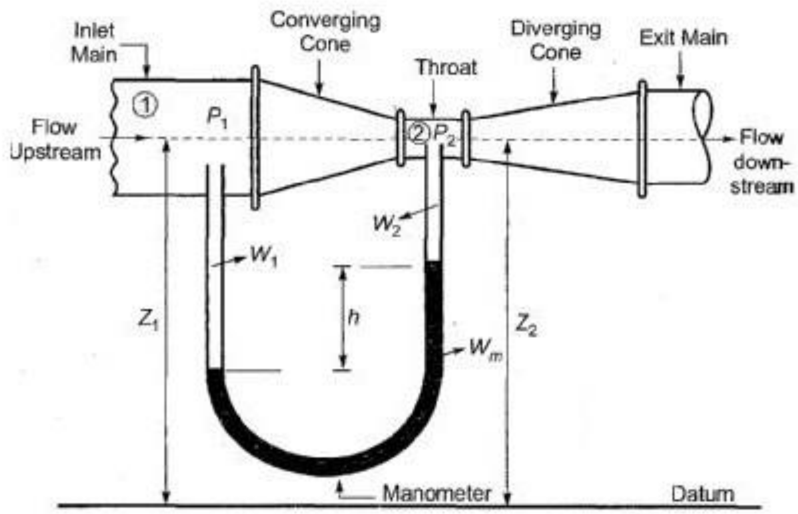
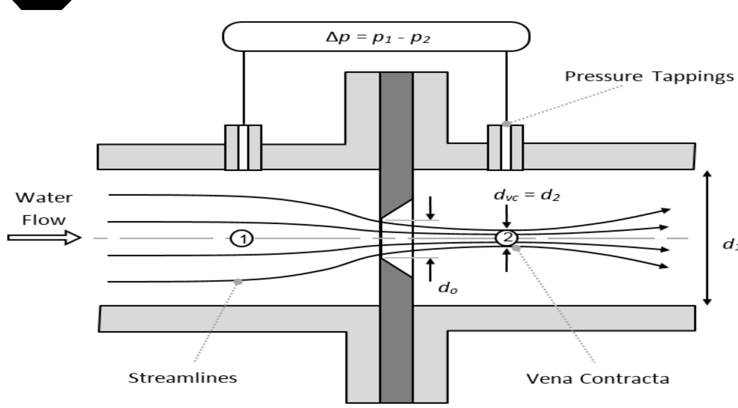
Explain the method of measuring force using a strain gauge load cell. (13M) (May 2014) BTL2
Answer: Page: 5.12 – Dr.G.K.Vijayaraghavan
Diagram (6M)

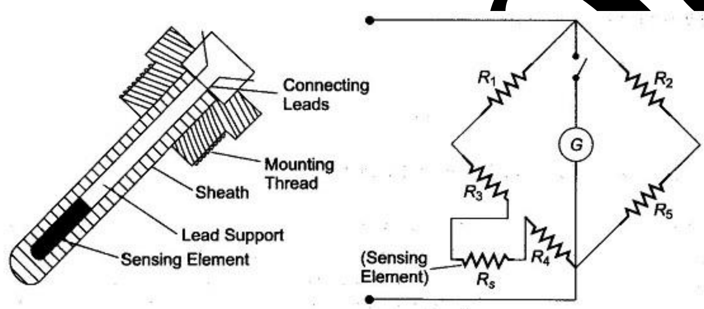


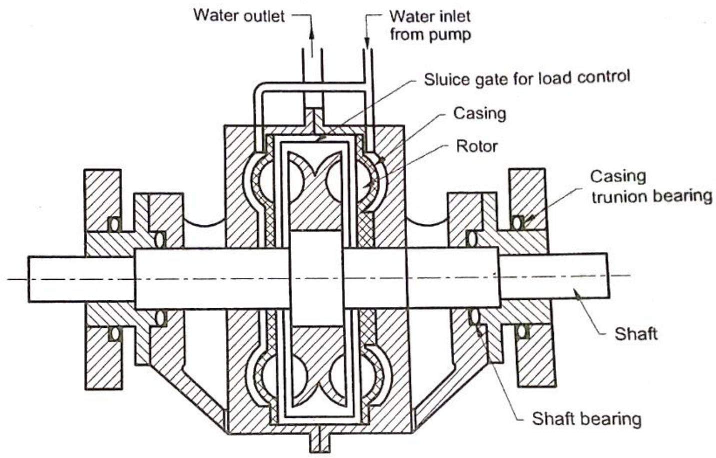
Working (7M)
Force transducers – elastic member – four strain gauges - maximum sensitivity – Wheatstone bridge – primary transducer – secondary transducer – change in resistance.

$$V_0 = \frac{R_1R_4 - R_2R_3}{(R_1 + R_2)(R_3 + R_4)}$$

where, V_1 = Input voltage

	V_2 = Output voltage, R_1, R_2, R_3, R_4 =resistance in strain gauges.
5	**Explain with a neat diagram the purpose and operating principle of a venturimeter. (13M)** BTL2 **Answer: Page: 5.64 – Dr.G.K.Vijayaraghavan** **Diagram** (6M)  **Working** (7M) Convergent cone – throat section – divergent cone – manometer – pressure head difference – discharge coefficient – flow rate. $$Venturi\ meter, Flow\ rate, Q = \frac{c_d a_1 a_2 \sqrt{2gx}}{\sqrt{a_1^2 - a_2^2}}$$ where, a_1 = area at the inlet a_2 = area at the section x = pressure head difference C_d = discharge coefficient
6	**With neat sketch discuss about the working of orifice meter. (13M)** BTL2 **Answer: Page:5.[illegible] – Dr.G.K.Vijayaraghavan** **Diagram** (6M)  **Working**(7M)

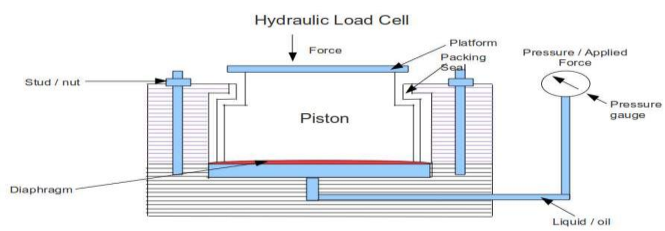
	Orifice plate – flow rate increases – pressure drop decreases – vena contracta – circular opening – concentric – eccentric – segmented. $$Orifice\ meter, Flow\ rate, Q = \frac{c_d a_1 a_0 \sqrt{2gh}}{\sqrt{a_1^2 - a_0^2}}$$ where, a_1 = area at section 1-1 a_0 = area of orifice C_d = discharge coefficient
	PART * C
1	**Explain the working principle of an electrical resistance thermometer and state its advantages. (15M)** BTL2 **Answer: Page: 5.110 – Dr.G.K.Vijayaraghavan** **Diagram** (5M)  **Working**(5M) Negative temperature coefficient – nonmetallic resistors – metal tube – thermistor sensing element – change in resistance – bridge amplifier circuit – wheat stone bridge. **Advantages**(2M) High accuracy – small sizes – high temperature – mechanical stress – electrical stress. **Limitations** (2M) Self heating – nonlinear – decrease of resistance. **Applications**(1M) Time delay circuits – thermistor – pressure measurement – flow measurement.
2	**Describe the construction of a hydraulic dynamometer and explain how it is used for power measurement. (15M) (Jun 2013)** BTL2 **Answer: Page:5.45 – Dr.G.K.Vijayaraghavan** **Diagram** (5M)



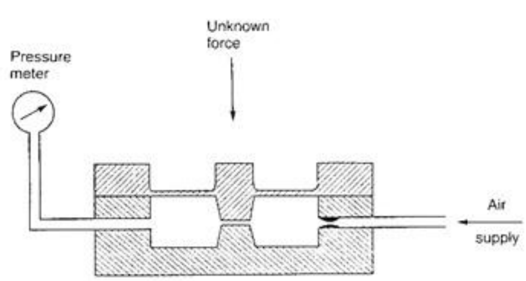
Working(6M)
Rotating disc – stationary casing – prime movers – antifriction bearings – helical path – vortices – eddy current – break arm – torque.
Advantages(2M)
Less place – low cost – no additional water.

3

Explain the working of hydraulic load cell & pneumatic load cell. (15M) (Dec 2012) BTL2
Answer: Page: 5.10 - Dr.G.K.Vijayaraghavan
Hydraulic load cell diagram(4M)



Construction (4M)
Piston – elastic diaphragm – pressure increase – bourdon tube – overstrain – mechanical stops – minimization of friction.
Pneumatic load cell diagram (4M)



Construction(3M)
Balancing pressure – cell arrangement – diaphragm – nozzle – pressure gauge arrangement – deflection in flexible material.

ME8593 DESIGN OF MACHINE ELEMENTS L T P C
2 0 4 4

OBJECTIVES:

- To familiarize the various steps involved in the Design Process
- To understand the principles involved in evaluating the shape and dimensions of a component to satisfy functional and strength requirements.
- To learn to use standard practices and standard data
- To learn to use catalogues and standard machine components

(Use of P S G Design Data Book is permitted)

UNIT I STEADY STRESSES AND VARIABLE STRESSES IN MACHINE MEMBERS 10

Introduction to the design process - factors influencing machine design, selection of materials based on mechanical properties - Preferred numbers, fits and tolerances – Direct, Bending and torsional stress equations – Impact and shock loading – calculation of principle stresses for various load combinations, eccentric loading – curved beams – crane hook and 'C' frame- Factor of safety - theories of failure – Design based on strength and stiffness – stress concentration – Design for variable loading.

UNIT II SHAFTS AND COUPLINGS 8

Design of solid and hollow shafts based on strength, rigidity and critical speed – Keys, keyways and splines - Rigid and flexible couplings.

UNIT III TEMPORARY AND PERMANENT JOINTS 9

Threaded fasteners - Bolted joints including eccentric loading, Knuckle joints, Cotter joints – Welded joints, riveted joints for structures - theory of bonded joints

UNIT IV ENERGY STORING ELEMENTS AND ENGINE COMPONENTS 9

Various types of springs, optimization of helical springs - rubber springs - Flywheels considering stresses in rims and arms for engines and punching machines- Connecting Rods and crank shafts.

UNIT V BEARINGS 9

Sliding contact and rolling contact bearings - Hydrodynamic journal bearings, Sommerfeld Number, Raimondi and Boyd graphs, -- Selection of Rolling Contact bearings

TOTAL: 45 PERIODS

OUTCOMES:

Upon completion of the course, the students can able to successfully design machine components

TEXT BOOK:

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. Robert C. Juvinall and Kurt M. Marshek, "Fundamentals of Machine Design", 4th Edition, Wiley, 2005
3. Alfred Hall, Halowenko, A and Laughlin, H., "Machine Design", Tata McGraw-Hill BookCo.(Schaum's Outline), 2010
4. Bernard Hamrock, Steven Schmid,Bo Jacobson, "Fundamentals of Machine Elements",2nd Edition, Tata McGraw-Hill Book Co., 2006.
5. Orthwein W, "Machine Component Design", Jaico Publishing Co, 2003.
6. Ansel Ugural, "Mechanical Design – An Integral Approach", 1st Edition, Tata McGraw-Hill Book Co, 2003.
7. Merhyle F. Spotts, Terry E. Shoup and Lee E. Hornberger, "Design of Machine Elements" 8th Edition, Printice Hall, 2003

Subject Code :ME8593 **Year/Semester: III /05**
Subject Name: DESIGN OF MACHINE ELEMENTS **Subject Handler: Mr.A.Gejendhiran**

UNIT I - STEADY STRESSES AND VARIABLE STRESSES IN MACHINE MEMBERS

Introduction to the design process - factors influencing machine design, selection of materials based on mechanical properties - Preferred numbers, fits and tolerances – Direct, Bending and torsional stress equations – Impact and shock loading – calculation of principle stresses for various load combinations, eccentric loading – curved beams – crane hook and 'C' frame- Factor of safety - theories of failure – Design based on strength and stiffness – stress concentration – Design for variable loading

PART * A

Q.No.	Questions
1	**Define design.** BTL1 Design is a process of activities to gather all the information necessary to **realize the designer's idea** as real product for optimization.
2	**What do you mean by optimum design? (Nov.2011)** BTL1 Optimization is a process of **maximizing** a desirable quantity or **minimizing** an undesirable quantity.
3	**What are the various phases of design process?** BTL1 • Recognition of need • Definition of problem • Synthesis • Analysis and optimization • Evaluation • Presentation
4	**List some factors that influences machine design.** BTL1 • Strength and stiffness • Surface finish and tolerance • Manufacturability • Economic and aesthetics • Working atmosphere • Safety and reliability cost
5	**How the machine design may be classified? (Nov. 2016)** BTL 1 Machine design may be classified as follows: • Adaptive design, • Modified design and • New design

6	**What is adaptive design? Where it is used? Give examples. (Nov. 2012)** BTL2 Adaptive design is used where a new product is developed just by making small changes to the existing product. This is best suited to occasions where no or limited scope is available to go for an entirely new design. **Example**: Geared bicycle
7	**What are the common materials used in mechanical engineering design? (Nov. 2015)** BTL1 Steels, Cast iron, alloys and composite materials are the common materials used in mechanical engineering design.
8	**Differentiate between hardness and toughness of materials. (May 2014)** BTL 2 **Toughness**: Ability of a material to withstand a suddenly applied load. It can also be defined as the energy absorbed by the material before failure. **Hardness**: **Hardness** is the ability of material to resist scratching and indentation.
9	**Define modulus of resilience and proof resilience. (May 2017)** BTL 1 The **modulus of resilience** is **defined** as the maximum energy that can be absorbed per unit volume without creating a permanent distortion. **Proof resilience** is **defined** as the maximum energy that can be absorbed up to the elastic limit, without creating a permanent distortion.
10	**Describe material properties hardness, stiffness and resilience. (Nov.2013, May 2016)** BTL2 Hardness is the ability of material to resist scratching and indentation. Stiffness is the ability of material to resist deformation under loading. Resilience is the ability of material to resist absorb energy and to resist shock and impact load.
11	**Define Poisson's ratio. (May 2011)** BTL1 In stress point view, the Poisson's ratio is the ratio of working stress in to the ultimate stress. In strain point of view, it is the ratio of lateral strain to longitudinal strain.
12	**Define stress concentration factor. (May 2014, May 2016)** BTL 1 Stress concentration is defined as the localization of high stresses due to the irregularities present in the component and abrupt changes of the cross section.
13	**What is an impact load? Give examples.** BTL1 If the time load application is less than one third of the lowest national period of vibration of the part, the load is called an impact load. Example: Punching presses, hammers, loads exerted on cams during the motion due to eccentricity, loads imposed on gear teeth due to irregular tooth profile.
14	**Define principal plane and principal stresses.** BTL1 A plane where only normal stresses act, with no shear stress acting is called principal plane. The (normal) stress acting on this plane is called principal stresses.
15	**Define factor of safety.** BTL1 The ratio between maximum stresses to working stress is known as factor of safety. Factor of safety= Maximum stress/ working stress
16	**List the important factors that influence the magnitude of factor of safety. (Nov.2011)** BTL2 • Material properties • Nature of load • Presence of localized stress • Presence of initial stress • Mode of failure

17	**What is the factor of safety for brittle materials? (May 2011)** BTL1 Factor of safety for brittle material is **4.**
18	**What are the factors that govern selection of materials while designing a machine component? (Nov.2010)**BTL1 a. Required material properties b. Material availability c. Cost of material d. Manufacturing ease
19	**State the difference between straight beams and curved beams. (Nov.2012)**BTL3

Feature	Straight beam	Curved beam
Centroidal Axis & Neutral Axis	Both axes coincides	Both axes will not coincide. Neutral Axis is shifted towards Centre of curvature.
Stress developed	Same throughout the section	Different at inner & outer radii of the section
Stress section	Linear	Hyperbolic

20	**Why normal stress theory is not suitable for ductile materials?** BTL2 Ductile materials mostly fail by shearing. But this theory considers only tensile or compressive stresses. So this is not suitable for ductile materials.
21	**Which theory of failure is suitable for the design of brittle materials?(Nov. 2015)** BTL1 The **Rankine's Theory** or maximum principal stress theory is best suitable for the design of brittle materials. Here failure occurs when the maximum normal stress is equal to the tensile yield strength. For brittle materials, some other popular failure criterion are: The **Tresca** or maximum shear stress failure criterion. The **Von Mises** or maximum elastic distortional energy criterion.
22	**State the various methods of finding stress concentration factors.** BTL1 • Photo elasticity method • Grid method • Brittle coating method • Strain gauge method • Finite element techniques
23	**Give some methods of reducing stress concentration.** BTL1 • Avoiding sharp corners • Providing fillets • Use of multiple holes instead of single holes
24	**What are the factors that affect notch sensitivity?** BTL1 • Materials • Notch radius • Size of component • Type of loading • Grain Structure
25	**What are the types of variable stresses?** BTL1 • Completely reverse or cyclic stresses • Fluctuating stresses

	• Repeated stresses • Alternating stresses
26	**Write Soderberg equation for a machine component subjected to** **(a) Combination of mean and variable torques** **(b) Combination of mean and variable bending moments. (Nov.2010)** BTL2 (a) $\frac{1}{F.S.} = \frac{\sigma_m}{\sigma_y} + \frac{\sigma_y}{\sigma_e}$ (b) $\frac{1}{F.S.} = \frac{\sigma_m}{\sigma_y} + \frac{\sigma_v \, X \, k_f}{\sigma_e X \, k_{sur} \, X \, k_{sz}}$
27	**What are the various theories of failure?** BTL1 a. Maximum principal stress theory b. Maximum shear stress theory c. Maximum principal strain theory d. Maximum strain energy theory
28	**Explain size factor in endurance strength.** BTL2 Size factor is used to consider the effect of the size on endurance strength. A large size object will have more defects compared to a small one. So endurance strength is reduced. If K is the size factor, Actual endurance strength = theoretical endurance limit x K
29	**What are the methods used to improve fatigue strength? (Nov. 2013, Nov. 2014)** BTL1 • Cold working like short peening, burnishing • Heat treatments like induction hardening • Annealing • Inducing favorable internal stresses after welding • Treatment of the weld reinforcement • Prestressing • Plastic coating
30	**What is an S-N curve? (Nov. 2016)** BTL1 An S-N curve has fatigue stress on Y- axis and number of loading cycles in X- axis. It is used to find the fatigue stress value corresponding to a given number of cycles.
31	**What is low and high cycle fatigue?** BTL1 Fatigue within 103 cycles is known as low cycle fatigue. Fatigue at high number cycles is called high cycle fatigue
32	**Why non symmetrical I and T sections are preferred in design of curved beams? (May 2017)** BTL 2 Non symmetrical sections are preferred to economize the structure. The consideration while designing are Bending capacity of structure in respective axis and Consideration for lateral torsional buckling. In structure where bending about a respective axis is prominent we would provide the orientation of section along higher M.I. (Moment of inertia). It is noted that section like C -channel provide higher torsional moment characteristics with lower cross sectional area. In the same way I-sections provide max M.I. with lower cross sectional area.
33	**Define limits and fits. (May 2015)** BTL1 The extreme permissible values of a dimension are known as limits. The degree of tightness or

	looseness between two mating parts that are intended to act together is known as the fit of the parts.
34	**Determine the force required to punch a hole of 20mm diameter in a 5 mm thick plate with ultimate shear strength of 250 Mpa. (Nov.2014)** BTL3 Force required to punch (F) = Shear strength x Shear area Shear area = $\pi dt = \pi \times 20 \times 5 = 314.15\ mm^2$ F = 250 x 314.15 = **78539.816 N**
	PART * B
1	**A 30 mm diameter machined steel cantilever 250 mm long is loaded on the end with a force that varies from 270 N down to 400 N up. Also there is axial force at the free end that varies from -500 N to +600 N. There is a 6 mm fillet where the member is connected to the support which causes a stress concentrator factor of 1.32. The notch sensitivity may be taken as 0.9. If the material has an ultimate strength of 550 MPa, endurance limit of 240 MPa, and yield strength of 415 Mpa, <u>Calculate the design factor 'n'</u>. (13 M) (Oct. 96 MU, May 2007 AU)** BTL 5 **Answer: Page: 1.154 - E.V.V.Ramanamurthy** **Revised axial loading:** $P_m = \frac{Pmax + Pmin}{2} = \frac{600-500}{2}$ = 50N; $P_A = \frac{Pmax - Pmin}{2} = \frac{600+500}{2}$ = 550N **(2 M)** $\sigma_m = \frac{P_m}{A}$ = 0.070N/mm^2; $\sigma_A = \frac{P_A}{A}$ = 0.778N/mm^2 $K_f = 1+q(k_t - 1)$; K_f = 1.288 **(2 M)** **Equivalent normal stress:** Normal $\sigma_{eq} = \sigma_m + K_f \frac{\sigma a\, \sigma y}{\sigma - 1}$; σ_{eq} = 1.802N/mm^2 **(2 M)** **Revised bending:** $P_m = \frac{Pmax + Pmin}{2} = \frac{400-270}{2}$ = 65N ; $P_A = \frac{Pmax - Pmin}{2} = \frac{400+270}{2}$ = 335N **(2 M)** M_m = 16250N-mm ; M_a = 83750N-mm $\sigma_m = \frac{Mm}{Z}$ = 6.133N/mm^2 ; $\sigma_a = \frac{Ma}{Z}$ = 31.61N/mm^2 **(2 M)** K_f = 1.288 **Equivalent bending stress:** Bending $\sigma_{eq} = \sigma_m + K_f \frac{\sigma a\, \sigma y}{\sigma - 1}$ = 64.237 N/mm^2; n = 6.28 **(3 M)**
2	**A pulley is keyed to shaft midway between two bearings. The shaft is made of cold drawn steel for which the ultimate strength is 550 Mpa and the yield strength is 400Mpa. The**

bending moment at the pulley varies from -150Nm to +400N-m as the torque on the shaft varies from -50Nm to +150N-m. Obtain the diameter of the shaft for an indefinite life. The stress concentration factors for the keyway at the pulley in bending and in torsion are 1.6 and 1.3 respectively. Take the following values factor of safety =1.5 load correction factors =1.0 in bending and 0.6 in torsion size effect factor =0.85 Surface effect factor =0.88 (13 M) (May 2004, May 2012, Nov.2012) BTL 5

Answer: Page: 167 - R.S.Khurmi and J.K.Gupta

Mean or Average bending moment:

$M_m = \frac{M_{Max} + M_{Min}}{2} = 125\times10^3$ Nmm

Variable bending moment:

$M_v = \frac{M_{Max} - M_{Min}}{2} = 275\times10^3$ Nmm

section modulus $Z = (\pi/32)\times d^3 = 0.0982 d^3$ (**2 M**)

Mean Bending stress:

$\sigma_m = \frac{M_m}{Z} = \frac{125\text{x}10^3}{0.0982\text{x}d^3} = \frac{1273\ x\ 10^3}{d^3}$ N/mm² (**2 M**)

Variable Bending stress:

$\sigma_v = \frac{M_v}{Z} = \frac{275\text{x}10^3}{0.0982\text{x}d^3} = \frac{2800\text{x}10^3}{d^3}$ (**2 M**)

$\sigma_{neb} = \sigma_{ne} = \sigma_m + \frac{\sigma_v \text{x} \sigma_y x K_{fb}}{\sigma_{eb}\ \text{x}k_{sur}\ \text{x}k_{sz}} = \frac{9985\text{x}10^3}{d^3}$ (**2 M**)

Torsional moment mean torque:

$T_m = \frac{T_{Max} + T_{Min}}{2} = \frac{150-50}{2} = 50\ \text{x}\ 10^3$ N.mm

Variable Torque $T_v = \frac{T_{max} - T_{min}}{2} = \frac{150-(-50)}{2} = 100\times10^3$ N.mm (1 **M**)

Mean shear stress

$\boldsymbol{\sigma_m} = \frac{16\text{x}T_m}{\pi \text{x}d^3} = \frac{16\text{x}50\text{x}10^3}{\pi \text{x}d^3} = \frac{255\text{x}10^3}{d^3}$ (N/mm^2) (**1 M**)

Variable shear stress

$\boldsymbol{\tau_v} = \frac{16\text{x}T_v}{\pi \text{x}d^3} = \frac{16\text{x}100\text{x}10^3}{\pi \text{x}d^3} = \frac{510\text{x}10^3}{d^3}$

Endurance limit stress for reversed torsional of shear loading:

$\tau_e = \sigma_e \times K_s$

$= 275\times0.6 = 165$ N/mm²

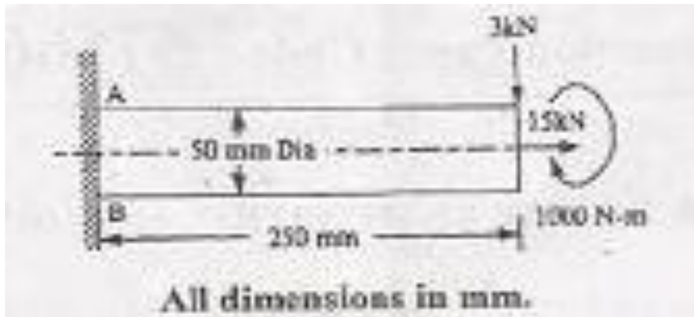
Assuming yield strength in shear

$\tau_y = 0.5\sigma_y = 0.5\times400 = 200$ N/mm² (**2 M**)

Maximum Equivalent Stress:

$\boldsymbol{\tau_{es}} = \tau_m + \frac{\tau_v \text{x} \tau_y \text{x}k_{fs}}{\tau_e \text{x}k_{su}\ x k_{sz}}$; $\tau_{es} = \frac{1329\text{x}10^3}{d^3}$ N/mm^2

The maximum Equivalent stress:

	$\tau_{es(max)}=\frac{\tau_y}{FOS} = 0.5\sqrt{\sigma_{ne}^2 + 4\,\tau_{es}^2}$ D = 33.84 = 35mm Req Diameter = **35mm** (**2 M**)
3	**A shaft, as shown in Fig, is subjected to a bending load of 3 kN, pure torque of 1000 N-m and an axial pulling force of 15 kN. Calculate the stresses at A and B. (13 M) (May 2016)** BTL 5  **Answer: Page: 114 - R.S.Khurmi and J.K.Gupta** Maximum principal stress at point A: $\sigma_{A(max)} = \frac{\sigma_A}{2} + \frac{1}{2}\left[\sqrt{(\sigma_A)^2 + 4\tau^2}\right]$ = **87.64 N/mm^2** **(3 M)** Minimum principal stress at point A: $\sigma_{A(min)} = \frac{\sigma_A}{2} - \frac{1}{2}\left[\sqrt{(\sigma_A)^2 + 4\tau^2}\right]$ = **-18.9 N/mm^2** **(2 M)** Maximum shear stress at point A: $\tau_{A(max)} = \frac{1}{2}\left[\sqrt{(\sigma_A)^2 + 4\tau^2}\right]$ = **53.27 N/mm^2** **(2 M)** Maximum principal stress at point B: $\sigma_{B(max)} = \frac{\sigma_B}{2} + \frac{1}{2}\left[\sqrt{(\sigma_B)^2 + 4\tau^2}\right]$ = **75.43 N/mm^2** **(2 M)** Minimum principal stress at point B: $\sigma_{B(min)} = \frac{\sigma_B}{2} - \frac{1}{2}\left[\sqrt{(\sigma_B)^2 + 4\tau^2}\right]$ = **-21.97 N/mm^2** **(2 M)** Maximum shear stress at point B:

	$\tau_{B(max)} = \frac{1}{2}\left[\sqrt{(\sigma_B)^2 + 4\tau^2}\right]$ = **48.7 N/mm²** **(2 M)**
4	**A bolt is subjected to an axial pull of 25 kN and a transverse shear force of 10 kN. The yield strength of a bolt material is 300 Mpa. Considering a factor of safety of 2.5. Determine the diameter of the bolt, using (i) maximum normal stress theory, (ii) maximum shear stress theory, and (iii) maximum principal strain theory. Take poisson's ratio as 0.25. (13 M) (Apr.2006, Nov. 2015)** BTL 5 **Answer: Page: 1.100 - E.V.V.Ramanamurthy** **Tensile load consideration:** Direct stress $\sigma_t = \frac{P}{A_b} = \frac{31.8\ X\ 10^3}{d_c^2}$ **(1 M)** With shear load consideration, $\tau = \frac{shear\ \ load}{A_b} = \frac{12.73\ X\ 10^3}{d_c^2}$ **(2 M)** From PSG DDB: 7.2, Maximum principal stress, $\sigma_{max} = \frac{1}{2}\ [(\sigma_x + \sigma_y) + \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2}] = \frac{36.265\ X\ 10^3}{d_c^2}$ **(2 M)** Minimum principal stress, $\sigma_{min} = \frac{1}{2}\left[(\sigma_x + \sigma_y) - \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2}\right] = \frac{4.465\ X\ 10^3}{d_c^2}$ **(2 M)** **(a) Maximum principal stress theory** $\sigma_{max} = \frac{\sigma_y}{n}$ **d_c = 17.38 mm** **d**=d_c/0.84 = **20.69 mm** **(2 M)** **(b) Maximum principal strain theory** $\sigma_1 - m(\sigma_2 + \sigma_3) = \sigma_y$ **d_c = 17.64 mm** **d**=d_c/0.84 = **21.01 mm** **(2 M)** **(c) Maximum shear stress theory** $\sigma_1 - \sigma_2 = \sigma_y$ **d_c = 18.42 mm** **d**=d_c/0.84 = **21.932 mm** **(2 M)**
5	**A cantilever rod of length 120 mm with circular section is subjected to a cyclic transverse load; varying from -100 N to 300 N at the free end. Determine the diameter 'd' of the rod, by (i) Good man method and (ii) Soderberg method using the following data:** **Factor of safety = 2; Theoretical stress concentration factor = 1.4; Notch sensitivity factor = 0.9; Ultimate strength = 550 Mpa; Yield strength = 320 Mpa; Endurance limit = 275 Mpa; Size correction factor = 0.85; Surface correction factor = 0.9. (13 M)(Nov.2015)** BTL5 **Answer: Page: 1.100 - E.V.V.Ramanamurthy** Mean load, $W_{mean} = \frac{w_{max} + W_{min}}{2} = \mathbf{200\ N}$

Amplitude load, $W_{amp} = \frac{w_{max} - W_{min}}{2} = \mathbf{100\ N}$ **(2 M)**

Mean bending moment, $M_{mean} = W_{mean}$ x Length = **24 x 10^3 N – mm**

Amplitude bending moment, $M_{amp} = W_{amp}$ x Length = **12 x 10^3 N – mm** **(2 M)**

Mean bending stress:

$(\sigma_b)_{mean} = \frac{M_{mean}}{2} = \frac{244.46\ X\ 10^3}{d^3}$ N/mm^2

Amplitude bending stress:

$(\sigma_b)_{mean} = \frac{M_{mean}}{2} = \frac{122.23\ X\ 10^3}{d^3}$ N/mm^2 **(3 M)**

(a) Good man method :

From PSG data book, page 7.6,

$$\frac{1}{n} = K_t \left[\frac{\sigma_m}{\sigma_u} + \frac{\sigma_q}{\sigma_{-1}}\right]$$

$\boldsymbol{d = 14.21\ mm}$ **(3 M)**

(b) Soderberg method:

From PSG data book, page 7.6,

$\frac{1}{n} = \frac{\sigma_m}{\sigma_y} + K_f \frac{\sigma_a}{\sigma_{-1}}$; $K_f = 1+q(k_t-1)$

$\boldsymbol{d}$ **= 14.59 mm** **(3 M)**

6 **A mild steel shaft of 50 mm diameter is subjected to a bending moment of 2000 N-m and a torque T. If the yield point of the steel in tension is 200 MPa, <u>find the maximum value of this torque</u> without causing yielding of the shaft according to maximum principal stress theory. (13 M)** BTL 5

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We know that maximum principal stress

$$\sigma_{max} = \frac{1}{2}\left[(\sigma_x + \sigma_y) + \sqrt{(\sigma_x - \sigma_y)^2 + 4\tau_{xy}^2}\right]$$

$\sigma_{max} = \frac{\sigma_1}{2} + \frac{1}{2}\ [\sqrt{(\sigma_1)^2 + 4\tau^2}]$ **(1 M)**

$= 81.5 + \sqrt{6642.5 + 1.65 \times 10^{-9} T^2}$ **(2 M)**

Minimum principal stress,

$\sigma_{min} = \frac{\sigma_1}{2} - \frac{1}{2}\ [\sqrt{(\sigma_1)^2 + 4\tau^2}]$ **(1 M)**

$= 81.5 - \sqrt{6642.5 + 1.65 \times 10^{-9} T^2}$ **(2 M)**

and maximum shear stress,

$\tau_{max} = \frac{1}{2}\left[\sqrt{(\sigma_1)^2 + 4\tau^2}\right]$ **(1 M)**

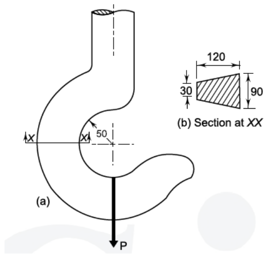
$= \sqrt{6642.5 + 1.65 \times 10^{-9} T^2}$ N/mm^2 **(2 M)**

	We know that according to maximum principal stress theory, $\sigma_{t1} = \sigma_{yt}$ $81.5 + \sqrt{6642.5 + 1.65 \times 10^{-9} T^2} = 200$ **T = 2118 x 103 N-mm Answer** **(4 M)**
	PART- C
1	**A machine component is subjected to fluctuating stress that varies from 40 to 100 N/mm^2. The corrected endurance limit stress for the machine component is 270 N/mm^2. The ultimate tensile strength and yield strength of the material are 600 and 450 N/mm^2 respectively. Find the factor of safety using** **(i) Gerber theory** **(ii) Soderberg line** **(iii) Goodman line** **Also, find the factor of safety against static failure. (15 M) (May 2013)** BTL 5 **Answer: Page: 175 - V.B.Bhandari** **Step I Permissible mean and amplitude stresses** $\sigma_a = \frac{1}{2}(100 - 40) = 30 \text{ N/mm}^2$ $\sigma_m = \frac{1}{2}(100 + 40) = 70 \text{ N/mm}^2$ $S_a = n\sigma_a = 30\,n$ $S_m = n\sigma_m = 70\,n$ **(3 M)** **Step II Factor of Safety using Gerber theory** $\frac{S_a}{S_e} + \left(\frac{S_m}{S_{ut}}\right)^2 = 1 \quad \text{or} \quad \left(\frac{30n}{270}\right) + \left(\frac{70n}{600}\right)^2 = 1$ $n = 5.41$ (i) **(3 M)** **Step III Factor of Safety using Soderberg line** The equation of the Soderberg line is as follows, $\frac{S_a}{S_e} + \frac{S_m}{S_{yt}} = 1$ $\left(\frac{30n}{270}\right) + \left(\frac{70n}{450}\right) = 1$ $n = 3.75$ (ii) **(3 M)**

	Step IV Factor of Safety using Goodman line The equation of the Goodman line is as follows: $$\frac{S_a}{S_e} + \frac{S_m}{S_{ut}} = 1$$ $$\left(\frac{30n}{270}\right) + \left(\frac{70n}{600}\right) = 1$$ $$n = 4.39 \qquad \text{(iii)}$$ **(3 M)** **Step IV Factor of Safety against static failure** The factor of safety against static failure is given by, $$n = \frac{S_{yt}}{\sigma_{max}} = \frac{450}{100} = 4.5 \qquad \text{(iv)}$$ **(3 M)**
2	**A mass of 50 kg drops through 25 mm at the centre of a 250 mm long simply supported beam. The beam has a square cross-section. It is made of steel 30C8 (S_{yt} = 400 N/mm^2) and the factor of safety is 2. The modulus of elasticity is 207 000 N/mm^2. <u>Determine the dimension of the cross section</u> of the beam. (15 M) (Apr.2015, Mumbai University)** BTL 5 **Answer: Page: 181 - V.B.Bhandari** ***Step I*** *Impact stress (σ_i)* $$\sigma_i = \sigma_s\left[1 + \sqrt{1 + \frac{2h}{\delta_s}}\right]$$ **(2 M)** ***Step II*** *Static stress (σ_s)* $$\sigma_s = \sigma_b = \frac{M_b y}{I}$$ $$= \frac{183\,973.5}{a^3}\ \text{N/mm}^2$$ **(2 M)**

	Step III *Static deflection* $$\delta_s = \frac{Wl^3}{48EI} = \frac{(490.5)(250)^3(12)}{48(207\,000)a^4} = \frac{9256.11}{a^4}\text{ mm}$$ **(3 M)** ***Step IV*** *Cross-section of beam* Substituting (d), (e) and (f) in Eq. (c), $$200 = \frac{183\,973.5}{a^3}\left[1 + \sqrt{1 + \frac{2(25)a^4}{9256.11}}\right]$$ Simplifying, $$\frac{a^3}{846160.82} - \frac{1}{459.94} = \frac{a}{185.12}$$ **(3 M)** ***Step V*** *Check for impact stresses* $$\sigma_s = \frac{183\,973.5}{a^3} = \frac{183\,973.5}{(70)^3} = 0.5363\text{ N/mm}^2$$ $$\delta_s = \frac{9256.11}{a^4} = \frac{9256.11}{(70)^4} = 3.855 \times 10^{-4}\text{ mm}$$ $$\sigma_i = \sigma_s\left[1 + \sqrt{1 + \frac{2h}{\delta_s}}\right]$$ $$= 0.5363\left[1 + \sqrt{1 + \frac{2(25)}{(3.855 \times 10^{-4})}}\right]$$ $$= 193.68\text{ N/mm}^2$$ $$\sigma_i < 200\text{ N/mm}^2$$ **(5 M)**
3	**A circular bar of 500 mm length is supported freely at its two ends. It is acted upon by a central concentrated cyclic load having a minimum value of 20 KN and a maximum value of 50 KN. <u>Determine the diameter of bar</u> by taking a factor of safety of 1.5, size effect of 0.85, surface finish factor of 0.9. The material properties of bar are given by: ultimate strength of 650 MPA, yield strength of 500 Mpa and endurance strength of 350 Mpa. (15 M)(Apr.2005)** BTL 5 **Answer: Page: 205 - R.S.Khurmi and J.K.Gupta**

	Maximum bending moment, $M_{max} = \frac{W_{max} \times l}{4} = 6250 \times 10^3$ N-mm And minimum bending moment, $M_{min} = \frac{W_{min} \times l}{4} = 2550 \times 10^3$ N-mm Mean or average bending moment, $M_m = \frac{M_{max} + M_{min}}{2} = 4375 \times 10^3$ N-mm and variable bending moment, $M_m = \frac{M_{max} - M_{min}}{2} = 1875 \times 10^3$ N-mm Section modulus of the bar, $Z = \frac{\pi}{32} \times d^3 = 0.0982\, d^3$ mm^3 Mean stress $\sigma_m = \frac{M_m}{Z} = \frac{44.5 \times 10^3}{d^3}$ N/mm^2 **M_{max}, M_{min} (2 M); Mm,mv (2 M); z, σ_m (2 M)** and variable bending stress, $\sigma_v = \frac{M_v}{Z} = \frac{19.1 \times 10^6}{d^3}$ N/mm^2 We know that according to good man's formula, $\frac{1}{F.S.} = \frac{\sigma_m}{\sigma_u} + \frac{\sigma_{v \times K_f}}{\sigma_{e \times K_{sur} \times K_{sz}}}$ $d^3 = 139 \times 10^3 \times 1.5 = 209 \times 10^3$ or $d = 59.3$ mm Soderberg's formula, $\frac{1}{F.S.} = \frac{\sigma_m}{\sigma_y} + \frac{\sigma_v \times K_f}{\sigma_e \times K_{sur} \times K_{sz}}$ $d^3 = 160 \times 10^3 \times 1.5 = 240 \times 10^3$ or $d = 62.1$ mm Taking larger of the two values, we have $d = 62.1$ mm **Ans.** **σ_v → (1 M); d value by Goodman (4 M); d value by Soderberg's formula (4 M)**
4	**A crane hook having an approximate trapezoidal cross-section is shown in Fig. It is made of plain carbon steel 45C8 (S_{yt} = 380 N/mm^2) and the factor of safety is 3.5.Determine the load carrying capacity of the hook. (15 M)(Nov.2012)** BTL 5 **Answer: Page: 132 - V.B.Bhandari**



Given data: S_{yt} = 380 N/mm^2 , (fs) = 3.5, b_i = 90 mm , b_o = 30 mm, h = 120 mm ,
R_o = 170 mm, R_i = 50 mm

Step I Calculation of permissible tensile stress

$$\sigma_{max.} = \frac{S_{yt}}{(fs)} = \frac{380}{3.5} = 108.57 \text{ N/mm}^2$$

Step II Calculation of eccentricity (e)

For the cross-section *XX*

$$R_N = \frac{\left(\frac{b_i + b_o}{2}\right)h}{\left(\frac{b_i R_o - b_o R_i}{h}\right)\log_e\left(\frac{R_o}{R_i}\right) - (b_i - b_o)}$$

$$R_N = \frac{\left(\frac{90+30}{2}\right)(120)}{\left(\frac{90\times170 - 30\times 50}{120}\right)\log_e\left(\frac{170}{50}\right) - (90-30)}$$

$$= 89.1816 \text{ mm}$$ **(4 M)**

$$R = R_i + \frac{h(b_i + 2b_o)}{3(b_i + b_o)}$$

$$= 50 + \frac{120(90 + 2\times 30)}{3(90+30)} = 100 \text{ mm}$$

$$e = R - R_N = 100 - 89.1816 = 10.8184 \text{ mm}$$ **(4 M)**

Step III Calculation of bending stress

$$h_i = R_N - R_i = 89.1816 - 50 = 39.1816 \text{ mm}$$

$$A = \frac{1}{2}[h\,(b_i + b_o)] = \frac{1}{2}[(120)(90+30)]$$

$$= 7200 \text{ mm}^2$$

M_b = PR = (100 P) N-mm **(4 M)**

The bending stress at the inner fibre is given by,

$$\sigma_{bi} = \frac{M_b h_i}{AeR_i} = \frac{(100P)(39.1816)}{(7200)(10.8184)(50)} = \frac{(7.2435)P}{(7200)} \text{ N/mm}^2$$

Step IV Calculation of direct tensile stress

$$\sigma_t = \frac{P}{A} = \frac{P}{(7200)} \text{ N/mm}^2$$

Step V Calculation of load carrying capacity

	Superimposing the two stresses and equating the resultant to permissible stress, we have $\sigma_{bi} + \sigma_t = \sigma_{max.}$ $\frac{(7.2435)P}{7200} + \frac{P}{7200} = 108.57$ $P = 94\ 827.95$ N **(3 M)**
UNIT II – SHAFTS AND COUPLING	
Design of solid and hollow shafts based on strength, rigidity and critical speed – Keys, keyways and splines - Rigid and flexible couplings	
Q.No.	**PART * A**
1	**What is a shaft?** (BTL1) A shaft is a rotating machine element, which transmits power from one point to another point.
2	**List the types of shaft.** (BTL1) • Line shaft • Spindle • Stub shaft • Counter shaft
3	**What are the materials used in shafts? (Nov.2015)** (BTL1) • Hot rolled plain carbon steel • Cold-drawn plain carbon/alloy composition • Alloy steels
4	**What is the difference between spindle and axle? (Apr.2015,Nov.2016)** (BTL2) An **axle**, through similar in shape to the shaft, is a stationary machine element and is used for transmission of bending moment only. It simply acts as a support for same some rotating body. A s**pindle** is a short shaft that imparts motion either to a cutting or to a work piece.
5	**What is meant by Jack shaft? (May 2010)** (BTL1) It is a short shaft connected to pulley, gears that transmit motion from a motor to a machine. It is also called as a counter shaft.
6	**List the types of stresses induced in shafts. (Nov 2011)** (BTL1) • Shear stresses due to transmission of torque (i.e. due to torsional load) • Bending stresses (tensile or compressive) due to the forces acting upon machine elements like gears, pulleys etc., as well as due to the weight of the shaft itself. • Stresses due to combined torsional and bending loads.
7	**What is meant by design of a shaft based on rigidity? (Nov 2015)**(BTL1) The diameter of the shaft is obtained from the equation, T/J=Gθ/L Where, θ = Angle of twist in radians, T = Torque, J = Polar moment of inertia, G = Modulus of rigidity, L = Length of twisting rod

8	**What do you mean by stiffness and rigidity with reference to shafts? (Nov 2010)** (BTL1) Stiffness is the resistance offered by the shaft for twisting and rigidity is the resistance offered by the shaft for lateral bending
9	**What are the types of rigidity?** (BTL1) • Torsional rigidity • Lateral rigidity
10	**Why a hollow shaft has greater strength and stiffness than solid shaft of equal weight? (Nov. 2012)** (BTL1) Stresses are maximum at the outer surface of a shaft. A hollow shaft has almost all the material concentrated at the outer circumference and so has a better strength and stiffness for equal weight.
11	**Why is maximum shear stress theory used for shaft?** (BTL1) Since, the shaft is made of ductile material; maximum shear stress thus is used
12	**What is the significance of slenderness ratio in shaft design?** (BTL1) If slenderness ratio is increased the shaft deviates from its "stub" behavior and it is essential to consider bucking while designing the shaft.
	Define the term critical speed. (Nov.2016)(BTL1) The speed, at which the shaft runs so that the additional deflection of the shaft from the axis of rotation becomes infinite, is known as **critical speed**.
13	**Define equivalent torsional moment of a shaft. (May 2017)**(BTL1) The equivalent torsional moment is defined as that the moment which acting alone produces the same torsional shear stress in the shaft as combined bending and torsional moment $$T_e = \sqrt{M^2 + T^2} = \frac{\pi}{16} \times \tau \times d^3$$
14	**Name the stresses induced in the shaft. (May 2011)**(BTL1) The following stresses are induced in the shafts: • Shear stress due to the transmission of torque (i.e. due to torsional load) • Bending stresses (tensile or compressive) due to the forces acting upon machine elements like gear, pulleys etc., as well as due to the weight of the shaft itself. • Stresses due to combined torsional and bending loads.
15	**How shaft is designed based on torsion only? (Nov.2012)** (BTL2) The diameter of shaft is designed based on torque equation. $$(\tau_{max})_{hollow} = \frac{16 M_t d_o}{\pi(d_o^4 - d_i^4)}$$ Let d = diameter of solid shaft Replace d_o = d and put d_i = 0 $$(\tau_{max})_{solid} = \frac{16 M_t}{\pi d^3}$$
16	**What is the effect of key ways cut into the shaft? (May 2016)**(BTL1) • It reduces the strength of the shaft because of material removal • It increases stress concentration
17	**At what angle of the crank the twisting moment is maximum in the crank shaft? (Nov.2011)**(BTL2) The Maximum twisting moment in the crank shaft angle lies around 65^0.

18 **What is a key?** (BTL1)
A key is a device which is used for connecting two machine parts for preventing relative motion of rotation with respect to each other.

19 **List the types of key.** (BTL1)
- Saddle key
- Tangent key
- Sunk key
- Round key and taper pins.

20 **What is the main use of woodruff keys? (Nov.2013)** (BTL1)
A woodruff key is used to transmit small value of torque in automotive and machine tool industries. The keyway in the shaft is milled in a curved shape whereas the key way in the hub is usually straight.

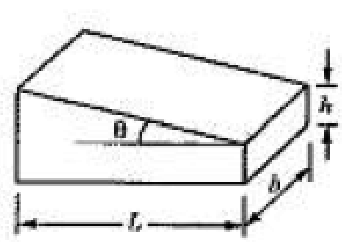
21 **What is a key? What types of stress are developed in the key? (Nov 2014)** (BTL1)
- A key is a device which is used for connecting two machine parts for preventing relative motion of rotation with respect to each other.
- Shear stress and crushing stress are developed.

22 **Discuss forces on keys. (Nov.2014)** (BTL2)
- Force due to the torque transmitted giving rise to shear and compressive stresses.
- Force due to the fit of the key. Tight fit leads to compressive stresses in the shaft and hub. It is impossible to predict the magnitude of the stresses.

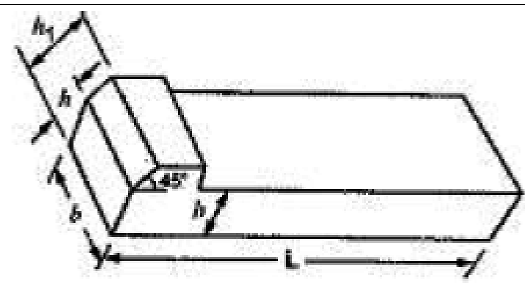
23 **Differentiate between keys and splines. (Nov 2011)** (BTL3)

S.No	KEYS	SPLINES
1	A shaft is having single keyway.	A shaft is having multiple keyways.
2	Keys are used in coupling.	Splines are used in automobiles and machine tools.

24 **List the different types of sunk keys and draw any one. (Nov 2017)** (BTL 2)
a) Parallel sunk key
b) Taper sunk key



c) Gib head sunk key



25 **What is coupling?** (BTL1)
The elements which join two shafts are coupling. It is used to connect sections of long transmissions shaft to the shaft of a driving machine. Couplings are used to connect sections of long transmission shafts and to connect the shaft of a driving machine to the shaft of a driven machine.

26 **What is the function of a coupling between two shafts?** (BTL1)
Couplings are used to connect sections of long transmission shafts and to connect the shaft of a driving machine to the shaft of a driven machine.

27 **State the reasons for which the couplings are located near the bearings. (May 2017)**(BTL2)
Couplings are located near the bearings due to the following two reasons:

- It reduces the bending moment and lateral deflection of shaft
- It reduces the angle of twist due to torsional moment

28 **Under what circumstances flexible couplings are used? (Nov.2012)**(BTL2)

- They are used to join the abutting ends of shafts when they are not in exact alignment.
- They are used to permit an axial misalignment of the shafts without under absorption of the power, which the shafts are transmitting.

29 **Where are flexible couplings used?** (BTL1)
Vehicle, Stationery machinery, Automotive drives and Machine tools.

30 **What is the material used for flange or flange coupling?** (BTL1)
Cast iron

31 **Justify the advantage of gear coupling.** (BTL1)
Gear coupling is a grid coupling with some flexibility because of using curved external teeth
Strength of gear coupling is very high.
Most compact coupling for high power transmission.

32 **What are the possible modes of failure of the pin (bolt) in flexible coupling? (Nov. 2015)** (BTL1)
Following are the possible modes of failure of the pin (bolt)in a flexible coupling: i) Bearing failure ii) Shear failure iii) Bending failure iv) Tensile failure due to combined bending and shear stress

33 **Differentiate between rigid coupling and flexible coupling. (May 2016)**(BTL2)

S.NO.	RIGID COUPLING	FLEXIBLE COUPLING
1	Rigid couplings produce the greatest reactions on component.	Flexible couplings produce the greatest flexibility while producing the lowest external loads on equipment.
2	Mechanical element type such as	The mechanical element type generally

	gear, chain, and grid couplings produce moderate to high moments and forces on equipment that are a function of torque and misalignment.	obtains their flexibility from loose-fitting parts or rolling or sliding of mating parts or from both.
3	Elastomeric element couplings produce moderate to low moments and forces that are slightly dependent on torque.	The elastomeric element types obtain their flexibility from stretching or compressing a resilient material (rubber, plastic, etc.,)
4	Metallic element couplings produce relatively low moments and forces which are relatively independent of torque.	The Metallic element types obtain their flexibility from the flexing of thin metallic disc or diaphragms.

34 **What are the types of flexible couplings and rigid couplings? (Nov-2016)**(BTL2)

Rigid couplings:

- Sleeve or muff coupling
- Clamp or split-muff coupling
- Flange coupling

Flexible coupling:

- Bushed pin type coupling
- Universal coupling
- Oldham coupling

35 **What are the different types of rigid couplings? (May 2011)** (BTL1)

The following coupling are the different types of rigid couplings:

- Sleeve or muff coupling
- Clamp or split-muff coupling
- Flange coupling

36 **Suggest suitable couplings for (i) Shafts with parallel misalignment (ii) Shafts with angular misalignment of 10^o (iii) shafts in perfect alignment. (Nov 2010)**(BTL3)

- **Flexible coupling** such as spring coupling can be used for shafts with **parallel misalignment.**
- **Universal coupling** is suitable for **shafts with angular misalignment of 10^o.**
- **Rigid coupling** can be used for shafts in **perfect alignment**.

37 **What is shock factor and what does it indicate? (Nov 2017)** (BTL1)

During operation, the shaft is subjected to shock due to bending and twisting conditions. The shock factor should be multiplied with twisting and bending moments in order to find the equivalent twisting and bending moments.

38 **A shaft of 750 mm long is subjected to shear stress of 40 MPa and has an angle of twist 0.017 radian.**
Determine the diameter of the shaft. Take G = 0.8×10^5MPa. (Nov 2013)(BTL3)

Angle of twist, $\theta = \frac{Tl}{GJ} = \frac{\frac{\pi}{16}\times\tau\times d^3\times l}{G\times\frac{\pi d^4}{32}} = \frac{2\tau l}{G\times d}$

$$0.017 = \frac{2\times 40\times 750}{0.8\times 10^5\times d}$$

d = 44.11 mm

	The standard diameter is **45 mm.**
39	**Shaft A has diameter which is double the diameter of shaft B of same material and transmit 80 kW if both shafts rotate at same speed, what is the power transmitted by shaft B. (Nov.2014)** (BTL3) $P = \frac{2\pi N T_A}{60} = 80\ kW$ $T_A = \frac{\pi}{16}\tau(d_A)^3$ = S $T_B = \frac{\pi}{16}\tau(d_B)^3$ $T_B = \frac{1}{8}T_A$ $P_B = \frac{2\pi N T_B}{60} = \frac{1}{8} \times 80 = \mathbf{10\ kW}$
	PART * B
1	**Design a rectangular key for the following application: A shaft 65 mm diameter transmits power at maximum shear stress of 67 MPa. The shear stress in the key should not exceed 75 % of the stress developed in the shaft. The key should be at least 2.5 times strong in crushing compared to shear failure of the key. (13 M) (May 2017)** BTL 6 **Answer: Page: 344 - P.C.Gope** From **DDB Page 5.16**, Select Key dimensions: **b = 18 mm** and **h = 11 mm** corresponding to shaft diameter 65 mm. **(2 M)** Limiting shear stress in the key, τ_{key} = 0.75 x 67 = **50.25 MPa** Limiting crushing stress in the key, $\sigma_{c, key}$ = 2.5 x 50.25 = **125.625 MPa** **(2 M)** $T = \frac{\pi}{16}\tau\ d^3$ = **3612.807 x 10^3 N-mm** **(2 M)** Shear stress induced in the key $\tau = \frac{2T}{dbl}$ Given that shear stress in the key = 75% of shear in the shaft $\frac{2T}{dbl}$ =0.75 x 67 $\boldsymbol{l = 123\ mm}$ **(4 M)** From crushing failure consideration, $\sigma_c = \frac{4T}{dhl} = 125.625$ $\boldsymbol{l = 160.88\ mm}$ **(3 M)** Hence, the length of the key is 161 mm
2	**Design a muff coupling to connect two steel shafts transmitting 25 kW power at 360 rpm. The shafts and key are made of plain carbon steel 30C8 ($S_{yt} = S_{yc}$ = 400 N/mm^2). The sleeve is made of grey cast iron FG 200 (S_{ut} = 200 N/mm^2). The factor of safety for the shafts and key is 4. For the sleeve, the factor of safety is 6 based on ultimate strength.** **(13 M) (May 2017)** BTL 6

Answer: Page: 358 – V.B.Bhandari

Step I Permissible stresses:

For the material of shafts and key,

$$\sigma_t = \frac{S_{yt}}{F.S.} = \frac{400}{4} = \mathbf{100\ N/mm^2}$$

$$\sigma_c = \frac{S_{yc}}{F.S.} = \frac{400}{4} = \mathbf{100\ N/mm^2}$$

$$\tau = \frac{S_{sy}}{F.S.} = \frac{0.5\, S_{yt}}{4} = \mathbf{50\ N/mm^2}$$

For sleeve material, $\tau = \frac{S_{su}}{F.S.} = \frac{0.5\, S_{ut}}{6} = \mathbf{16.67\ N/mm^2}$

(4 M)

Step II Diameter of each shaft:

$$M_t = \frac{60 \times 10^6}{2\pi N} = 663145.60\ \boldsymbol{N - mm}$$

W.k.t.

$$\tau = \frac{16\, M_t}{\pi d^3}$$

∴ d = 40.73 or **45mm**

(2 M)

Step III Dimensions of sleeve:

D = (2d + 13) = 2 x 45 + 13 = 103 or **105 mm**

L = 3.5d = 3.5 (45) = 157.5 or **160 mm**

The torsional shear stress in the sleeve is calculated by treating it as a hollow cylinder.

$$J = \frac{\pi(D^4 - d^4)}{32} = \frac{\pi(105^4 - 45^4)}{32} = 11530626.79\ mm^4$$

R = D/2 = 105/2 = 52.5 mm

$$\tau = \frac{M_t r}{J} = \frac{(663145.60)(52.5)}{(11530626.79)}$$

=3.02 N/mm^2

$$\therefore\ \tau < 16.67 \frac{N}{mm^2}$$

(3 M)

Step IV Dimensions of key:

From DDB Page: 5.16; the standard cross-section of flat sunk key for a 45 mm diameter shaft is 14 x 9 mm. The length of key in each shaft is one-half of the length of sleeve.

Therefore, l=L/2 = 160/2 = **80 mm**

The dimensions of the key are 14 x 9 x 80 mm.

(2M)

Step V Check for stresses in key:

W.K.T.

$$\tau = \frac{2\, M_t}{dbl} = \frac{2\,(663145.60)}{(45)(14)(80)} = 26.32\ N/mm^2$$

$$\therefore \boldsymbol{\tau} < 50\ N/\boldsymbol{mm^2}$$

$$\sigma_c = \frac{4\, M_t}{dhl} = \frac{4\,(663\,145.60)}{(45)(9)(80)} = 81.87\ N/mm^2$$

	$\therefore \boldsymbol{\sigma_c} < 100\ N/\boldsymbol{mm^2}$ The design of the key is safe from shear and compression considerations. **(2 M)**
3	**Design and make a neat dimensioned sketch of a muff coupling which is used to connect two steel shafts transmitting 40 kW at 350 rpm. The material for the shafts and key is plain carbon steel for which allowable shear and crushing stresses may be taken as 40 MPa and 80 MPa respectively. The material for the muff is cast iron for which the allowable shear stress may be assumed as 15 MPa. (13 M) (Nov.2016) (Apr.2011)** BTL 6 **Answer: Page: 2.98 - E.V.V.Ramanamurthy, Page: 481 - R.S.Khurmi & J.K.Gupta** **Step-1:Design for shaft:** Let d = Diameter of the shaft We know that the torque transmitted by the shaft, key and muff, $$T = \frac{P \times 60}{2\pi N} = 1100 \times 10^3 N - mm$$ We also know that the torque transmitted (T), $$1100 \times 10^3 = \frac{\pi}{16} \times \tau \times d^3$$ By calculation, ***d* = 52 say 55 mm** **(3 M)** **Step-2: Design for sleeve:** Outer diameter of the muff, $D = 2d + 13$ mm = 2 × 55 + 13 = 123 say **125 mm** Length of the muff, $L = 3.5\ d$ = 3.5 × 55 = 192.5 say **195 mm** $$1100 \times 10^3 = \frac{\pi}{16} \times \tau_c \left(\frac{D^4 - d^4}{D}\right)$$ $\therefore\ \tau_c$ **= 2.97 N/mm^2** Since the induced shear stress in the muff (cast iron) is less than the permissible shear stress of 15 N/mm^2, therefore the design of muff is safe. **(3 M)** **Step-3: Design for key:** From DDB Page: 5.16, we find that for a shaft of 55 mm diameter (Shaft diameter range 50 – 58), Width of key, ***w* = 16 mm** Since the crushing stress for the key material is twice the shearing stress, therefore a square key may be used. ∴ Thickness of key, ***t* = *w* = 16 mm** We know that length of key in each shaft, $l = L / 2$ = 195 / 2 = **97.5 mm** **(3 M)** **Shearing of the key:** We know that torque transmitted (T),

$$1100 \times 10^3 = l \times w \times \tau_{sk} \times \frac{d}{2}$$

$\boldsymbol{\tau_{sk} = 22.8\ N/mm^2}$

Crushing of the key:

$$1100 \times 10^3 = l \times \frac{t}{2} \times \sigma_{ck} \times \frac{d}{2}$$

$\boldsymbol{\sigma_{ck} = 45.6\ N/mm^2}$

Since the induced shear and crushing stresses are less than the permissible stresses, therefore the design of key is safe.

(4 M)

4 **A hollow shaft of 0.5 m outside diameter and 0.3 m inside diameter is used to drive a propeller of a marine vessel. The shaft is mounted on bearings 6 metre apart and it transmits 5600 kW at 150 rpm. The maximum axial propeller thrust is 500 kN and the shaft weighs 70 kN.**

Determine

(i) The maximum shear stress developed in the shaft, and (ii) The angular twist between the bearings. (13 M) (Nov.2016) BTL 5

Answer: Page: 546 - R.S.Khurmi and J.K.Gupta

(i) The maximum shear stress developed in the shaft:

$$T = \frac{P \times 60}{2\pi N} = 356460\ N - m$$

$$M = \frac{WL}{8} = 52500\ N - m$$

Let, r = radius of gyration,

$$r = \sqrt{\frac{I}{A}} = \sqrt{\frac{\frac{\pi}{64}\left[(d_o)^4 - (d_i)^4\right]}{\frac{\pi}{4}\left[(d_o)^2 - (d_i)^2\right]}}$$

$r = \mathbf{0.1458\ m}$

(4 M)

∴ Slenderness ratio, L/r = 41.15

$$and\ column\ factor, \alpha = \frac{1}{1 - 0.0044\left(\frac{L}{r}\right)} = 1.22$$

Assume that the load is applied gradually on the revolving shaft

From DDB Page: 7.21,

Kb = 1.5 and Kt = 1

Also k = di/do = 0.3/0.5 = 0.6

Equivalent twisting moment for hollow shaft,

$$T_e = \sqrt{\left[K_b M + \frac{\alpha F d_o (1 + k^2)}{8}\right]^2 + (K_t T)^2} = 380 \times 10^3 N - m$$

We also know that,

$$T_e = \frac{\pi}{16} \tau (d_o)^3 (1 - k^4)$$

∴ τ = **19 N/mm²**

(4 M)

(ii) The angular twist between the bearings:

$$J = \frac{\pi}{32}[(d_o)^4 - (d_i)^4] = 0.00534\, m^4$$

(2 M)

From Torsion equation,

$$\frac{T}{J} = \frac{G\theta}{L}$$

We have,

$$\theta = \frac{T\,L}{G\,J} = 0.0048\, rad = \mathbf{0.275°}$$

(3 M)

5 **Design and draw a protective type of cast iron flange coupling for a steel shaft transmitting 15 kW at 200 r.p.m. and having an allowable shear stress of 40 MPa. The working stress in the bolts should not exceed 30 MPa. Assume that the same material is used for shaft and key and that the crushing stress is twice the value of its shear stress. The maximum torque is 25% greater than the full load torque. The shear stress of cast iron is 14 MPa. (13 M) (May 2016)** BTL6

Answer: Page: 490 - R.S.Khurmi & J.K.Gupta

Step-1: Design for hub:

$$T_{mean} = \frac{P \times 60}{2\pi N} = 716 \times 10^3 N - mm$$

$$T_{max} = 1.25\, T_{mean} = 895 \times 10^3 N - mm$$

$$895 \times 10^3 = \frac{\pi}{16} \times \tau_s \times d^3$$

d = 48.4 mm say 50 mm

(2 M)

We know that the outer diameter of the hub, $D = 2\, d = 2 \times 50 =$ **100 mm**

and length of the hub, $L = 1.5\, d = 1.5 \times 50 =$ **75 mm**

Let us now check the induced shear stress for the hub material which is cast iron, by considering it as a hollow shaft.

We know that the maximum torque transmitted (*Tmax*),

$$895 \times 10^3 = \frac{\pi}{16} \times \tau_c \times \left(\frac{D^4 - d^4}{D}\right)$$

$$\boldsymbol{\tau_c = 4.86\, MPa}$$

Since the induced shear stress in the hub is less than the permissible value of 14 MPa, therefore the design for hub is safe.

(2 M)

Step-2: Design for key:

Since the crushing stress for the key material is twice its shear stress, therefore a square key may be used.

From DDB Page: 5.16, we find that for a shaft of 50 mm diameter (Shaft diameter range 50 – 58),

Width of key, ***w* = 16 mm**

Since the crushing stress for the key material is twice the shearing stress, therefore a square key

may be used.
∴ Thickness of key, ***t* = *w* = 16 mm**
The length of key (l) is taken equal to the length of hub. l = L = **75 mm**

Shearing of the key:
We know that torque transmitted (*T*),

$$895 \times 10^3 = l \times w \times \tau_{sk} \times \frac{d}{2}$$

$\boldsymbol{\tau_{sk} = 29.8\, N/mm^2 = 29.8 MPa}$

(2 M)

Crushing of the key:

$$895 \times 10^3 = l \times \frac{t}{2} \times \sigma_{ck} \times \frac{d}{2}$$

$\boldsymbol{\sigma_{ck} = 59.6\, N/mm^2 = 59.6 MPa}$

(2 M)

Since the induced shear and crushing stresses are less than the permissible stresses, therefore the design of key is safe.

Step-3: Design for flange:
The thickness of the flange (t_f) is taken as 0.5 d.
$t_f = 0.5 \times 50 =$ **25 mm**

$$895 \times 10^3 = \frac{\pi D^2}{2} \tau_c t_f$$

$\tau_c = 2.5\, \boldsymbol{N/mm^2 = 2.5 MPa}$

(2 M)

Since the induced shear stress in the flange is less than the permissible value of 14 MPa, therefore the design for flange is safe.

Step-4:Design for bolts:
Let d_1 = Nominal diameter of bolts.
Since the diameter of shaft is 50 mm, therefore let us take the number of bolts, $n = 4$
and pitch circle diameter of bolts, $D_1 = 3\,d = 3 \times 50 =$ **150 mm**

$$895 \times 10^3 = \frac{\pi}{4}(d_1)^2 \tau_b n \frac{D_1}{2}$$

d_1 = 11.25 mm

(2 M)

Assuming coarse threads, the nearest standard diameter of the bolt is 12 mm (M 12).
Other proportions of the flange are taken as follows:
Outer diameter of the flange,
$D_2 = 4\,d = 4 \times 50 =$ **200 mm**
Thickness of the protective circumferential flange, $t_p = 0.25\,d = 0.25 \times 50 =$ **12.5 mm**

(1 M)

6 **Design a shaft to transmit power from an electric motor to a lathe head stock through a pulley by means of a belt drive. The pulley weights 200 N and is located at 300 mm from the center of the bearing. The diameter of the pulley is 200 mm and the maximum power transmitted is 1 kW at 120 rpm. The angle of lap of the belt is 180^0 and coefficient of friction**

	between the belt and the pulley is 0.3. The shock and fatigue factors for bending and twisting are 1.5 and 2 respectively. The allowable shear stress in the shaft may be taken as 35 MPa. (13 M) (Nov.2011) BTL 6 **Answer: Page: 447 - R.S.Khurmi and J.K.Gupta** $T = \frac{P \times 60}{2\pi N} = \frac{1000 \times 60}{2\pi \times 120} = 79.6$ N-m **(2 M)** $T_1 - T_2 = \frac{79.6 \times 10^3}{100} = 796\ N$ …. (i) **(2 M)** $\log\left(\frac{T_1}{T_2}\right) = \frac{0.9426}{2.3} = 0.4098$ $\frac{T_1}{T_2} = 2.57$ **…. (ii)** **(3 M)** From (i) and (ii), T_1 = 1303 N, T_2 = 507 N **(2 M)** WKT, Equivalent Twisting moment, $T_e = \sqrt{(K_m \times M)^2 + (K_t \times T)^2}$ $= \sqrt{(1.5 \times 603 \times 10^3)^2 + (2 \times 79.6 \times 10^3)^2}$ = 918 x 10^3 N-mm **(2 M)** Also, Equivalent Twisting moment, $T_e = \frac{\pi}{16}\tau d^3$ $918 \times 10^3 = 6.87\ d^3$ **d = 55 mm** **(2 M)**
7	**Design a rigid flange coupling to transmit a torque of 250 N-m between two coaxial shafts. The shaft is made of alloy steel, flanges out of cast iron and bolts out of steel. Four bolts are used to couple the flanges. The shafts are keyed to the flange hub. The permissible stresses are given below:** **Shear stress on shaft =100 MPa** **Bearing or crushing stress on shaft =250 MPa** **Shear stress on keys =100 MPa** **Bearing stress on keys =250 MPa** **Shearing stress on cast iron =200 MPa** **Shear stress on bolts =100 MPa** **After designing the various elements, make a neat sketch of the assembly indicating the important dimensions. The stresses developed in the various members may be checked if thumb rules are used for fixing the dimensions. (13M)(Nov.2013)**BTL6 **Answer: Page: 494 - R.S.Khurmi and J.K.Gupta** **Step-1.Design of shaft diameter:** W.K.T., $T = \frac{\pi}{16}\tau d^3$ By substitution of τ and T values, we get d = 23.35 mm **Say 24 mm** **(1 M)** **Step-2.Other dimensions of the flange coupling:**

Length of sleeve, **L** = 3.5 d = **84 mm**
Thickness of flange, t_f = 0.5 d **= 12 mm**
Outer diameter of hub, **D =** 2 d **= 48 mm**
Pitch circle dia. Of bolts, D_1 = 3d = **72 mm**
Outside dia. of flange, D_2 **=** 4d = **96 mm** **(2 M)**

Step-3.Design of hub:

$T = \frac{\pi}{16}\tau_{hub} D^3(1-k^4)$; k = d/D = 0.5; $\tau_{hub} = 12.28 \frac{N}{mm^2}$

The design is satisfactory, since the calculated value is within design stress. **(2 M)**

Step-4.Design of key:

From PSG DDB 5.16,
For shaft dia. D =24 mm, width of key, b = 8 mm
and height of key, h = 7 mm
Length of key, l = L/2 = 42 mm

$$T = b \times l \times \tau_{key} \times \frac{d}{2}$$

From calculation, $\tau_{key} = 62.003 \frac{N}{mm^2}$
As $\tau_{key}\ (calculated) < \tau_{key}\ (design$ value)
Therefore, the design is satisfactory. **(2 M)**

Step-5.Design of flange:

$$T = \pi \times \frac{D^2}{2} \times t_f \times \tau_{flange}$$

By calculation, $\boldsymbol{\tau_{flange} = 5.756bN/mm^2}$
The design is satisfactory, since the calculated value is within design stress. **(2 M)**

Step-6.Design of bolt:

(a) Considering shearing

$T = n \times \frac{\pi}{4} \times \tau_{bolt} \times (d_b)^2 \frac{D_1}{2}$ ---- (1)

Tangential force acting on the bolt circle, F_t = T / Radius of the bolt circle

$F_t = \frac{T}{\frac{3d}{2}}$ = 6944.44 N

$F_{tb} = \frac{F_t}{n}$ =1736.11 N

Also, $F_{tb} = \frac{\pi}{4} \times (d_b)^2 \times \tau_{bolt}$

d_b = **4.70 mm**

From equation (1), $\tau_{bolt} = 96.82\ N/mm^2$

The design is satisfactory, since the calculated value is within design stress. **(2 M)**

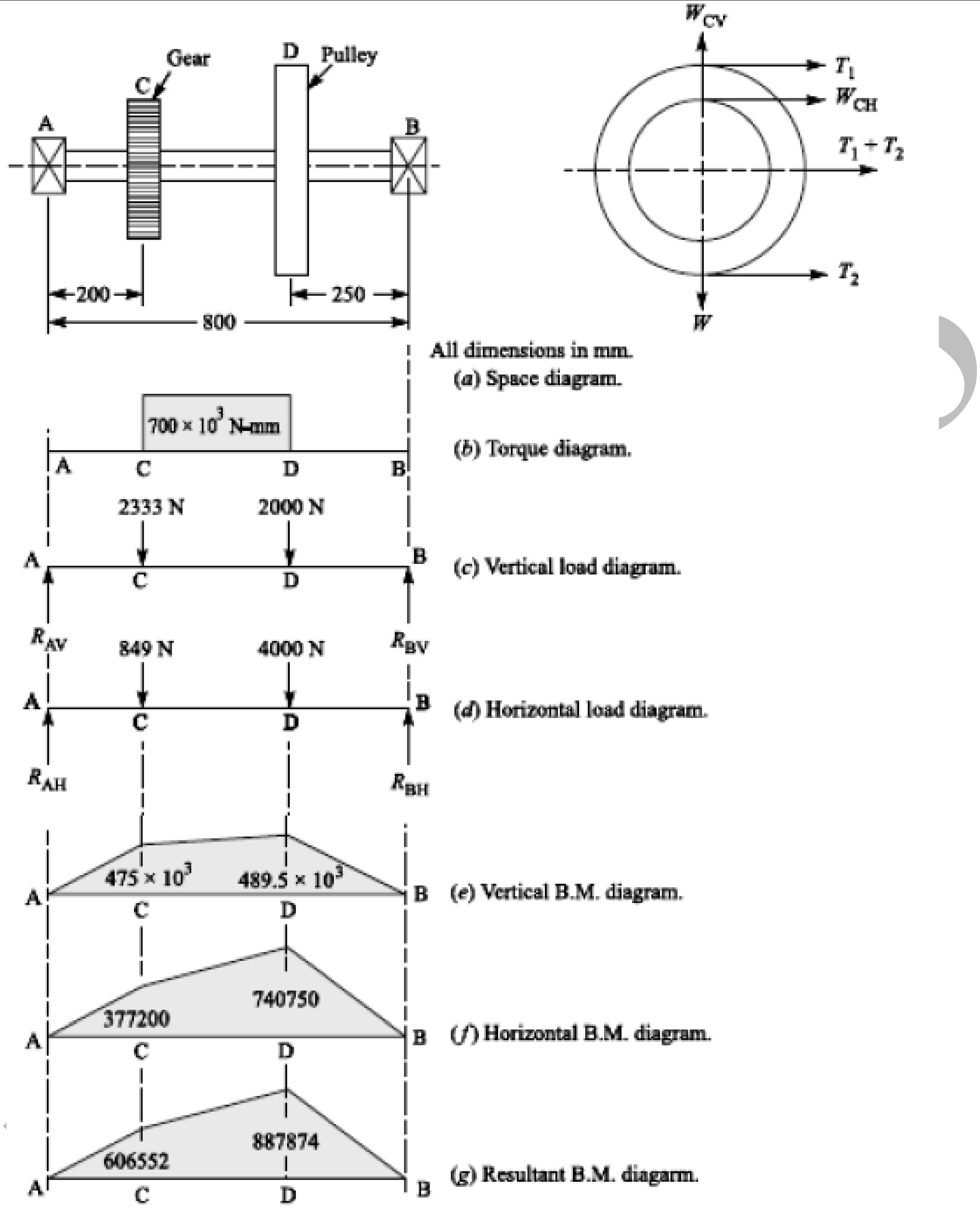
(b) Considering crushing

$$T = n \times (t_f d_b) \times (\tau_c)_{bolt} \times (d_b)^2 \frac{D_1}{2}$$

By calculation, $(\tau_c)_{bolt} = 30.78\ N/mm^2$

The design is satisfactory, since the calculated value is within design stress. **(2 M)**

	PART- C
1	**A shaft is supported on bearings A and B, 800 mm between centers. A 20º straight tooth spur gear having 600 mm pitch diameter, is located 200 mm to the right of the left hand bearing A, and a 700 mm diameter pulley is mounted 250 mm towards the left of bearing B. The gear is driven by a pinion with a downward tangential force while the pulley drives a horizontal belt having 180º angle of wrap. The pulley also serves as a flywheel and weighs 2000 N. The maximum belt tension is 3000 N and the tension ratio is 3:1. Determine the maximum bending moment and the necessary shaft diameter if the allowable shear stress of the material is 40 MPa. (15 M) (Apr.97,Oct.2006)**BTL 5 **Answer: Page: 441 - R.S.Khurmi and J.K.Gupta** $$M_D = \sqrt{(M_{DV})^2 + (M_{DH})^2} = \mathbf{887\ 874\ Nmm}$$ **Maximum bending moment is 887.87 N-m** **(3 M)** $T_{e=} \sqrt{M^2 + T^2} = \mathbf{1131\ \times 10^3\ Nmm}$ Also, $T_e = \frac{\pi}{16} \tau d^3$ $d^3 = 144 \times 10^3$ **d = 55 mm** Necessary shaft diameter is **55 mm** **(6 M)**

	 **(6M)**
2	**A solid steel shaft is supported on two bearings 1.8 m apart and rotates at 250 r.p.m. A 20° involute gear D, 300 mm diameter is keyed to the shaft at a distance of 150 mm to the left on the right hand bearing. Two pulleys B and C are located on the shaft at distances of 600 mm and 1350 mm respectively to the right of the left hand bearing. The diameters of the pulleys B and C are 750 mm and 600 mm respectively. 30 kW is supplied to the gear, out of which 18.75 kW is taken off at the pulley C and 11.25 kW from pulley B. The drive from B is vertically downward while from C the drive is downward at an angle of 60° to the**

horizontal. In both cases the belt tension ratio is 2 and the angle of lap is 180°. The combined fatigue and shock factors for torsion and bending may be taken as 1.5 and 2 respectively.
Design a suitable shaft taking working stress to be 42 MPa in shear and 84 MPa in tension. (15 M) (May 2016) BTL6
Answer: Page: 539 - R.S.Khurmi & J.K.Gupta

For gear D:
We know that torque transmitted by the gear *D*,

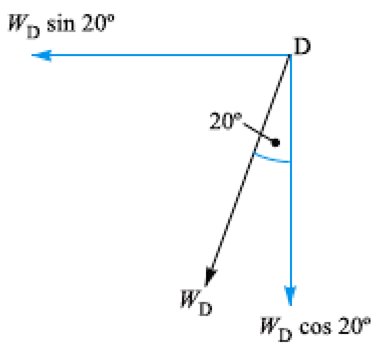
$$T_D = \frac{P_D \times 60}{2\pi N} = 1146\ N - m$$

Tangential force acting on the gear D,

$$F_{tD} = \frac{T_D}{R_D} = 7640\ N$$

Normal load acting on the gear tooth,

$$W_D = \frac{F_{tD}}{\cos 20°} = 8130\ N$$



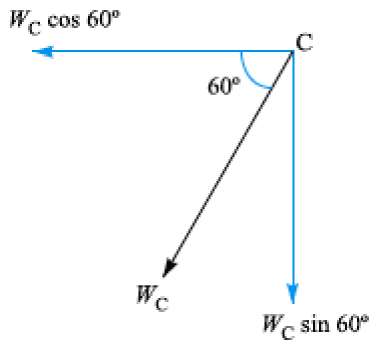
Vertical component of W_D,
$= W_D cos 20° = 7640$ N
Horizontal component of W_D,
$= W_D sin 20° = 2780$ N

(3 M)

For pulley C:
We know that torque transmitted by pulley *C*,

$$T_c = \frac{P_c \times 60}{2\pi N} = 716\ N - m$$

$716 = (T_{c1} - T_{c2})\ R_C$
$T_{c1} - T_{c2} = 2387$ N
$T_{C1} / T_{C2} = 2$
$T_{c2} = 2387$ N; $T_{c1} = 4774$ N
$W_C = T_{C1} + T_{C2} = 7161$ N



Vertical component of W_C,
$= W_c sin 60° = 6200$ N
Horizontal component of Wc,
$= W_D \cos 60° = 3580$ N

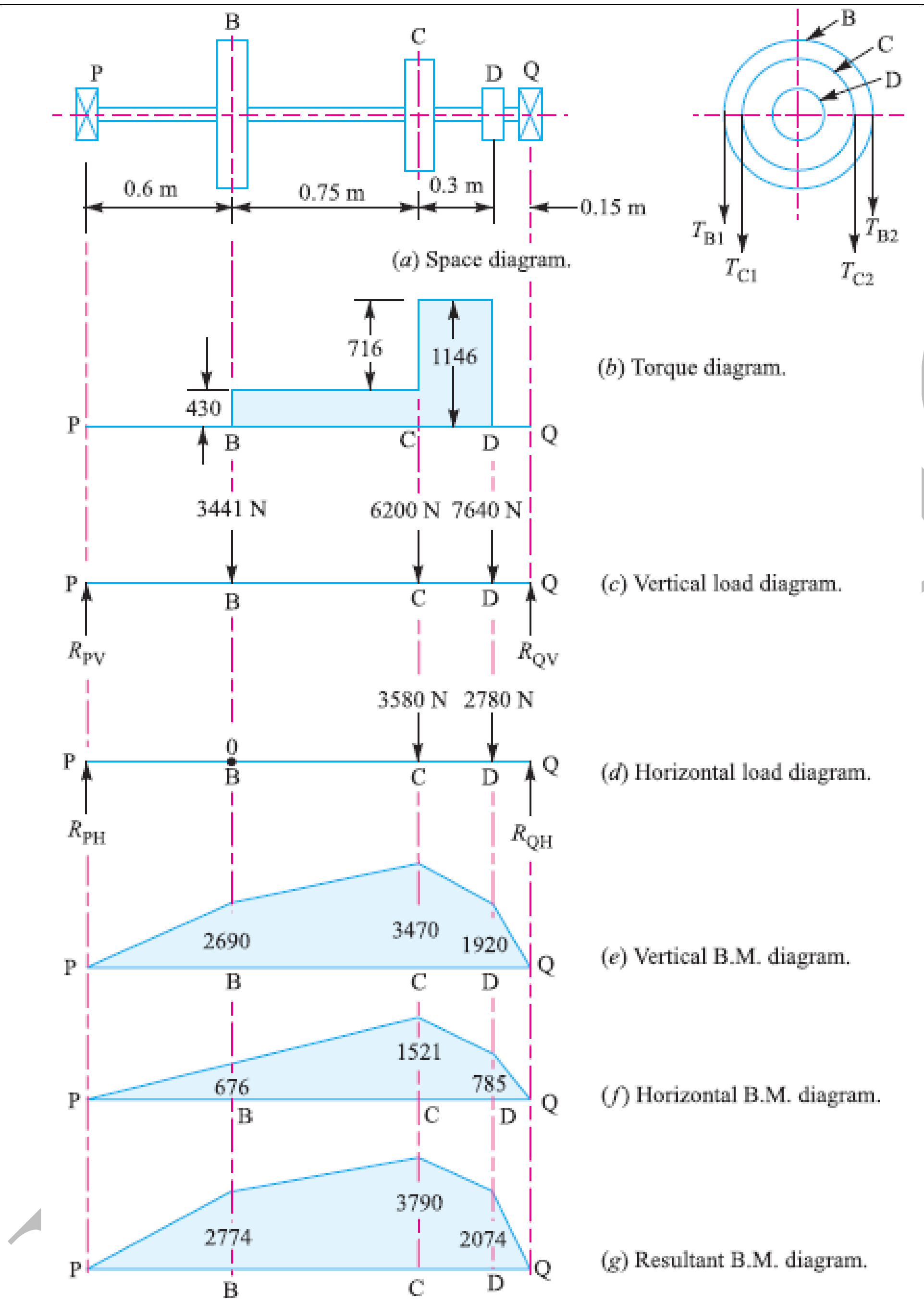
(3 M)

For pulley B:
We know that torque transmitted by pulley *B*,

$$T_B = \frac{P_B \times 60}{2\pi N} = 430\ N - m$$

$430 = (T_{B1} – T_{B2})\ R_B$
$T_{B1} / T_{B2} = 2$
T_{B2} =1147 N; T_{B1} = 2294 N
$W_B = T_{B1} + T_{B2} = 3441$N
Vertical loading:
R_{PV} and R_{QV} be the reactions at bearings P and Q respectively for vertical loading.
We know that
$R_{PV} + R_{QV}$ = 17 281 N
Taking moments about *P*, we get
$R_{QV} \times 1.8$ = 23 041
Taking moments about *P*, we get
R_{PV} = 4481 N
$M_{PV} = M_{QV} = 0$
B.M. at B, $M_{BV} = 4481 \times 0.6 = 2690$ N-m
B.M. at C, $M_{CV} = 4481 \times 1.35 – 3441 \times 0.75 = 3470$ N-m
B.M. at D, M_{DV} = 12 800 × 0.15 = 1920 N-m

(3 M)



Horizontal loading:

$R_{PH} + R_{QH} = 6360$ N

$R_{QH} \times 1.8 = 9420$ N

$R_{QH} = 5233$ N

$RPH = 6360 – 5233 = 1127$ N

$M_{PH} = M_{QH} = 0$

B.M. at B, $M_{BH} = 1127 \times 0.6 = 676$ N-m

	B.M. at C, M_{CH} = 1127 × 1.35 = 1521 N-m B.M. at D, M_{DH} = 5233 × 0.15 = 785 N-m **(3 M)** Resultant B.M. at B = $\sqrt{(M_{BV})^2+(M_{BH})^2}$ = 2774 N-m Resultant B.M. at C = $\sqrt{(M_C)^2+(M_{CH})^2}$ = 3790 N-m Resultant B.M. at D = $\sqrt{(M_{DV})^2+(M_{DH})^2}$ = 2074 N-m Resultant bending moment is maximum at *C*. M_{max} = M_C = 3790 N-m and maximum torque at *C*, T = Torque corresponding to 30 kW = T_D = 1146 N-m Equivalent twisting moment, $T_e = \sqrt{(K_m \times M)^2 + (K_t \times T)^2}$= **7772 x 10^3 N-m** $7772 \times 10^3 = \frac{\pi}{16} \times \tau \times d^3$ **d = 98 mm** $M_e = \frac{1}{2}\left[K_m \times M + \sqrt{(K_m \times M)^2 + (K_t \times T)^2}\right]$ = **7676 x 10^3 N-m** Also, $M_e = \frac{\pi}{32} \times \sigma_b \times d^3$ **d = 97.6 mm** Taking the larger of the two values, we have **d = 98 say 100 mm** **(3 M)**
3	**Design a clamp coupling to transmit 30 kW at 100 r.p.m. The allowable shear stress for the shaft and key is 40 MPa and the number of bolts connecting the two halves are six. The permissible tensile stress for the bolts is 70 MPa. The coefficient of friction between the muff and the shaft surface may be taken as 0.3. (15 M)(May 2013)** BTL 6 **Answer: Page: 484 - R.S.Khurmi & J.K.Gupta** **Step-1.Design of shaft:** P $= \frac{2\pi NT}{60}$ T = $\frac{\pi}{16}\tau_s d^3$ $d^3 = \frac{2865 \times 10^3}{7.86}$ So **d = 71.4 say 75 mm** **(4 M)** **Step-2.Design for Muff:** D = 2d + 13 mm = **163 mm** L = 3.5 d = **262.5 mm** **(3 M)** **Step-3.Design for key:** From DDB 5.16, Width of key, **w = 22 mm** Thickness of key, **t = 14 mm** Length of key = length of muff = **262.5 mm** **(4 M)** **Step-4.Design of bolts:**

	$$2865 \times 10^3 = \frac{\pi^2}{16} \times \mu(d_b)^2 \sigma_t \times n \times d = 5830(d_b)^2$$ **$d_b = 22.2\ mm$** **(4 M)**
4	**Determine the dimensions of flange coupling that connects a motor and a pump shaft. The power to be transmitted is 2 KW at a shaft speed of 960 rpm. Select suitable materials for the parts of the coupling and list the dimensions. (15 M)** BTL 5 **Answer: Page: 532 - R.S.Khurmi & J.K.Gupta** $\tau_b = \tau_k = \tau_s = 45 N/mm^2$ $\sigma_{ck} = \sigma_{cb} = 160 N/mm^2$ P $= \frac{2\pi NT}{60}$ T= $\frac{60\ X\ 2\ X 10^3}{2 X \pi X\ 960}$ T = 19.90 N-m T = $\frac{\pi}{16}\tau_s d^3$ d = 13.11 Say **15mm** **(3 M)** **Step-1.Design of hub:** D = 2d = 2X15 = 30mm T = $\frac{\pi}{16}\tau_{ci}[DE4 - de4]$ $\tau_{ci} = 4 N/mm^2 < 8 N/mm^2$ So, design of hub is safe. **(3 M)** **Step-2.<u>Design of Key:</u>** For d = 15 mm W= 5 mm, t = 5mm From DDBP.No.5.16 L=1.5d = 1.5(15) = 22.5 mm= l **(2 M)** **Step-3.<u>Checking induced shear stress:</u>** T = l w $\tau_k[d/2]$ $\tau_k = 23.58$ N/mm2 < 45 N/mm^2 **Step-4.<u>Checking induced crushing stress:</u>** T = l $(t/2)\sigma_{ck}(d/2)$ $\sigma_{ck} = 47.17 N/mm^2 < 160N/mm^2$ Induced shear and crushing stresses for key material are under safe limit.therefore design of key is safe. **(3 M)** **Step-5.<u>Design of Flange:</u>** D = 2d = 2(15) = 30mm L = 1.5 d = 1.5 (15) = 22.5 mm D_1= 3d = 3(15) = 45 mm D_2 = 4d = 4(15) = 60 mm t_f = d/2 = 15/2 = 7.5 mm t_r = d/4 = 15/4 = 3.75 mm **(2 M)** **Step-6.<u>Design of bolts:</u>** T = $\frac{\pi}{4} d_1^2 \tau_b n[D1/2]$ N = 3 upto d = 40 mm

	d_1 = 2.88 mm from page 5.42 (DDB) M_4 size of bolts is selected **(2 M)**
UNIT III - TEMPORARY AND PERMANENT JOINTS	
Threaded fasteners - Bolted joints including eccentric loading, Knuckle joints, Cotter joints – Welded joints, riveted joints for structures - theory of bonded joints.	
Q.No.	**PART * A**
1	**Why throat is considered while calculating stresses in fillet welds? (May 2017)**BTL1 Failure of the fillet weld occurs due to shear along the minimum cross-section at the throat. So it is required to consider the throat while calculating stresses in fillet welds. The minimum area of the weld is obtained at the throat, which is given by the product of the throat thickness and length of weld.
2	**What are the different applications of screwed fasteners? (Nov. 2017)** BTL1 The helical thread screw is the basis of power screws which change angular motion into linear motion to transmit power or to develop larger forces (presses, jacks, etc).
3	**State the two types of eccentric welded connection.(Nov. 2017, Nov. 2013)** BTL2 • Framed beam connection • Column bracket connection
4	**What are the stresses acts on screw fastenings due to static loading? (May 2016)** BTL1 • Initial stresses due to screwing up • Stresses due to external forces • Combined stresses
5	**List the two types of fillet weld. (May 2016)** BTL1 • Transverse fillet weld • Parallel fillet weld
6	**What is the total shear in a double strap butt joint with equal length of straps? (Nov. 2015)** BTL1 In a double strap butt joint, the edges of the main plates butt against each other and two cover plates are placed on both sides of the main plates and then riveted together.
7	**Calculate the bending stress induced in the weld when a circular rod of diameter d, welded to a rigid plate by a circular fillet weld of size 't', which is subjected to a bending moment 'M'. (Nov. 2015)** BTL2 Bending stress due to bending moment (M) may be calculated by bending stress equation $\sigma b = P \times e / Zw$
8	**Why Are ACME threads preferred over square thread for power screw? (Nov.2014)** BTL2 ACME threads are stronger than the square thread. These threads are frequently used on screw cutting lathes, brass valves, cocks and bench vices.
9	**List the disadvantages of welding. (Nov.2014)** BTL1 • It requires a highly skilled labour and supervisors, • The inspections of welding work is more difficult than riveting work • Since there is an uneven heating and cooling during fabrication, the members may be distorted and additional stresses may develop.

10	**Define gib. Why is it provided in a cotter joint? (Nov.2013)** BTL1 Gib is an element made up of mild steel with thickness equal to cotter. A gib is used in combination with cotter to provide the following advantages: • Reduce bending of socket, and • increasing the bending area of contact between the mating surfaces
11	**Define the term self-locking of power screws. (Nov. 2012)** BTL1 If the friction angle (φ) is greater than helix angle (α) of the power screw, the torque applied to lower the load will be positive, indicating that an effort is applied to lower the load. This type of screw is known as self-locking screw.
12	**What are the possible modes of failure in riveted joint? (Nov.2012, May2011)** BTL1 • Crushing of rivets • Shearing of rivet • Tearing of the plate at the edge • Tearing of the plate between rivets
13	**What do you understand by the single start and double start threads? (Nov.2011)** BTL1 A screw made by cutting a single helical groove on the cylinder is known as single threaded (or single-start) screw and if a second thread is cut in the space between the grooves of the first, a double threaded (or double-start) screw is formed.
14	**Classify the rivet heads according to IS specifications. (Nov.2011)** BTL2 According to Indian standard specifications, the rivet heads are classified into the following three types: • Rivet heads for general purposes (below 12 mm diameter) according to IS : 2155 – 1982 (Reaffirmed 1996) • Rivet heads for general purposes (From 12 mm to 48 mm diameter), according to IS: 1929 – 1982 (Reaffirmed 1996) • Rivet heads for boiler work (from 12 mm to 48 mm diameter), according to IS : 1928 – 1961 (Reaffirmed 1996).
15	**Where the knuckle joints can be used? (May 2011)** BTL2 Knuckle joints are used in the automobiles. Knuckle joint is used for connecting two rods and transmitting axial force. This joint permits a small amount of flexibility.
16	**State three conditions where tap bolts are used. (Nov.2010)** BTL2 • One of the parts is thick enough to accommodate a threaded hole. • It has sufficient strength to ensure durable threads • There is no place to accommodate the nut
17	**What are reasons of replacing riveted joint by welded joint in modern equipment? (Nov. 2010)** BTL2 • Welded joints provide maximum efficiency • Alterations can be easily made • It has good strength • Provides vary rigid joint
18	**How is bolt designated? Give example.** BTL2 M30 × 2.5

Md × P
M – Metric thread
d – Nominal diameter in ‘mm’
P – Pitch in ‘mm’

19 **How will you fulfill the condition of minimum weld size?** BTL2

It is defined as the minimum size of the weld for a given thickness of the thinner part joined or plate to avoid cold cracking by escaping the rapid cooling.

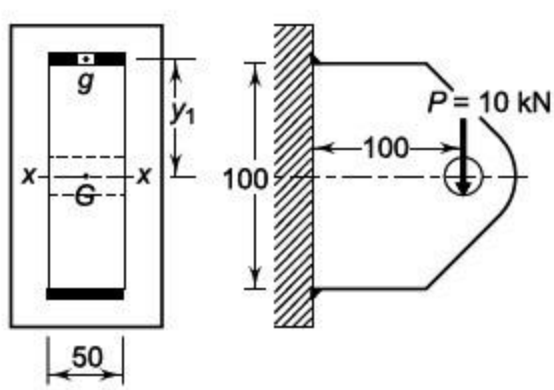
Size of fillet weld h = = 1.4142t

20 **Mention the various modes of failures in knuckle joints.** BTL2

- Failure of the solid rod in tension
- Failure of the knuckle pin in shear
- Failure of the single eye or rod end in tension
- Failure of the single eye or rod end in shearing
- Failure of the single eye or rod end in crushing
- Failure of the forked end in tension
- Failure of the forked end in shearing
- Failure of the forked end in crushing

PART * B

1 **A bracket is welded to the vertical column by means of two fillet welds as shown in Fig. Determine the size of the welds, if the permissible shear stress in the weld is limited to 70 N/mm^2. (13 M) (May 2017)** BTL5



Answer: Page : 291 – V.B.Bhandari

Step I Primary Shear Stress:

The area of the two welds is given by,

A = 2 (50 t) = (100 t) mm^2

The primary shear stress is given by, $\tau = \frac{P}{A} = \frac{100}{t}$ N/mm^2 … (i)

(3 M)

Step II Bending stress:

The moment of inertia of the top weld about the *X*-axis passing through its centre of gravity *g* is ($50t^3/12$). This moment of inertia is shifted to the centre of gravity of the two welds at *G* by the parallel axis theorem. It is given by,

$I_{xx} = \frac{50t^3}{12} + Ay_1^2 = \frac{50t^3}{12} + (50t)(50)^2$ mm^4

The dimension *t* is very small compared with 50. The term containing t^3 is neglected. Therefore,
$I_{xx} = 50^3$ t mm^4
Since there are two welds,
$I = 2\ I_{xx} = 250\ 000$ t mm^4
The bending stress in the top weld is given by,
$\sigma_b = \frac{M_b y}{I}$ = 200/t N/mm^2 … (ii) **(3 M)**

Step III Maximum shear stress:
The maximum principal shear stress in the weld is given by,

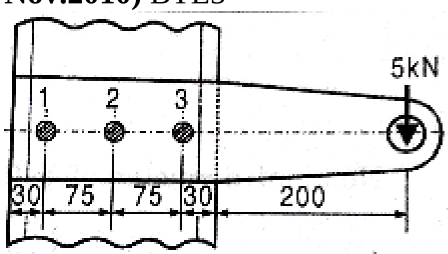
$$\tau = \sqrt{\left(\frac{\sigma_b}{2}\right)^2 + (\tau_1)^2} = 141.42/t \text{ N/mm}^2$$

(3 M)

Step IV Size of weld:
The permissible shear stress in the weld is 70 N/mm^2.
Therefore, 141.42/t = 70
t = 2.02 mm
h = t/0.707 = 2.86
h = 3mm

(4 M)

2 **A steel plate is subjected to a force of 5 kN and fixed to a channel by means of three identical bolts as shown in Fig. The bolts are made from 45C8 steel (Syt = 380 N/mm^2) and the factor of safety is 3. Specify the size of the bolts. (13 M) (May 2017, Nov.2014, Nov.2010)** BTL5



Answer: Page : 3.25 – E.V.V.Ramanamurthy and S.Ramachandran

Primary Shear Force:

$$W_1' = W_2' = W_3' = \frac{W}{No.of\ bolts} = \mathbf{1666.67\ N}$$

(3 M)

Secondary shear force:

$$W_1'' = W_3'' = \frac{W r_1 e}{r_1^2 + r_2^2} = \mathbf{10166.7\ N}$$

(3 M)

Resultant shear force at bolt (3):

$$W_3 = W_3'' + W_3' = \mathbf{11833.4\ N}$$

Shear Force:

$$\tau = \frac{0.557\sigma_y}{F.S.}$$

Take material as plain carbon steel

Refer PSG DDB P.No. 1.9,
Select yield stress value
σy = 380 N/mm^2
τ = 73.09 N/mm^2

(3 M)

Bolt dimensions:

$\tau = \frac{W_3}{A}$

Substituting W3 and τ values,
A = 161.09 mm^2
From $A = \frac{\pi}{4} {d_c}^2$
d_c = 14.35 mm
d = d_c/0.84 = 17.09 mm
The standard size of the bolt is **M20.**

(4 M)

3 **Figure.1 shows a solid forged bracket to carry a vertical load of 13.5 kN applied through the centre of hole. The square flange is secured to the flat side of a vertical stanchion through four bolts. Estimate the tensile load on each top bolt and the maximum shearing force on each bolt, if the permissible stress is 65 MPa in shear. All dimensions are in mm. (13 M) (Nov 2017)** BTL5

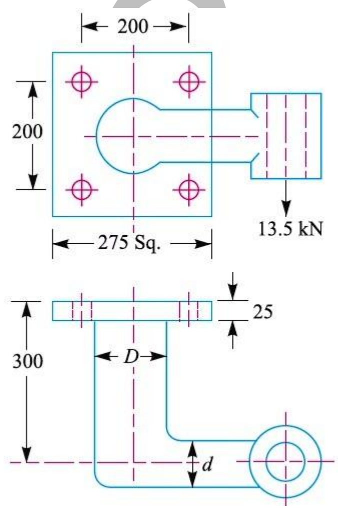


Figure.1

Answer: Page :424 – R.S.Khurmi and J.K.Gupta

Diameter D for the arm of the bracket:

The section of the arm having *D* as the diameter is subjected to bending moment as well as twisting moment.
We know that bending moment,
M = 13 500 × (300 – 25) = 3712.5 × 10^3 N-mm
and twisting moment, T = 13 500 × 250 = 3375 × 10^3 N-mm
Equivalent twisting moment, $T_e = \sqrt{M^2 + T^2}$ = 5017 × 10^3 N-mm
Also, Equivalent twisting moment, $T_e = \frac{\pi}{16}\tau D^3$
D = 73.24 say 75 mm **Ans.**

(3 M)

Diameter (d) for the arm of the bracket:

The section of the arm having *d* as the diameter is subjected to bending moment only.

We know that bending moment,

M = 13500 [250 – (75/2)] = 2869.8 x 10^3 N-mm

And section modulus, $z = \frac{\pi}{32} d^3 = 0.0982 d^3$

We know that bending (tensile) stress(σ_t),

σ_t = M/Z =

d = 64.3 say 65 mm **Ans.**

(3 M)

Tensile load on each top bolt:

Due to the eccentric load *W*, the bracket has a tendency to tilt about the edge *E*–*E*, as shown in Fig.2.

Let

w = Load on each bolt per mm distance from the tilting edge due to the tilting effect of the bracket.

Since there are two bolts each at distance *L*1 and *L*2 as shown in Fig.2,

therefore total moment of the load on the bolts about the tilting edge *E*–*E* =

$2(w.L_1)L_1 + 2(w.L_2)L_2 = 2w[(L_1)^2 + (L_2)^2]$= 115 625 w N-mm …(i)

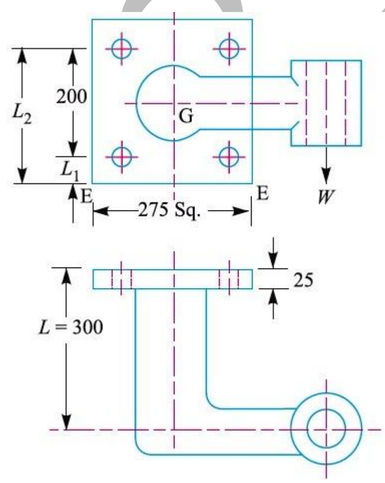


Figure.2

and turning moment of the load about the tilting edge

= *W.L* = 13 500 × 300 = 4050 × 103 N-mm ...(ii)

From equations (i) and (ii), we have

w = 4050 × 103 / 115 625 = 35.03 N/mm

∴ Tensile load on each top bolt

= *w.L*2 = 35.03 × 237.5 = 8320 N **Ans.**

(3 M)

Maximum shearing force on each bolt:

We know that primary shear load on each bolt acting vertically downwards,

We know that primary shear load on each bolt acting vertically downwards,

W_{s1} = W/n = 3375 N ...(∵ No. of bolts, n = 4)

Since all the bolts are at equal distances from the centre of gravity of the four bolts (G),

Therefore the secondary shear load on each bolt is same.
Distance of each bolt from the centre of gravity (G) of the bolts,
l1 = l2 = l3 = l4 = $\sqrt{100^2 + 100^2}$ = 141.4 mm
Secondary shear load on each bolt,
$W_{s2} = \frac{W.e.l_1}{(l_1)^2+(l_2)^2+(l_3)^2+(l_4)^2}$ = **5967 N**
Since the secondary shear load acts at right angles to the line joining the centre of gravity of the bolt group to the centre of the bolt as shown in Fig.3, therefore the resultant of the primary and secondary shear load on each bolt gives the maximum shearing force on each bolt.
From the geometry of the Fig. 3, we find that

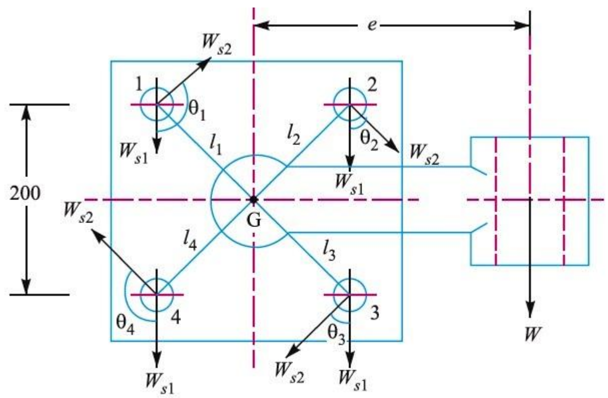


Figure.3

$\theta_1 = \theta_4 = 135°$, and $\theta_2 = \theta_3 = 45°$

Maximum shearing force on the bolts 1 and 4,
$\sqrt{(W_{s1})^2 + (W_{s2})^2 + 2W_{s1} \times W_{s2} \times \cos 135°}$ = **4303 N**
And maximum shearing force on the bolts 2 and 3,
$\sqrt{(W_{s1})^2 + (W_{s2})^2 + 2W_{s1} \times W_{s2} \times \cos 45°}$ = **8687 N**

(4 M)

4 **Design a double riveted butt joint with two cover plates for the longitudinal seam of a boiler shell 1.5 m in diameter subjected to a steam pressure of 0.95 N/mm^2. Assume joint efficiency as 75%, allowable tensile stress in the plate 90 MPa; compressive stress 140 MPa; and shear stress in the rivet 56 MPa. (13 M) (Nov. 2017)** BTL6

Answer: Page :305 – R.S.Khurmi and J.K.Gupta

Thickness of boiler shell plate:
We know that thickness of boiler shell plate,
$$t = \frac{P.D.}{2\sigma_t \times \eta_l} + 1 \text{ mm}$$
= 11.6 = **12 mm**

(2 M)

Diameter of rivet:
Since the thickness of the plate is greater than 8 mm, therefore the diameter of the rivet hole,
$d = 6\sqrt{t}$ = **20.8 mm**
From Table on PSG DDB P.No.5.29, we see that according to IS : 1928 – 1961 (Reaffirmed

1996), the standard diameter of the rivet hole (d) is 21 mm and the corresponding diameter of the rivet is 20 mm.

(2 M)

Pitch of rivets:

Let p = Pitch of rivets.

The pitch of the rivets is obtained by equating the tearing resistance of the plate to the shearing resistance of the rivets.

We know that tearing resistance of the plate,

$P_t = (p - d)\, t \times \sigma_t = (p - 21)12 \times 90 = 1080\,(p - 21)\text{N}$ ...(*i*)

Since the joint is double riveted double strap butt joint, as shown in Fig., therefore there are two rivets per pitch length (*i.e.* $n = 2$) and the rivets are in double shear.

Assuming that the rivets in double shear are 1.875 times stronger than in single shear,

we have Shearing strength of the rivets

$P_s = n \times 1.875 \times \frac{\pi}{4} \times d^2 \times \tau = 72745$ N … (ii)

From equations **(*i*)** and **(*ii*),** we get

$1080\,(p - 21) = 72\,745$

$\therefore\ p - 21 = 72\,745 / 1080 = 67.35$ or $p = 67.35 + 21 = 88.35$ say 90 mm

According to I.B.R., the maximum pitch of rivets for longitudinal joint of a boiler is given by

$pmax = C \times t + 41.28$ mm

From Table 9.5, we find that for a double riveted double strap butt joint and two rivets per pitch length, the value of C is 3.50.

So, $p_{max} = 3.5 \times 12 + 41.28 = 83.28$ say 84 mm

Since the value of p is more than p_{max}, therefore we shall adopt pitch of the rivets,

$p = p_{max}$ = **84 mm Ans.**

(3 M)

Distance between rows of rivets:

Assuming zig-zag riveting, the distance between the rows of the rivets (according to I.B.R.),

$p_b = 0.33\,p + 0.67\,d = 0.33 \times 84 + 0.67 \times 21 = 41.8$ say **42 mm Ans.**

Thickness of cover plates:

According to I.B.R., the thickness of each cover plate of equal width is

$t_1 = 0.625\,t = 0.625 \times 12 =$ **7.5 mm Ans.**

(2 M)

Margin:

We know that the margin,

$m = 1.5\,d = 1.5 \times 21 = 31.5$ say **32 mm Ans.**

Efficiency:

Let us now find the efficiency for the designed joint.

Tearing resistance of the plate,

$Pt = (p - d)\, t \times \sigma_t = (84 - 21)12 \times 90 = 68\,040$ N

Shearing resistance of the rivets,

$P_s = n \times 1.875 \times \frac{\pi}{4} \times d^2 \times \tau = 72745$ N

and crushing resistance of the rivets,

$Pc = n \times d \times t \times \sigma_c = 2 \times 21 \times 12 \times 140 = 70\,560$ N

Since the strength of riveted joint is the least value of *Pt*, *Ps* or *Pc*, therefore strength of the riveted joint,

P_t = 68 040 N

We know that strength of the un-riveted plate,

$P = p \times t \times \sigma_t$ = 84 × 12 × 90 = 90 720 N

Efficiency of the designed joint,

$\eta = \frac{P_t}{P}$ = 0.75 = **75%**

Since the efficiency of the designed joint is equal to the given efficiency of 75%, therefore the design is satisfactory.

(4 M)

5 **A steam engine of effective diameter 300 mm is subjected to a steam pressure of 1.5 N/mm^2. The cylinder head is connected by 8 bolts having yield point 330 MPa and endurance limit at 240 MPa. The bolts are tightened with an initial preload of 1.5 times the steam load. A soft copper gasket is used to make the joint leak-proof. Assuming a factor of safety 2, find the size of bolt required. The stiffness factor for copper gasket may be taken as 0.5. (13 M) (May2016, Nov.2015)**BTL5

Answer: Page :401 – R.S.Khurmi and J.K.Gupta

We know that steam load acting on the cylinder head,

$P_2 = \frac{\pi}{4}(D)^2 p$ = 106 040 N

Initial pre-load,

$P_1 = 1.5\ P_2$ = 159 060 N

We know that the resultant load (or the maximum load) on the cylinder head,

$P_{max} = P_1 + K.P_2$ = 212 080 N

This load is shared by 8 bolts, therefore maximum load on each bolt,

P_{max} = 212 080 / 8 = **26 510 N**

(3 M)

and minimum load on each bolt,

$P_{min} = P_1 / n$ = **19 882 N**

We know that mean or average load on the bolt,

$P_m = \frac{P_{max} + P_{min}}{2}$ = **23196 N**

And the variable load on the bolt,

$P_v = \frac{P_{max} - P_{min}}{2}$ = **3314 N**

(3 M)

Let dc = Core diameter of the bolt in mm

Then stress area on the bolt, $A_s = \frac{\pi}{4}(d_c)^2 = 0.7854(d_c)^2$ mm^2

We know that mean or average stress on the bolt,

$\sigma_m = \frac{P_m}{A_s} = \frac{29534}{(d_c)^2}$ N/mm^2

and variable stress on the bolt,

$\sigma_v = \frac{P_v}{A_s} = \frac{4220}{(d_c)^2}$ N/mm^2

(3 M)

According to Soderberg's formula, the variable stress,

$$\sigma_v = \sigma_e\left(\frac{1}{F.S.} - \frac{\sigma_m}{\sigma_y}\right)$$

d_c = **14.6 mm**

From Table 11.1 (coarse series), the standard core diameter is d_c = 14.933 mm and the corresponding size of the bolt is **M18**

(4 M)

6 **A rectangular steel plate is welded as a cantilever to a vertical column and supports a single concentrated load P, as shown in Fig. Determine the weld size if shear stress in the same is not to exceed 140 MPa. (13 M) (May 2016, Nov.2012)**BTL5

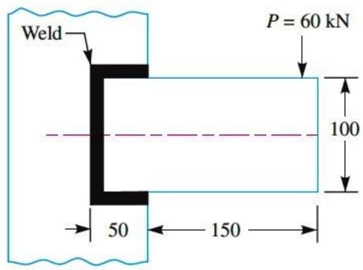


Figure.1

Answer: Page :369 – R.S.Khurmi and J.K.Gupta

First of all, let us find the centre of gravity (*G*) of the weld system, as shown in Fig.2

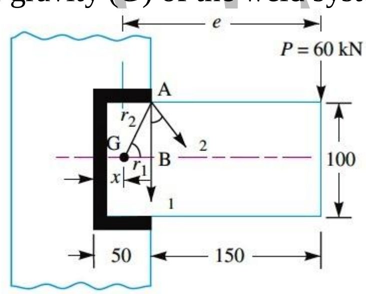


Figure.2

Let *x* be the distance of centre of gravity (*G*) from the left hand edge of the weld system. From Table 10.7, we find that for a section as shown in Fig.2,

$x = \frac{l^2}{2l+b}$ = **12.5 mm**

and polar moment of inertia of the throat area of the weld system about *G*,

$$J = t\left[\frac{(b+2l)^3}{12} - \frac{l^2(b+l)^2}{b+2l}\right]$$

= 275 × 10^3 *s* mm^4

(3 M)

Distance of load from the centre of gravity (*G*) *i.e.* eccentricity,

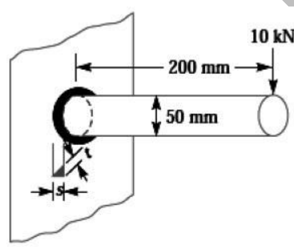
e = 150 + 50 – 12.5 = 187.5 mm

*r*1 = *BG* = 50 – *x* = 50 – 12.5 = 37.5 mm

AB = 100 / 2 = 50 mm

We know that maximum radius of the weld,

$r_2 = \sqrt{(AB)^2 + (BG)^2}$ = 62.5 mm

	$cos\theta = \frac{r_1}{r_2}$ = 0.6 We know that throat area of the weld system, $A = 2 \times 0.707s \times l + 0.707s \times b = 0.707\ s\ (2l + b)$ $= 0.707s\ (2 \times 50 + 100)$ = **141.4 s mm²** **(3 M)** Direct or primary shear stress, $\tau_1 = \frac{P}{A} + \frac{60\times10^3}{141.4\ s} = \frac{\mathbf{424}}{\boldsymbol{s}}$ **N/mm²** and shear stress due to the turning moment or secondary shear stress, $\tau_2 = \frac{P\times e\times r_2}{J} = \frac{\mathbf{2557}}{\boldsymbol{s}}$ **N/mm²** **(3 M)** We know that the resultant shear stress, $\tau = \sqrt{(\tau_1)^2 + (\tau_2)^2 + 2\times\tau_1\times\tau_2\times cos\theta}$ *s* = 2832 / 140 = **20.23 mm** **(4 M)**
7	**A 50 mm diameter solid shaft is welded to a flat plate as shown in Fig. If the size of the weld is 15 mm, find the maximum normal and shear stress in the weld. (13 M) (May 2014)** BTL5  *Figure.1* **Answer: Page :366 – R.S.Khurmi and J.K.Gupta** Let *t* = Throat thickness. The joint, as shown in Fig.1, is subjected to direct shear stress and the bending stress. We know that the throat area for a circular fillet weld, A = t × π D = 0.707 s × π D = **1666 mm²** **(3 M)** Direct shear stress, T = P/A = **6 MPa** We know that bending moment, *M* = *P* × *e* = 10 000 × 200 = **2 × 10⁶ N-mm** **(3 M)** From table 10.7, we find that for a circular section, section modulus, $Z = \frac{\pi t D^2}{4}$ = **20825 mm³** Bending stress, σ_b = M/Z = **96 MPa** **(3 M)** **Maximum normal stress** We know that the maximum normal stress, $\sigma_{t(max.)} = \frac{1}{2}\sigma_b + \frac{1}{2}\sqrt{(\sigma_b)^2 + 4\tau^2}$ = **96.4 MPa**

	Maximum shear stress We know that the maximum shear stress, $\tau_{max} = \frac{1}{2}\sqrt{(\sigma_b)^2 + 4\tau^2}$ = **42.4 MPa** **(4 M)**
	PART- C
1	**Design a knuckle joint to transmit 150 kN. The design stresses may be taken as 75 MPa in tension, 60 MPa in shear and 150 MPa in compression. (15 M) (Nov.2012, Nov.2011)** BTL6 **Answer: Page : 3.41 – E.V.V.Ramanamurthy and S.Ramachandran** **Step 1. Failure of solid rod in tension:** $F = \frac{\pi}{4} d^2 \sigma_t$ **d = 50.46 mm** **(2 M)** **Step 2. Standard proportions of knuckle joints:** Diameter of pin, $d_1 = d$ = **50 mm** Outer diameter of eye, $d_2 = 2d$ = **101 mm** Diameter of pin head, $d_3 = 1.5\ d$ = **75.69 mm** Thickness of eye, $t = 1.25\ d$ = **63.075 mm** Thickness of fork, $t_1 = 0.75\ d$ = **37.845 mm** Thickness of pin head, $t_2 = 0.5\ d$ = **25.23 mm** **(3 M)** **Check for shear stress:** **1. Failure of knuckle pin by double shears** $F = 2 \times \frac{\pi}{4} {d_1}^2 \tau$ τ = **37.5 N/mm^2** This value is less than permissible shear stress (60 MPa). Hence the design is safe. **(2 M)** **2. Failure of single eye (or) rod end in double shear** $F = (d_2 - d_1)t \times \tau$ τ = **47.05 N/mm^2** Since this induced stress is less than permissible shear stress (60 MPa), the design is safe. **(2 M)** **3. Failure of fork ends in double shear** $F = (d_2 - d_1)t \times 2 \times \tau$ τ = **23.52 N/mm^2** Since this induced stress is less than permissible shear stress (60 MPa), the design is safe. **(2 M)**

Check for tensile stress:

1. **Failure of the single eye or rod end in tension**

$F = (d_2 - d_1)t\,\sigma_t$

σ_t = **47.05 N/mm^2**

Since this induced stress is less than permissible tensile stress (75 MPa), the design is safe.

2. **Failure of fork end in tension**

$F = (d_2 - d_1)t \times 2 \times \sigma_t$

σ_t = **39.217 N/mm^2**

Since this induced stress is less than permissible tensile stress (75 MPa), the design is safe.

(2 M)

Check for crushing stress:

1. **Failure of single eye (or) rod end in crushing**

$F = d_1 \times t \times \sigma_c$

σ_c = **47.13 N/mm^2**

Since this induced stress is less than permissible crushing stress (150 MPa), the design is safe.

2. **Failure of fork end in crushing**

$F = d_1 \times t \times 2 \times \sigma_c$

σ_c = **39.27 N/mm^2**

Since this induced stress is less than permissible crushing stress (150 MPa), the design is safe.

(2 M)

2 **Design a knuckle joint to withstand a load of 100 kN. All the parts of the joint are made of the same material with $\sigma_{ut} = \sigma_{uc}$ = 480 MPa, and τ_u = 360 MPa. Use factor of safety of 6 on ultimate strength. (15 M) (Nov. 2015)** BTL6

Answer: Page :80 – Notes

Step 1. Calculation of permissible stresses:

$\sigma_t = \frac{480}{6} = 80$ N/mm^2

$\sigma_c = \frac{480}{6} = 80$ N/mm^2

$\tau = \frac{360}{6} = 60$ N/mm^2

(2 M)

Step 2. Design of diameter of rod (d):

Compare tensile strength to the applied load,

$\frac{\pi}{4} d^2 \sigma_{ut} \geq F$

$d \geq 39.89$ mm

Take d= 40 mm

(2 M)

Step 3. Standard proportions of knuckle joints:

Diameter of pin, $d_1 = d$ = 4**0 mm**

Outer diameter of eye,	$d_2 = 2d$ = **80 mm**
Diameter of pin head,	$d_3 = 1.5\,d$ = **60 mm**
Thickness of eye,	$t = 1.25\,d$ = 5**0 mm**
Thickness of fork,	$t_1 = 0.75\,d$ = **30 mm**
Thickness of pin head,	$t_2 = 0.5\,d$ = **20 mm**

(2 M)

Step 4. Check for shear stress:
Failure of knuckle pin by double shears

$$F = 2 \times \frac{\pi}{4} {d_1}^2 \tau$$

τ = **39.79 N/mm^2**

This value is less than permissible shear stress (60 N/mm^2). Hence the design is safe.

(3 M)

Step 5. Design of single eye rod:

1. **Failure of the single eye or rod end in tension**

$F = (d_2 - d_1) t\, \sigma_t$

σ_t = **50 N/mm^2**

Since this induced stress is less than permissible tensile stress (80 MPa), the design is safe.

2. **Failure of the single eye or rod end in shear**

$F = (d_2 - d_1) t\, \tau$

τ = **50 N/mm^2**

Since this induced stress is less than permissible shear stress (60 MPa), the design is safe.

3. **Failure of single eye (or) rod end in crushing**

$F = d_1 \times t \times \sigma_c$

σ_c = **50 N/mm^2**

Since this induced stress is less than permissible crushing stress (80 MPa), the design is safe.

(3 M)

Step 6. Design of double eye rod:

1. **Failure of the double eye rod in tension**

$F = (d_2 - d_1) 2t_1\, \sigma_t$

σ_t = 41.66 N/mm^2

Since this induced stress is less than permissible tensile stress (80 MPa), the design is safe.

2. **Failure of the double eye rod in shear**

$F = (d_2 - d_1) 2t_1\, \tau$

τ = 41.66 N/mm^2

Since this induced stress is less than permissible shear stress (60 MPa), the design is safe.

3. Failure of the double eye rod in crushing

$F = d_1 \times t \times 2 \times \sigma_c$

σ_c = **41.66 N/mm²**

Since this induced stress is less than permissible crushing stress (80 MPa), the design is safe.

(3 M)

3 **Design and draw a cotter joint to support a load varying from 30 kN in compression to 30 kN in tension. The material used is carbon steel for which the following allowable stresses may be used. The load is applied statically. Tensile stress = compressive stress = 50 MPa; shear stress = 35 MPa and crushing stress= 90 MPa. (15 M) (May 2013,Nov.2005)** BTL6

Answer: Page : 3.43 – E.V.V.Ramanamurthy and S.Ramachandran

Step 1. Design of the rod (d):

Failure of rod due to tensile stress

$$\sigma_t = \frac{4F}{\pi d^2}$$

d = 27.63 mm

(1 M)

Step 2. Design of inside diameter of the socket (d_1) or diameter of spigot:

(a) Failure due to tensile stress:

$$\sigma_t = \frac{4F}{\pi {d_1}^2 - 4 d_1 t}$$

Assume, $t = d_1/4$

d_1 = **33.47 mm**

(1 M)

(b) Failure due to crushing stress:

$\sigma_c = \frac{F}{d_1 t}$ = 107.09 N/mm²

Since $(\sigma_c) > [\sigma_c]$, the design is not safe.

So, change the value of t and recalculate d_1

Assume $t = d_1/3$

$$[\sigma_t] = \frac{4F}{\pi d_1^2 - 4 d_1 \frac{d_1}{3}}$$

d_1 = **36.39 mm**

and

t = **12.13 mm**

$$(\sigma_c) = \frac{F}{d_1 t}$$

σ_c = 67.96 N/mm²

$(\sigma_c) < [\sigma_c]$ Therefore, the design is safe

(2 M)

Step 3. Design of outside diameter of the socket (d_3):

$$\sigma_t = \frac{4F}{\pi(d_3^2 - d_1^2) - 4t(d_3 - d_1)}$$

$$d_3^2 - 15.45d_3 - 1526.92 = 0$$

d_3 = **47.55 mm**

(2 M)

Step 4. Design of Cotter width (b):
Failure of cotter in shear,

$F = 2bt[\tau]$

b = **35.33 mm**

(1 M)

Step 5. Design of distance (a):
Failure of rod in shear,

$$\tau = \frac{F}{2ad_1}$$

a = **11.77 mm**

(2 M)

Step 6. Design of diameter of socket collar (d_4):
Failure of socket collar in crushing,

$$\sigma_c = \frac{F}{(d_4 - d_1)t}$$

d_4 = **63.87 mm**

(2 M)

Step 7. Design of diameter of spigot collar (d_2):

$$\sigma_c = \frac{4F}{\pi\left({d_2}^2 - {d_1}^2\right)}$$

d_2 = **41.81 mm**

(1 M)

Step 8. To find distance (c):

$$\tau = \frac{F}{2c(d_4 - d_1)}$$

c = **15.595 mm**

(1 M)

Step 9. Design of thickness of socket collar (e):

$$\tau = \frac{F}{\pi d_1 e}$$

e = 7**.49 mm** **(2 M)**

UNIT IV - ENERGY STORING ELEMENTS AND ENGINE COMPONENTS

Various types of springs, optimization of helical springs - rubber springs - Flywheels considering stresses in rims and arms for engines and punching machines- Connecting Rods and crank shafts.

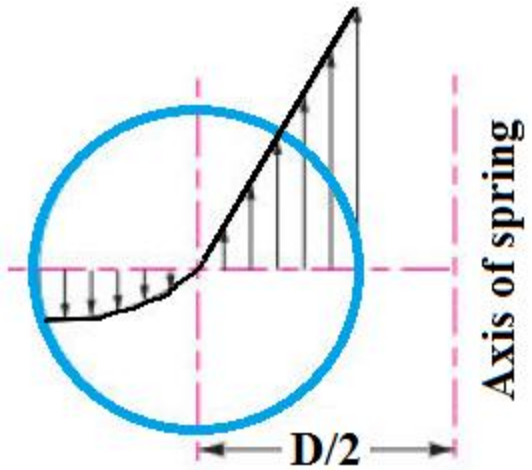
Q.No. **PART * A**

1 **What are the forces acting on connecting rod? (May 2017)(Nov.2012)(Nov.2011)** BTL1

The combined effect of (i) load on the piston due to the gas pressure and due to inertia of the reciprocating parts, and (ii) the friction of the piston rings, piston, piston rod and cross head.

- Inertia of the connecting rod.
- The friction force in the gudgeon and crank pin bearing

2 **Sketch the stresses induced in the cross section of a helical spring, considering Wahl's effect. (May2017)** BTL2



Maximum shear stress induced in the wire,

$$\tau = K \times \frac{8WD}{\pi d^3} = K \times \frac{8WC}{\pi d^2}$$

Where, $K = \frac{4C-1}{4C-4} + \frac{0.615}{C}$

3 **State any two functions of springs. (Nov.2017)** BTL2

- To measure forces in spring balance, meters and engine indicators.
- To store energy.

4 **How does the function of flywheel differ from that of governor? (Nov.2017) (Nov.2012) (Nov.2011)** BTL2

A governor regulates the mean speed of an engine when there are variations in the mean loads. It automatically controls the supply of working fluid to engine with the varying load condition and keeps the mean speed within the limits. It does not control the speed variation caused by the varying load. A flywheel does not maintain constant speed.

5 **Define spring rate.(May 2016) (Nov.2011)** BTL1

The spring stiffness (k) or spring constant is defined as the load required per unit deflection of the spring.

k= w/y

Where, w-load; y-deflection

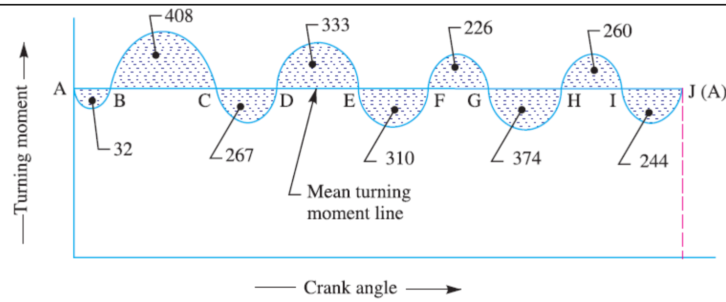
6	**Define the term 'fluctuation of speed' and 'fluctuation of energy'. (May 2016) (Nov.2014)** BTL1 **Coefficient of fluctuation of speed:** The ratio of maximum fluctuation of speed to the mean speed is called 'coefficient of fluctuation of speed' (C_S) $C_s = \frac{N_1 - N_2}{N}$ or $\frac{\omega_1 - \omega_2}{\omega}$ N_1 or $\omega_1 \rightarrow$ Max. speed N_2 or $\omega_2 \rightarrow$ Min. speed N or $\omega \rightarrow$ Mean speed **Coefficient of fluctuation of energy:** It is defined as the ratio of maximum fluctuation of energy to the work done per cycle. $C_E = \frac{\text{Maximum fluctuation of energy}}{\text{Workdone per cycle}}$
7	**What is the purpose of the flywheel? (Nov.2015) (Nov.2013)(Nov.2011) (May 2011)** BTL1 A flywheel is a heavy rotating mass which is placed between the power source and the driven member to act as a reservoir of energy. The flywheel will absorb the energy when the demand is less and it will release the energy when the demand is more than the energy being supplied.
8	**What type of spring is used to maintain an effective contact between a cam and a reciprocating roller or flat faced follower? (Nov.2015)** BTL1 Helical compression or extension spring is suitable for maintaining effective contact between cam and follower.
9	**Distinguish between closed coiled and open coiled helical springs. (Nov.2014)** BTL2 **Close-Coiled spring:** If the helix angle is small (10° – 12°), the plane of the coils can be safely assumed to be perpendicular to the axis of the spring. The effect of bending moment on such a spring is very small and that can be neglected. The torsional stress due to twisting moment predominates in close coiled spring. **Open-Coiled spring:** Helix angle is significant and hence plane of coil cannot be assumed to be perpendicular to the axis. The wire will experience the effects twisting as well as bending moments.
10	**Define (a) spring index (b) spring rate (Nov.2011)** BTL1 **(a) Spring index:** The ratio of mean or pitch diameter to the diameter of wire for the spring. **(b) Spring rate:** It is the ratio of load to deflection. k = load / deflection = P/y (or) W/δ
11	**Explain the following terms of the spring:** **(a) Free length** **(b) Spring index (May 2011)** BTL1 **(a) Free Length:** Free length of the spring is the length of the spring when it is free or unloaded condition. It is equal to the solid length plus the maximum deflection or compression plus clash allowance. L_f = solid length + Y_{max} + 0.15 Y_{max} **(a) Spring index:** The ratio of mean or pitch diameter to the diameter of wire for the spring is called 'spring index'. i.e., C = D/d
12	**What is the effect of increase in wire dia. on the allowable stress value? (Nov.2010)** BTL1 When the wire diameter increases, the allowable stress increases. When the load applied on the

	wire is more, then the allowable stress value should be increased.
13	**What type of stresses is produced in a disc flywheel? (Nov.2010)** BTL1 • Tensile stress due to centrifugal force • Tensile bending stress • Shrinkage stress due to unequal rate of cooling of casting
14	**What are the various types of springs? (May 2012)** BTL1 • Helical springs • Spiral springs • Leaf springs • Disc spring or Belleville springs
15	**Define: Belleville Springs.** BTL1 They are made in the form of a cone disc to carry a high compressive force. In order to improve their load carrying capacity, they may be stacked up together. The major stresses are tensile and compressive.
16	**What is buckling of springs?** BTL1 The helical compression spring behaves like a column and buckles at a comparative small load when the length of the spring is more than 4 times the mean coil diameter.
17	**What type of external force act on connecting rod? (Nov.2012) (May 2017)** BTL1 • Compressive stress • Shear force • Crushing force
18	**Write the formula for natural frequency of spring. (Nov.2012)** BTL1 $f = \frac{d}{\pi D^2 n}\sqrt{\frac{Gg}{2\gamma}}$; γ – density of material
19	**Why is piston end of a connecting rod kept smaller than the crank pin end? (Nov.2010)** BTL2 • It should have enormous strength to withstand the high pressure and inertia force • It should be of sufficient rigid construction to withstand thermal and mechanical distortion.
20	**A helical spring of rate 12 N/mm is mounted on the top of another spring of rate 8 N/mm. Find the force required to give deflection of 50 mm. (Nov.2013)** BTL3 **Given:** K_1 = 12 N/mm; K_2 = 8 N/mm and δ = 50 mm w.k.t. $\frac{1}{K} = \frac{1}{K_1} + \frac{1}{K_2}$ $\frac{1}{K} = \frac{1}{12} + \frac{1}{8}$ K = 4.8 N/mm K = P / δ So, P = K x δ = 4.8 x 50 = **240 N**
	PART * B
1	**A helical compression spring of the exhaust valve mechanism is initially compressed with a pre-load of 375 N. When the spring is further compressed and the valve is fully opened, the torsional shear stress in the spring wire should not exceed 750 N/mm^2. Due to space limitations, the outer diameter of the spring should not exceed 42 mm. The spring is to be designed for minimum weight. Calculate the wire diameter and the mean coil diameter of**

	the spring. (13 M) (May 2017) BTL5 **Answer: Page: 431 – V.B.Bhandari** **Step I: Design of Wire diameter:** $P_{max.} = 2\ P_{min.} = 750$ N Assuming the outer diameter to be 42 mm, Do = D+d = Cd +d = d (C+1) Or d = Do / (C+1) = 42/(C+1) … (a) **(2 M)** $\tau_{max.} = K\left(\frac{8\ P_{max.}D}{\pi d^3}\right) = K\left(\frac{8\ P_{max.}C}{\pi d^2}\right)$ Therefore, $750 = K\left(\frac{8\ (750)C(C+1)^2}{\pi(42)^2}\right)$ $C(C+1)^2K = 692.72$ … (b) **(2 M)** The problem is solved by trial and error method. In practice spring index varies from 6 to 10. Considering values of C in this range, the results are tabulated in the following manner. <table><tr><td>C</td><td>K</td><td>(C+1)^2</td><td>CK (C+1)^2</td></tr><tr><td>5</td><td>1.311</td><td>36</td><td>235.98</td></tr><tr><td>6</td><td>1.253</td><td>49</td><td>368.38</td></tr><tr><td>7</td><td>1.213</td><td>64</td><td>543.42</td></tr><tr><td>8</td><td>1.184</td><td>81</td><td>767.23</td></tr></table> Comparing Eq. (b) and the values in above table, C=8 d = 42 / (C+1) = 4.67 mm d = 5 mm … (i) **(4 M)** **Step II Mean coil diameter** Since D_o = D+d 42 = D +5 D = 37 mm … (ii) **(2 M)** **Step III Check for design** C = D/d = 7.4 $K = \frac{4C-1}{4C-4} + \frac{0.615}{C} = 1.2$ $\tau_{max.} = K\left(\frac{8\ PC}{\pi d^2}\right)$ = 678.38 N/mm^2 Since $\tau_{max.} < 750$ N/mm^2, the dimensions are satisfactory. **(3 M)**
2	**Design a leaf spring for the following specifications :** **Total load = 140 kN ; Number of springs supporting the load = 4 ; Maximum number of leaves = 10; Span of the spring = 1000 mm ; Permissible deflection = 80 mm.** **Take Young's modulus, E = 200 kN/mm^2 and allowable stress in spring material as 600**

	MPa. (Nov 2017) BTL 6 **Answer: Page: 874 – R.S.Khurmi & J.K.Gupta** We know that load on each spring $2W = \frac{\text{Total load}}{\text{No .of springs}} = \frac{140}{4} = 35$ kN W = 17.5 kN = 17500 N **(3 M)** Let, t = Thickness of the leaves, and b = width of the leaves. w.k.t. bending stress $\sigma = \frac{6WL}{nb\,t^2} = \frac{52.5\times10^6}{nb\,t^2}$ $nbt^2 = 87.5 \times 10^3$ … (i) **(3 M)** and deflection of the spring $\delta = \frac{6WL^3}{nEb\,t^3} = \frac{65.6\times10^6}{nb\,t^3}$ $nbt^3 = 0.82 \times 10^6$ … (ii) **(3 M)** Dividing equation (ii) by equation (i), we have T = 9.37 say **10 mm** **Now from equation (i), we have** $b = \frac{87.5 \times10^3}{nt^2}$ = **87.5 mm** **(2 M)** and from eqn (ii), we have $b = \frac{0.82 \times10^6}{nt^3}$ = **82 mm** Taking larger of the two values, we have width of leaves, b = 87.5 say **90 mm** **(2 M)**
3	**A safety valve of 60 mm diameter is to blow off at a pressure of 1.2 N/mm^2. It is held on its seat by a close coiled helical spring. The maximum lift of the valve is 10 mm. Design a suitable compression spring of spring index 5 and providing an initial compression of 35 mm. The maximum shear stress in the material of the wire is limited to 500 MPa. The modulus of rigidity for the spring material is 80 kN/mm^2. Calculate : 1. Diameter of the spring wire, 2. Mean coil diameter, 3. Number of active turns, and 4. Pitch of the coil. (May 2016)** BTL 5 **Answer: Page: 841 – R.S.Khurmi & J.K.Gupta** **Step 1. Diameter of the spring wire** Let *d* = Diameter of the spring wire. We know that the maximum load acting on the valve when it just begins to blow off, W_1 = Area of the valve × Max. pressure = 3394 N And maximum compression of the spring, $\delta_{max.} = \delta_1 + \delta_2$ = **45 mm** Since a load of 3394 N keeps the value on its seat by providing initial compression of 35 mm, therefore the maximum load on the spring when the valve is open (i.e., for maximum compression of 45 mm), $W = \frac{3394}{35} \times 45 = 4364$ N **(3 M)**

	W.K.T., Wahl's stress factor, $K = \frac{4C-1}{4C-4}$ =1.31 We also know that the maximum shear stress, $\tau = K\frac{8WC}{\pi d^2} = \frac{72780}{d^2}$ **d = 12.06 mm** From the table of "Standard wire gauge (SWG) number and corresponding diameter of spring wire", we shall take standard wire of size SWG 7/0 having diameter (d) **= 12.7 mm** **(3 M)** **Step 2.Mean coil diameter (D):** Spring index C = D/d D = C.d = **63.5 mm** **(2 M)** **Step 3. Number of active turns (n):** Maximum compression of the spring, $\delta = \frac{8\,WC^3 n}{Gd}$ 45 = 4.3 n n = **10.5 say 11** Taking the ends of the coil as squared and ground, the total number of turns, n'=n+2 = 11+2 **= 13** **(3 M)** **Step 4. Pitch of the coil:** Free length of the spring, L_F = n'.d +δmax. +0.15 δmax. = **216.85 mm** Pitch of the coil = Free length / n'-1 = **18.1 mm** **(2 M)**
4	**The areas of the turning moment diagram for one revolution of a multi-cylinder engine with reference to the mean turning moment, below and above the line, are – 32, + 408, – 267, + 333, – 310, + 226, – 374, + 260 and – 244 mm^2. The scale for abscissa and ordinate are: 1 mm = 2.4° and 1 mm = 650 N-m respectively. The mean speed is 300 r.p.m. with a percentage speed fluctuation of ± 1.5%. If the hoop stress in the material of the rim is not to exceed 5.6 MPa, determine the suitable diameter and cross-section for the flywheel, assuming that the width is equal to 4 times the thickness. The density of the material may be taken as 7200 kg / m^3. Neglect the effect of the boss and arms. (Nov 2017)** BTL 5 **Answer: Page: 793 – R.S.Khurmi & J.K.Gupta** **Diameter of flywheel (D):** Peripheral velocity, $v = \frac{\pi DN}{60} = 15.71$ D **m/s** Hoop stress, $\sigma_t = \rho v^2$ By substituting, **D = 1.764 m** **(2 M)** **Cross section of the flywheel:** Let t = Thickness of the flywheel rim in meters, and b = Width of the flywheel rim in meters = 4 t (Given) A = b x t = 4t x t = 4 t^2 m^2 Now let us find the maximum fluctuation of energy. The turning moment diagram for one revolution of a multi cylinder engine is shown in Fig.



Since the scale of crank angle is 1 mm = 2.4° $= 2.4 \times \frac{\pi}{180}$ = 0.042 rad. and the scale of turning moment is 1 mm = 650 N-m.

(2 M)

Therefore, 1 mm^2 on the tuning moment diagram = 650 x 0.042 = 27.3 N-m
Let the total energy at A = E.
From Fig. we find that
Energy at B = E – 32
Energy at C = E – 32+ 408 = E + 376
Energy at D = E +376 – 267 = E + 109
Energy at E = E + 109 +333 = E + 442
Energy at F = E + 442 – 310 = E +132
Energy at G = E + 132 + 226 = E + 358
Energy at H = E + 358 – 374 = E – 16
Energy at I = E – 16 + 260 = E + 244
Energy at J = E +244 – 244 = E = Energy at A

(3 M)

From above we see that the energy is maximum at E and minimum at B.
Max. energy = E +442
and Min. energy = E – 32
Max. fluctuation of energy = Max. energy – Min. energy = 474 mm^2
= 474 x 27.3 = 12940 N-m

(3 M)

Since the fluctuation of speed is $\pm 1.5\%$ of the mean speed, total fluctuation of speed
$\omega_1 - \omega_2 = 3\%$ of the mean speed = 0.03 ω
and coefficient of fluctuation of speed C_s,

$$C_s = \frac{\omega_1 - \omega_2}{\omega} = 0.03$$

Let m = mass of flywheel rim
Maximum fluctuation of energy $\Delta E = mR^2\omega^2 C_s$ = 23 m = 12940
m = 563 kg
Also we know that m = A πD ρ
563 = 159624 t^2
t = 60 mm
b = 240 mm

(3 M)

5 **A helical compression spring made of oil tempered carbon steel is subjected to a load which varies from 400 N to 1000 N. The spring index is 6 and the design factor of safety is 1.25. If**

the yield stress in shear is 770 MPa and endurance stress in shear is 350 MPa, find: 1. Size of the spring wire, 2. Diameters of the spring, 3. Number of turns of the spring, and 4. Free length of the spring.
The compression of the spring at the maximum load is 30 mm. The modulus of rigidity for the spring material may be taken as 80 kN/mm^2. (Nov.2013) BTL 5

Answer: Page: 855 – R.S.Khurmi & J.K.Gupta

(i) Size of spring wire:

Let d = diameter of the spring wire, and
D = Mean diameter of the spring = Cd = 6d

Mean load, $W_m = \frac{W_{max} + W_{min}}{2}$ = 700 N

Variable load, $W_v = \frac{W_{max} - W_{min}}{2}$ = 300 N

(3 M)

Shear stress factor, $K_s = 1 + \frac{1}{2C}$ = 1.083

Wahl's stress factor,

$K = \frac{4C-1}{4C-4} + \frac{0.615}{C}$ = 1.2525

Mean shear stress

$$\tau_m = K_S \times \frac{8W_m \times D}{\pi d^3} = \frac{11582}{d^2}$$

and variable shear stress,

$$\tau_v = K \times \frac{8W_v \times D}{\pi d^3} = \frac{5740}{d^2}$$

We know that

$$\frac{1}{F.S.} = \frac{\tau_m - \tau_v}{\tau_y} + \frac{2\,\tau_v}{\tau_e}$$

d = 7.1 mm

(4 M)

(ii) Diameters of spring

D = C.d = **42.6 mm**

Outer diameter of spring, D_o = D + d = **49.7 mm**

and inner diameter of spring, D_i = D – d = **35.5 mm**

(2 M)

(iii) Number of turns of the spring (n):

Deflection of the spring $\delta = \frac{8\,W\,D^3 n}{G d^4}$

30 = 3.04 n

N = 9.87 say 10

Assuming the ends of the spring to be squared and ground, the total number of turns of the spring, n' = n+2 = **12**

(2 M)

(iv) Free length of the spring

Free length of spring, $L_F = n'.d + \delta + 0.15\delta$ = 119.7 say **120 mm**

(2 M)

6 **Design a helical spring for a spring loaded safety valve (Ramsbottom safety valve) for the following conditions :**

Diameter of valve seat = 65 mm ; Operating pressure = 0.7 N/mm2; Maximum pressure when the valve blows off freely = 0.75 N/mm^2; Maximum lift of the valve when the pressure rises from 0.7 to 0.75 N/mm^2 = 3.5 mm ; Maximum allowable stress = 550 MPa ; Modulus of rigidity = 84 kN/mm^2; Spring index = 6. (Nov.2012) BTL 6

Answer: Page: 840 – R.S.Khurmi & J.K.Gupta

Given: D_1 = 65 mm; p_1 = 0.75 N/mm^2;δ = 3.5 mm; τ = 550 Mpa = 550 N/mm^2; G = 84 kN/mm^2 = 84 x 10^3 N/mm^2; C = 6

1. **Mean Diameter of the spring coil**
   Initial tensile force of the spring
   $W_1 = \frac{\pi}{4}(D_1)^2 p_1$ = 2323 N
   and maximum tensile force acting on the spring
   $W_2 = \frac{\pi}{4}(D_2)^2 p_2$ = 2489 N

Force which produces the deflection of 3.5 mm, W = $W_2 - W_1$ = 166 N

(3 M)

Since the diameter of the spring wire is obtained for the maximum spring load (W2), therefore maximum twisting moment on the spring, T = W_2 x (D/2) = 7467 d

Also, $T = \frac{\pi}{16}\tau d^3$

7467 d = 108 d^3

d = 8.3 mm

From the table of "Standard wire gauge (SWG) number and corresponding diameter of spring wire", we shall take standard wire of size SWG 7/0 having diameter (d) **= 8.839 mm**

Mean diameter of the coil, D = 6d =**53.034 mm**

Outside diameter of the coil, D_o = D + d = **61.873 mm**

Inside diameter of the coil, D_i = D – d = **44.195 mm**

(4 M)

2. **Number of turns of the coil (n):**
   Deflection of the spring, $\delta = \frac{8\,WC^3 n}{Gd}$
   3.5 = 0.386 n
   n = 9.06 say 10
   For a spring having loop on both ends, the total number of turns, n' = n+1 = **11**

(2 M)

3. **Free length of the spring(L_F):**
   Taking the least gap between the adjacent coils as 1 mm when the spring is in free state, the free length of the tension spring,
   L_F = n.d + (n-1)1= **97.39 mm**

(2 M)

4. **Pitch of the coil**

Pitch of the coil = Free length / (n-1) = **10.82 mm**

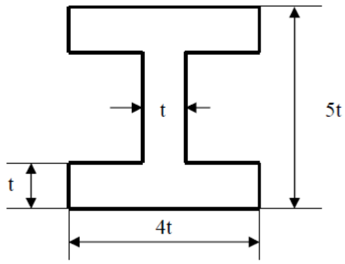
(2 M)

7 **Design a suitable connecting rod for a petrol engine for the following details, diameter of the piston = 100 mm, weight of reciprocating parts per cylinder = 20 N, connecting rod length =**

300 mm, compression ratio = 7:1, maximum explosion pressure = 3 N/mm^2, stroke = 140 mm, speed of the engine = 2000 rpm. (May 2012) (Nov. 2011) BTL 6

Answer: Page: 143 – Class notes

(i) Dimensions of I-section of connecting rod: From PSG DDB 7.122



$a = 11t^2$; $I_{xx} = 419/12\ t^4$; $k_{xx}^2 = 3.18\ t^2$

(1 M)

(ii) **Load due to burning of gas (FG) :** From PSG DDB 7.122

$F_G = \frac{\pi d^2}{4} \times p$ = **23561.94 N**

(1 M)

(iii) Crippling load (Fcr):

$F_{cr} = F.S. \times F_G$ (Assume F.S. = 6)

$\mathbf{F_{cr} = 141371.67\ N}$

(1 M)

(iv) Crippling load by Rankine's formula:

$$F_{cr} = \frac{\sigma_c \times a}{1 + c\left[\frac{l}{k_{xx}}\right]^2}$$

$$141371.6 = \frac{330 \times 11t^2}{1 + \frac{1}{7500}\left[\frac{300}{3.18t^2}\right]^2}$$

$t^2 = 42.412$

t = 6.15 mm ≅ 7 mm

(2 M)

(v) Dimensions of cross section:

Height of I section = 5 t = **35 mm**

Width of I section = 4 t = **28 mm**

(1 M)

(vi) Design of small end pin:

$L_1/d_1 = 1.75$ (Assume P_b = 13 N/mm^2)

$F_G = L_1 \times d_1 \times P_b$

d_1 = 32.18 mm = **33 mm**

L_1 = 1.75 d1 = **58 mm**

(1 M)

(vii) Design of big end pin:

$L_2/d_2 = 1$

$F_G = L_2 \times d_2 \times P_b$

d_2 = **44 mm**

L_2 = 44 **mm**

(1 M)

(viii) Diameter of bolt:

From PSG DDB 7.122

$L_1/d_1 = 1.75$

$$F_i = \frac{p}{g}\omega^2 r\left[\cos\theta + \frac{\cos 2\theta}{\frac{l}{r}}\right]$$

$\omega = \frac{2\pi N}{60}$ = 209.44 rad/sec

l = 300 mm = 0.3 m

r = radius of crank = stroke length / 2 = 70 mm = 0.07 m

Fi = 7720.736 N

w.k.t.

$$F_i = n \times \frac{\pi d_c^2}{4} \times \tau$$

d_c = 4.95 mm = 5 mm

Diameter of bolt (d) = d_c/0.84 = **6 mm**

(3 M)

(ix) Thickness of big end cap:

Bending moment, $m_c = \frac{F_i \times x}{6}$ (x = 1.5 d_2)

= 84920 N mm

Modulus, $Z = \frac{bt_c^2}{6}$ (b = L_2)

$$\sigma_b = \frac{m_c}{Z}$$

(Assume $\sigma_b = 120\ N/mm^2$)

t_c = 9.5 mm

(2 M)

PART – C

1 **A single cylinder double acting steam engine delivers 185 kW at 100 r.p.m. The maximum fluctuation of energy per revolution is 15 per cent of the energy developed per revolution. The speed variation is limited to 1 per cent either way from the mean. The mean diameters of the rim are 2.4 m. Design and draw two views of the flywheel. (Nov.2013)** BTL 6

Answer: Page : 807 - R.S.Khurmi & J.K.Gupta

Given:

P = 185 kW = 185 x 10^3 W; N =100 r.p.m.; ΔE = 15 % E = 0.15 E; D =2.4 m or R = 1.2 m

1. Mass of the flywheel rim (m):

Work done or energy developed per revolution,

E = (P x 60) /N = 111000 N-m

Maximum fluctuation of energy, ΔE = 15 % E = 0.15 E = 16650 N-m

Since the speed variation is 1% either way from the mean, therefore the total fluctuation of speed, $N_1 - N_2$ = 2 % of mean speed = 0.02 N

And coefficient of fluctuation of speed,

$C_s = \frac{N_1 - N_2}{N} = 0.02$

Velocity of flywheel,

$v = \frac{\pi DN}{60} = 12.57$ m/s

$\Delta E = mv^2 C_s = 3.16$ m

16650 = 3.16 m

m = 5270 kg

(3 M)

2. **Cross sectional dimensions of flywheel rim:**

Let t = thickness of the flywheel rim in meters, and

b = breadth of the flywheel rim in meters = 2t …(Assume)

Cross sectional area of the rim, A = b x t = 2t x t = $2t^2$

Mass of the flywheel rim (m),

$5270 = A \times \pi D \times \rho = 108588t^2$ …(Taking density as 7200 kg/m^3)

t = 0.22 m or **220 mm**

b = 2 t = **440 mm**

(3 M)

3. **Diameter and length of the hub:**

Let d = Diameter of the hub,

d_1 = Diameter of the shaft, and

l = length of hub

$T_{mean} = \frac{P \times 60}{2\pi N}$ = 17664 N-m

Assuming that the maximum torque transmitted (T_{max}) by the shaft is twice the mean torque,

$T_{max} = 2 \times T_{mean} = 35.328 \times 10^6$ N-m

$T_{max} = \frac{\pi}{16}\tau(d_1)^3$

$35.328 \times 10^6 = 7.855\,(d_1)^3$ … (Assuming τ = 40 Mpa = 40 N/mm^2)

d_1 = **165 mm**

$d = 2d_1$ = 330 mm

l= b = **440 mm**

(3 M)

4. **Cross sectional dimensions of the elliptical arm:**

Let a_1 = Major axis,

b_1 = Minor axis = 0.5 a_1 … (Assumption)

n = Number of arms = 6 … (Assumption)

σ_b = Bending stress for the material of the arms

= 14 MPa = 14 N/mm^2 … (Assumption)

We know that the maximum bending moment in the arm at the hub end which is assumed as cantilever is given by,

$M = \frac{T}{R.n}(R - r) = \frac{T}{D.n}(D - d) = 5078 \times 10^3$ N-mm … (d is taken in meters)

And section of modulus for the cross section of the arm,

$Z = \frac{\pi}{32} b_1 (a_1)^2 = 0.05(a_1)^3$

	$\sigma_b = \frac{M}{Z}$ a_1 = 193.6 Say **200 mm** b_1 = 0.5 a1 = **100 mm** **(3 M)** **5. Dimensions of key:** The standard dimensions of rectangular sunk key for a shaft of 165 mm diameter are as follows: Width of key, w = **45 mm** And thickness of key = **25 mm** The length of key (L) is obtained by considering the failure of key in shearing. $T_{max} = L \times w \times \tau \times \frac{d_1}{2}$ = 148500 L L = **238 mm** Let us now check the total stress in the rim which should not be greater than 14 MPa. We know that the total stress in the rim, $\rho v^2 \left(0.75 + \frac{4.935 \times R}{n^2 \times t}\right)$ = 1.71 x 10^6 N/m^2 = 1.71 MPa Since this calculated stress is less than 14 MPa, the design is safe. **(3 M)**
2	**A punching press pierces 35 holes per minute in a plate using 10 kN-m of energy per hole during each revolution. Each piercing takes 40 per cent of the time needed to make one revolution. The punch receives power through a gear reduction unit which in turn is fed by a motor driven belt pulley 800 mm diameter and turning at 210 r.p.m. Find the power of the electric motor if overall efficiency of the transmission unit is 80 per cent. Design a cast iron flywheel to be used with the punching machine for a coefficient of steadiness of 5, if the space considerations limit the maximum diameter to 1.3 m.** **Allowable shear stress in the shaft material = 50 MPa** **Allowable tensile stress for cast iron = 4 MPa** **Density of cast iron = 7200 kg / m^3** **(May 2016)** **Answer: Page:810 - R.S.Khurmi & J.K.Gupta** **Given:** No. of holes = 35 per min.; Energy per hole = 10 kN-m = 10000 N-m; d = 800 mm = 0.8 m; N= 210 r.p.m.; h = 80 % = 0.8; 1/Cs = 5 or Cs = 1/5 = 0.2; Dmax = 1.3 m; τ = 50 MPa = 50 N/mm^2; σ_t = 4 MPa = 4 N/mm^2; ρ = 7200 Kg/m^3 **Power of the electric motor:** We know that energy used for piercing holes per minute = No. of holes pierced x energy used per hole = 350000 N-m /min. Power needed for the electric motor, $P = \frac{\text{Energy used per minute}}{60 \times \eta}$ P = 7292 W = **7.292 kW** **(2 M)** **Design of cast iron flywheel:**

First of all, let us find the maximum fluctuation of energy.
Since the overall efficiency of the transmission unit is 80%, total energy supplied during each revolution

E_T = 10000/0.8 = 12500 N-m

v = πDN = 528 m/min.

Net tension or pull acting on the belt = P x 60/v = 828.6 N

Since each piercing takes 40 percent of the time needed to make one revolution, the time required to punch a hole = 0.4 / 35 = 0.0114 min.

And the distance travelled by the belt during punching a hole = velocity of the belt X Time required to punch a hole = 6.03 m

Energy supplied by the belt during punching a hole

EB = Net tension x Distance travelled by belt
= 828.6 x 6.03 = 4996 N-m

$\Delta E = E_T - E_B$ = 7504 N-m

(3 M)

(i) Mass of the flywheel (m):

Since the space considerations limit the maximum diameter of the flywheel as 1.3 m; let us take the mean diameter of the flywheel

D = 1.2 m or R = 0.6 m

$\omega = \frac{2\pi N}{60}$ = 22 rad/s

$\Delta E = mR^2\omega^2 C_S$ = 34.85 m

m = **215.3 kg**

(2 M)

(ii) Cross sectional dimensions of flywheel rim:

Let t = thickness of the flywheel rim in meters, and
b = breadth of the flywheel rim in meters = 2t

Cross sectional area of the rim, A = b x t = 2t x t = $2t^2$

Mass of the flywheel rim (m),

215.3 = $A \times \pi D \times \rho$ = 54.3 x $10^3 t^2$

t = 0.065 m or **65 mm**

b = 2 t = **130 mm**

(2 M)

(iii) Diameter and length of the hub:

Let d = Diameter of the hub,
d_1 = Diameter of the shaft, and
l = length of hub

$T_{mean} = \frac{P\times 60}{2\pi N}$ = 331.5 N-m

Assuming that the maximum torque transmitted (T_{max}) by the shaft is twice the mean torque,

T_{max} = 2 x T_{mean} = 663 x 10^3 N-mm

$T_{max} = \frac{\pi}{16}\tau(d_1)^3$

663 x 10^3 = 9.82 $(d_1)^3$

d_1 = **45 mm**

d = $2d_1$ = **90 mm**

l= b = **130 mm**

	(2 M) **(iv) Cross sectional dimensions of the elliptical arm:** Let a_1 = Major axis, b_1 = Minor axis = 0.5 a_1 … (Assumption) n = Number of arms = 6 … (Assumption) We know that the maximum bending moment in the arm at the hub end which is assumed as cantilever is given by, $M = \frac{T}{R.n}(R - r) = \frac{T}{D.n}(D - d)$ = 102200 N-mm And section of modulus for the cross section of the arm, $Z = \frac{\pi}{32} b_1 (a_1)^2 = 0.05 (a_1)^3$ $\sigma_b = \frac{M}{Z}$ a_1 = **80 mm** b_1 = 0.5 a1 = **40 mm** **(2 M)** **(v) Dimensions of key:** The standard dimensions of rectangular sunk key for a shaft of 45 mm diameter are as follows: Width of key, w = **16 mm** And thickness of key = **10 mm** The length of key (L) is obtained by considering the failure of key in shearing. $T_{max} = L \times w \times \tau \times \frac{d_1}{2}$ = 18 x 10^3 L L = **38 mm** Let us now check the total stress in the rim which should not be greater than 4 MPa. v = πDN / 60 = 13.2 m/s We know that the total stress in the rim, $\rho v^2 \left(0.75 + \frac{4.935 \times R}{n^2 \times t}\right)$ = 2.5 x 10^6 N/m^2 = 2.5 MPa Since this calculated stress is less than 4 MPa, the design is safe. **(2 M)**
3	**A railway wagon moving at a velocity of 1.5 m/s is brought to rest by a bumper consisting of two helical springs arranged in parallel. The mass of the wagon is 1500 kg. The springs are compressed by 150 mm in bringing the wagon to rest. The spring index can be taken as 6. The springs are made of oil-hardened and tempered steel wire with ultimate tensile strength of 1250 MPa and modulus of rigidity of 81.37 GPa. The permissible shear stress for the spring wire can be taken as 50% of the ultimate tensile strength.** **Design the spring and calculate:** **(i) wire diameter;** **(ii) mean coil diameter;** **(iii) number of active coils;** **(iv) total number of coils;** **(v) solid length;**

(vi) free length;
(vii) pitch of the coil
(Nov.2015) BTL5
Answer: Page:412 - V.B.Bhandari

Given: m =1500 kg; v = 1.5 m/s; δ = 150 mm; C =6; S_{ut} = 1250 N/mm^2; G = 81370 N/mm^2; τ = 0.5S_{ut}

Step I: Wire Diameter:
The kinetic energy of the moving wagon is absorbed by the springs. The kinetic energy of the wagon is given by,
K.E. = ½ mv^2 = 1687.5 x 10^3 N-mm … (a)
Suppose P is the maximum force acting on each spring and causing it to compress by 150 mm, then the strain energy absorbed by two springs is given by,
$E = 2\left[\frac{1}{2}P\delta\right]$ = 150 P N-mm … (b)
The strain energy absorbed by the two springs is equal to the kinetic energy of the wagon. Therefore,
150 P = 1687.5 x 10^3
P = 11250 N
The permissible shear stress for the spring wire is given by, τ = 0.5 x 1250 = 625 N/mm^2
$K = \frac{4C-1}{4C-4} + \frac{0.615}{C}$ = 1.2525
$\tau = K\left(\frac{8PC}{\pi d^2}\right)$
d = 18.56 or **20 mm**

(4 M)

Step II Mean coil diameter:
D =Cd = **120 mm**

(1 M)

Step III Number of active coils
$$\delta = \frac{8\,PD^3N}{Gd^4}$$
N = 12.56 or **13 coils**

(2 M)

Step IV Total number of coils
It is assumed that the springs have square and ground ends. The number of inactive coils is 2. Therefore,
N_t = N+2 = **15 coils**

(1 M)

Step V Solid length of spring
Solid length = N_t d = **300 mm**

(1 M)

Step VI Free length of spring
The actual deflection of the spring is given by,
$$\delta = \frac{8\,PD^3N}{Gd^4} = 155.29\text{ mm}$$

It is assumed that there will be a gap of 2 mm between adjacent coils when the spring is subjected to the maximum force of 11250 N. Since the total number of coils is 15, the total axial gap will be (15-1)x2 = 28 mm

Free length = Solid length + total axial gap + δ

= 483.29 or **485 mm**

(3 M)

Step VII Pitch of coils:

$$\text{Pitch of coil} = \frac{\text{Free length}}{(N_t - 1)} = 34.64 \text{ mm}$$

(1 M)

Step VIII Required spring rate:

$$k = \frac{P}{\delta} = 75 \text{ N/mm}$$

(1 M)

Step IX Actual spring rate:

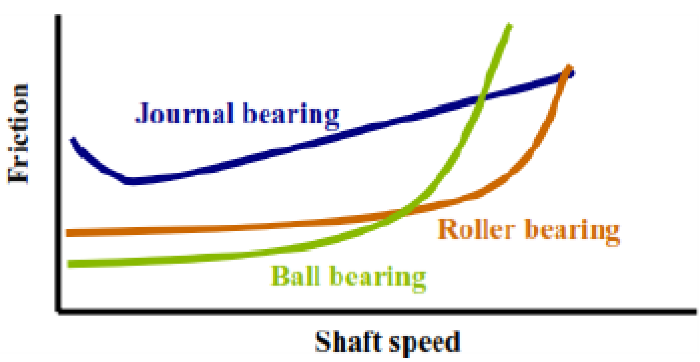
$$k = \frac{Gd^4}{8D^3N} = \mathbf{72.44\ N/mm}$$

(1 M)

UNIT V - ENERGY STORING ELEMENTS AND ENGINE COMPONENTS

Sliding contact and rolling contact bearings - Hydrodynamic journal bearings, Sommerfeld Number, Raimondi and Boyd graphs, Selection of Rolling Contact bearings

Q.No.	PART * A
1	**What are anti-friction bearings? (May 2017)** BTL1 In rolling contact bearings, the contact between the bearing surfaces is rolling instead of sliding as in sliding contact bearings. A rolling contact bearing has a low starting friction over a sliding bearing. Due to this low friction offered by rolling contact bearings, these are called antifriction bearings.
2	**Plot the friction induced in various bearings based on shaft speed. (May 2017)** BTL3



It is observed that for the lower shaft speeds the journal bearing have more friction than roller and ball bearing and ball bearing friction being the lowest. For this reason, the ball bearings and roller bearings are also called as anti-friction bearings. However, with the increase of shaft speed the friction in the ball and roller bearing phenomenally increases but the journal bearing friction is relatively lower than both of them.

Hence, it is advantageous to use ball bearing and roller bearing at low speeds. Journal bearings are mostly suited for high speeds and high loads.

3	**Classify the types of bearings. (Nov. 2016)** BTL2 • Based on the type of load acting on the shaft: a. Radial bearing b. Thrust bearings • Based on the nature of contact a. Sliding contact b. Rolling contact (or) antifriction bearings
4	**Define the term reliability of a bearing. (Nov. 2016)** BTL1 Reliability is defined as the probability that a system or product will successfully operate for a • given range of operating conditions • specific environmental condition • prescribed economic survival time
5	**What is meant by hydrodynamic lubrication? (May 2016)** BTL1 In hydrodynamic lubrication, a thin film of lubrication is created between shaft and bearing or between two sliding surfaces to separate them.
6	**What are the advantages of rolling contact bearings over sliding contact bearings? (May 2016)** BTL1 • They produce low starting and running friction except at very high speeds • It can withstand momentary shock loads • Accuracy of shaft alignment is high • Low cost of maintenance is sufficient as no lubrication is required while in service • The bearings have small overall dimensions • They provide good reliability of service • They are easy to mount and erect • viii. They provide more cleanliness
7	**What is meant by square journal bearing? (Nov. 2015)** BTL1 When the length of journal (l) is equal to the diameter of the journal (d), then the bearing is called square bearing.
8	**Give an example for anti-friction bearing. (Nov. 2015)** BTL1 • Ball bearings • ii. Roller bearings
9	**In hydrodynamic bearing, what are the factors which influence the formation of wedge film? (Nov.2014)** BTL1 In hydrodynamic bearing, there is a thick film of lubricant between the journal and the bearing. A pressure is build up in the clearance space when the journal is rotating about an axis that is eccentric with the bearing axis. The load can be supported by this fluid pressure without any actual contact between the journal and bearing. The load supporting pressure in hydrodynamic bearings arises from either 1. The flow of a viscous fluid in a converging channel (known as wedge film lubrication), or 2. The resistance of a viscous fluid to being squeezed out from between approaching surfaces(known as squeeze film lubrication).
10	**Define static capacity of bearing. (Nov.2014)** BTL1 It is defined as load acting on a non-rotating bearing under which permanent deformation is 0.0001 times the ball or roller diameter.

11	**Define life of anti-friction bearing. (Nov.2013)** BTL1 For an individual rolling bearing, the number of revolutions which one of the bearing rings (or washers) makes in relation to the other rings (or washers) under the prevailing working conditions before the first evidence of fatigue develops in the material of one of the rings (or washers) or rolling elements. In other words, the life of bearings is expressed as statistical life. The rating life of a group of identical bearings is defined as the number of revolutions or hours at some constant speed that 90%. According to Wiebull, the relation between the bearing life and the reliability, $\frac{L}{L_{90}} = \left[\frac{\log_e(1/R)}{\log_e(1/R_{90})}\right]^{1/b}$ ... (∵ b = 1.17)
12	**List the essential requirements in an end face seal. (Nov.2013)** BTL1 • Surfaces of the seals (stationary and rotating) should be polished and perfectly flat. • Seal faces must be perpendicular to the shaft. • Spring force should be sufficient to hold the sea faces in contact. • No friction between shaft and seal parts.
13	**What do you meant by life of an individual bearing? (May 2013)** BTL1 The life of individual bearing may be defined as the number of revolution which the bearing runs before the first evidence of fatigue develops in the material of one of the rings or any of the rolling elements.
14	**Define the term dynamic load carrying capacities of rolling contact bearing. (Nov.2012)** BTL1 Dynamic load rating is defined as the radial load in radial bearings that can be carried for a minimum life of one million revolutions.
15	**Classify the sliding contact bearings according to the thickness of layer of the lubricant between the bearing and journal. (May 2012)** BTL1 • Thick film bearing • Thin film bearing • Zero film bearing • Hydrostatic bearing
16	**List the basic assumptions used in the theory of hydrodynamic lubrication. ((Nov.2011)** BTL2 • The lubricant obeys Newton's law of viscous flow. • The pressure is assumed to be constant throughout the film thickness. • The lubricant is assumed to be incompressible. • The viscosity is assumed to be constant throughout the film thickness. • The flow is one dimensional.
17	**Name the materials used for sliding contact bearings. (May 2011)** BTL1 • Babbit metal • Bronzes. • Cast iron • Silver • Non metals
18	**What is sommerfeld number? State its importance in the design of journal bearing. (May 2015)** BTL1 Sommerfeld number is a dimensionless bearing characteristic number.

	Sommerfeld number = $\frac{ZN}{p}\left(\frac{d}{c}\right)^2$ Z = Absolute viscosity of the lubricant, in kg/m-s, N = Speed of the journal in r.p.m., P = Bearing pressure on the projected bearing area in N/mm^2, d = Diameter of the journal, l = Length of journal, and c = Diametral clearance.
19	**For a journal bearing the maximum operating temperature must be less than 80^0 C. Why? (Nov.2010)** BTL2 Temperature rise will result in the reduction of the viscosity of the oil used in the bearing. This would lead to metal to metal contact, thereby affecting the bearing performance & life.
20	**What is self-aligning ball bearing? State its unique feature. (May 2015)** BTL1 Self-aligning ball bearing has two rows of balls and a common sphered raceway in the outer ring. The bearings are insensitive to angular misalignment of the shaft relative to the housing.
	PART * B
1	**A ball bearing, subjected to a radial load of 5 kN, is expected to have a life of 8000 hrs at 1450 rpm with a reliability of 99%. Calculate the dynamic load capacity of the bearing, so that it can be selected from the manufacturer's catalogue based on a reliability of 90%. (Nov. 2016)** BTL5 **Answer: Page : 593 – V.B.Bhandari** **Given** Fr = 5 Kn; N = 1450 rpm ; L_{99h} = 8000 h **Step I** Bearing life with 99% reliability $L_{99} = \frac{60nL_{99h}}{10^6} = \frac{60 \times 1450 \times 8000}{10^6}$ = 696 million rev. **(4 M)** **Step II** Bearing life with 90% reliability $\left(\frac{L_{99}}{L_{10}}\right) = \left[\frac{log_e\left(\frac{1}{R_{99}}\right)}{log_e\left(\frac{1}{R_{90}}\right)}\right]^{1/1.17} = \left[\frac{log_e\left(\frac{1}{0.99}\right)}{log_e\left(\frac{1}{0.90}\right)}\right]^{1/1.17}$ Therefore, $L_{10} = \frac{L_{99}}{0.1342} = \frac{696}{0.1342} = 5186.29$ million rev. **(6 M)** **Step III** Dynamic load carrying capacity of bearing: C = P (L10)$^{1/3}$ = 5000 (5186.29)$^{1/3}$ = **86 547.7 N Answer** **(3 M)**
2	**Select a single row deep groove ball bearing for a radial load of 4000 N and an axial load of 5000 N, operating at a speed of 1600 r.p.m. for an average life of 5 years at 10 hours per**

	day. Assume uniform and steady load. **(May 2016) (Nov.2015)** BTL5 **Answer: Page : 1014 – R.S.Khurmi & J.K.Gupta** **Given :** W_R = 4000 N ; W_A = 5000 N ; N = 1600 r.p.m. Since the average life of the bearing is 5 years at 10 hours per day, therefore life of the bearing in hours, $L_H = 5 \times 300 \times 10 = 15\,000$ hours ... (Assuming 300 working days per year) and life of the bearing in revolutions, $L = 60\,N \times L_H = 60 \times 1600 \times 15\,000 =$ **1440×10^6 rev** **(3 M)** We know that the basic dynamic equivalent radial load, $W = X.V.W_R + Y.W_A$ ...***(i)*** In order to determine the radial load factor (X) and axial load factor (Y), we require W_A / W_R and W_A / C_0. Since the value of basic static load capacity (C_0) is not known, therefore let us take $W_A / C_0 = 0.5$. **(2 M)** Now from Table , we find that the values of X and Y corresponding to $W_A / C_0 = 0.5$ and $WA/WR = 5000 / 4000 = 1.25$ (which is greater than $e = 0.44$) are $X = 0.56$ and $Y = 1$ Since the rotational factor (V) for most of the bearings is 1, therefore basic dynamic equivalent radial load, $W = 0.56 \times 1 \times 4000 + 1 \times 5000 = 7240$ N **(2 M)** From Table, we find that for uniform and steady load, the service factor (KS) for ball bearings is 1. Therefore the bearing should be selected for W = 7240 N. We know that basic dynamic load rating, $C = W \left(\frac{L}{10^6}\right)^{1/k}$ = 81.76 N From Table , let us select the bearing : 315 which has the following basic capacities, C_0 = 72 kN = 72 000 N and C = 90 kN = 90 000 N **(3 M)** Now $W_A / C_0 = 5000 / 72\,000 = 0.07$ ∴ From Table, the values of X and Y are $X = 0.56$ and $Y = 1.6$ Substituting these values in equation ***(i)***, we have dynamic equivalent load, $W = 0.56 \times 1 \times 4000 + 1.6 \times 5000 = 10\,240$ N ∴ Basic dynamic load rating, C = 115635 N = 115.635 N From Table , the bearing number 319 having **C = 120 kN**, may be selected. **Answer** **(3 M)**
3	**The load on the journal bearing is 150 kN due to turbine shaft of 300 mm diameter running at 1800 r.p.m. Determine the following :** **1. Length of the bearing if the allowable bearing pressure is 1.6 N/mm^2, and** **2. Amount of heat to be removed by the lubricant per minute if the bearing temperature is 60°C and viscosity of the oil at 60°C is 0.02 kg/m-s and the bearing clearance is 0.25 mm.** **(Nov.2011)** BTL5

	Answer: Page : 980 – R.S.Khurmi & J.K.Gupta **Solution.** Given : W = 150 kN = 150 × 103 N ; d = 300 mm = 0.3 m ; N = 1800 r.p.m. ; p = 1.6 N/mm2 ; Z = 0.02 kg / m-s ; c = 0.25 mm **1. Length of the bearing** Let l = Length of the bearing in mm. We know that projected bearing area, $A = l \times d = l \times 300 = 300\, l \text{ mm}^2$ **(3 M)** and allowable bearing pressure (p), $$1.6 = \frac{w}{a} = \frac{500}{l}$$ So, l = 500 / 1.6 = **312.5 mm Answer** **(3 M)** **2. Amount of heat to be removed by the lubricant** We know that coefficient of friction for the bearing, $\mu = \frac{33}{10^8}\left(\frac{ZN}{p}\right)\left(\frac{d}{c}\right) + k$ =0.011 **(3 M)** Rubbing velocity, $V = \frac{\pi dN}{60}$ = 28.3 m/s So, Amount of heat to be removed by the lubricant, $Qg = \mu.W.V$ = 46 695 J/s or W **= 46.695 kW Answer**. **(4 M)**
4	**A single-row deep groove ball bearing : 6002 is subjected to an axial thrust of 1000 N and a radial load of 2200 N. Find the expected life that 50% of the bearings will complete under this condition. (Nov.2010)** BTL5 **Answer: Page : 580 – V.B.Bhandari** **Given** F_a = 1000 N; F_r = 2200 N; Bearing = : 6002 **Step I** X and Y factors Referring to Table, the capacities of bearing : 6002 are, C_o = 2500 N and C = 5590 N Also, F_a = 1000 N and F_r = 2200 N $\left(\frac{F_a}{F_r}\right) = \left(\frac{1000}{2200}\right) = 0.455$ and $\left(\frac{F_a}{C_o}\right) = \left(\frac{1000}{2500}\right) = 0.4$ Referring to table, $\left(\frac{F_a}{F_r}\right) > e$ The value of Y is obtained by linear interpolation. $Y = 1.2 - \frac{(1.2 - 1.0)}{(0.5 - 0.25)} \times (0.4 - 0.25) = 1.08$ and x=0.56 **X = 0.56 ; Y = 1.08**

	(6 M) **Step II** Bearing life (L_{10}) $P = X F_r + Y F_a = 0.56(2200) + 1.08(1000) = 2312$ N W.K.T., $C = P (L_{10})^{1/3}$ $5590 = 2312 (L_{10})^{1/3}$ So, **L_{10} = 14.13 million rev.** **(4 M)** **Step III** Bearing life (L_{50}) It can be proved that the life (L_{50}), which 50% of the bearings will complete or exceed, is approximately five times the life L_{10} which 90% of the bearings will complete or exceed. Therefore, $L_{50} = 5L_{10} = 5\ (14.13) =$ **70.65 million rev.** **(3 M)**
5	**A single-row deep groove ball bearing is subjected to a radial force of 8 kN and a thrust force of 3 kN. The values of X and Y factors are 0.56 and 1.5 respectively. The shaft rotates at 1200 rpm. The diameter of the shaft is 75 mm and Bearing : 6315 (C =112 000 N) is selected for this application.** **(i) Estimate the life of this bearing, with 90% reliability.** **(ii) Estimate the reliability for 20 000 h life.** BTL5 **Answer: Page : 593 – V.B.Bhandari** **Given** *Fr* = 8 kN; *Fa* = 3 kN; *X* = 0.56; *Y* = 1.5; *n* = 1200 rpm; *d* = 75 mm; *C* = 112 000 N **Step I** Bearing life with 90% reliability $P = XF_r + YF_a = 0.56\ (8000) + 1.5\ (3000) = 8980$ N **(4 M)** **Step II** Reliability for 20000 hr life $$\left(\frac{L}{L_{10}}\right) = \left[\frac{log_e\left(\frac{1}{R}\right)}{log_e\left(\frac{1}{R_{90}}\right)}\right]^{\frac{1}{b}}$$ Or $$\left(\frac{L}{L_{10}}\right)^b = \left[\frac{log_e\left(\frac{1}{R}\right)}{log_e\left(\frac{1}{R_{90}}\right)}\right]$$ Substituting the following values, L = 20 000 h; **L_{10} = 26 945.83 h; Answer** **(5 M)** $R_{90} = 0.90$; b = 1.17 we get, $$\left(\frac{20000}{26945.83}\right)^{1.17} = \left[\frac{log_e\left(\frac{1}{R}\right)}{log_e\left(\frac{1}{0.90}\right)}\right]$$

	R = 0.9283 or 92.83% Answer **(4 M)**
6	**A single-row deep groove ball bearing is subjected to a radial force of 8 kN and a thrust force of 3 kN. The shaft rotates at 1200 rpm. The expected life L_{10h} of the bearing is 20 000 h. The minimum acceptable diameter of the shaft is 75 mm. Select a suitable ball bearing for this application.** BTL5 **Answer: Page : 577 – V.B.Bhandari** *Fr* = 8 kN; *Fa* = 3 kN; *L*10h = 20 000 hr; *n* = 1200 rpm; *d* = 75 mm **Step I** X and Y factors When the bearing is subjected to radial as well as axial load, the values of *X* and *Y* factors are obtained from Table by trial and error procedure. It is observed from Table, that values of *X* are constant and the values of *Y* vary only in case when, $\left(\frac{F_a}{F_r}\right) > e$ In this case, the value of *Y* varies from 1.0 to 2.0. We will assume the average value 1.5 as the first trial value for the factor *Y*. Therefore, X = 0.56 ;Y = 1.5; Fr = 8000 N; Fa = 3000 N $P = X F_r + Y F_a = 0.56(8000) + 1.5(3000) = 8980$ N Wkt., $L_{10} = \frac{60nL_{10h}}{10^6} = \frac{60 \times 1200 \times 20000}{10^6} = \mathbf{1440\ million\ rev}.$ **(2 M)** $C = P(L_{10})^{\frac{1}{3}} = (8980)(1440)^{\frac{1}{3}} = 101406.04$ N From Table , it is observed that for the shaft of 75 mm diameter, Bearing : 6315 (*C* = 112 000) is suitable for the above data. For this bearing, C_o = 72 000 N Therefore, $\left(\frac{F_a}{F_r}\right) = \left(\frac{3000}{8000}\right) = 0.375$ $\left(\frac{F_a}{C_o}\right) = \left(\frac{3000}{72000}\right) = 0.375$ **(3 M)** Referring to Table, e = 0.24 (approximately) and $\left(\frac{F_a}{F_r}\right) > e$ The value of Y is obtained by linear interpolation. $Y = 1.8 - \frac{(1.8 - 1.6)}{(0.07 - 0.04)} \times (0.04167 - 0.04) = 1.79$ and X = 0.56 **X= 0.56; Y=1.79** **(3 M)** **Step II** Dynamic load capacity $P = X F_r + Y F_a = 0.56(8000) + 1.79(3000) =$ **9850 N**

	$C = P (L_{10})^{1/3} = 9850 (1440)^{1/3} =$ **111 230.46 N** **(3 M)** **Step III** Selection of bearing From Table , Bearing : 6315 (C = 112 000) is suitable for the above application. **(2 M)**
7	**A 80 mm long journal bearing supports a load of 2800 N on a 50 mm diameter shaft. The bearing has a radial clearance of 0.05 mm and the viscosity of the oil is 0.021 kg / m-s at the operating temperature. If the bearing is capable of dissipating 80 J/s, determine the maximum safe speed. (May 2011)** BTL 5 **Answer: Page : 983 – R.S.Khurmi & J.K.Gupta** Given : l = 80 mm ; W = 2800 N ; d = 50 mm ; = 0.05 m ; c / 2 = 0.05 mm or c = 0.1 mm ; Z = 0.021 kg/m-s ; Qd = 80 J/s Let N = Maximum safe speed in r.p.m. We know that bearing pressure, $p = \frac{W}{l.d}$ **=0.7 N/mm²** **(3 M)** and coefficient of friction, $\mu = \frac{33}{10^8}\left(\frac{ZN}{p}\right)\left(\frac{d}{c}\right) + 0.002$ $= \frac{495\ N}{10^8} + 0.002$ **(5 M)** $\therefore$ Heat generated, $Q_g = \mu WV = \mu W\left(\frac{\pi dN}{60}\right)$ J/s $= \left(\frac{495\ N}{10^8} + 0.002\right) 2800 \left(\frac{\pi \times 0.05 N}{60}\right)$ $= \frac{3628\ N^2}{10^8} + 0.014\ 66\ N$ Equating the heat generated to the heat dissipated, we have $\frac{3628\ N^2}{10^8} + 0.014\ 66\ N = 80$ $N^2 + 404\ N – 2.2 \times 106 = 0$ **N = 1295 r.p.m.** **(5 M)**
	PART * C
1	**Design a journal bearing for a centrifugal pump from the following data :** **Load on the journal = 20 000 N; Speed of the journal = 900 r.p.m.; Type of oil is SAE 10, for which the absolute viscosity at 55°C = 0.017 kg / m-s; Ambient temperature of oil = 15.5°C ; Maximum bearing pressure for the pump = 1.5 N / mm².** **Calculate also mass of the lubricating oil required for artificial cooling, if rise of temperature** **of oil be limited to 10°C. Heat dissipation coefficient = 1232 W/m²/°C. (May 2016)**

(Nov.2013) (May 2011) BTL 6

Answer: Page : 979 – R.S.Khurmi & J.K.Gupta

Given :

W = 20 000 N ; N = 900 r.p.m. ; T_0 = 55°C ; Z = 0.017 kg/m-s ; T_a = 15.5°C ;
p = 1.5 N/mm^2 ; T = 10°C ; C = 1232 W/m^2/°C

The journal bearing is designed as discussed in the following steps :

1. First of all, let us find the length of the journal (*l*).
   Assume the diameter of the journal (*d*) as 100 mm. From PSG DDB: 7.31, we find that the ratio of *l* / *d* for centrifugal pumps varies from 1 to 2.

Let us take *l* / *d* = 1.6.

∴ *l* = 1.6 *d* = 1.6 × 100 = **160 mm Ans.**

(2 M)

2. We know that bearing pressure,
   $$p = \frac{w}{l.d} = 1.25$$

Since the given bearing pressure for the pump is 1.5 N/mm^2, therefore the above value of *p* is safe and hence the dimensions of *l* and *d* are safe.

(2 M)

3. $\frac{ZN}{p} = 12.24$

   From PSG DDB: 7.31, we find that the operating value of
   $$\frac{ZN}{p} = 28$$

(2 M)

We know that the minimum value of the bearing modulus at which the oil film will break is given by

$$\boldsymbol{3k = \frac{ZN}{p}}$$

Bearing modulus at the minimum point of friction,

$$\mathbf{k = \frac{1}{3}\left(\frac{ZN}{p}\right) = 9.33}$$

Since the calculated value of bearing characteristic number $\boldsymbol{\frac{ZN}{p} = 12.24}$ is more than 9.33, the bearing will operate under hydrodynamic conditions.

(2 M)

4. **From PSG DDB 7.31,** we find that for centrifugal pumps, the clearance ratio (*c/d*) = 0.0013
5. **We** know that coefficient of friction,

$$\mu = \frac{33}{10^8}\left(\frac{ZN}{p}\right)\left(\frac{d}{c}\right) + k$$

   = 0.0051 (Assuming k=0.002)

   $Q_g = \mu WV = \mu W\left(\frac{\pi dN}{60}\right)$ J/s

6. Heat generated,
   = 480.7 W

	(2 M) **7.** Heat dissipated, $Q_d = CA(t_b - t_a) = Cld(t_b - t_a)W$ .... $(\because A = l \times d)$ We know that $(t_b - t_a) = \frac{1}{2}(t_0 - t_a) = 19.75°C$ $\therefore Q_d = 1232 \times 0.16 \times 0.1 \times 19.75 = 389.3\,W$ We see that the heat generated is greater than the heat dissipated which indicates that the bearing is warming up. Therefore, either the bearing should be redesigned by taking t_0 = 63°C or the bearing should be cooled artificially. We know that the amount of artificial cooling required = Heat generated – Heat dissipated = *Qg* – *Qd* = 480.7 – 389.3 = 91.4 W **(3 M)** **Mass of lubricating oil required for artificial cooling** Let *m* = Mass of the lubricating oil required for artificial cooling in kg / s. We know that the heat taken away by the oil, *Qt* = *m.S.t* = *m* × 1900 × 10 = 19 000 *m* W ... [∵ Specific heat of oil (*S*) = 1840 to 2100 J/kg/°C] Equating this to the amount of artificial cooling required, we have 19 000 *m* = 91.4 ∴ *m* = 91.4 / 19 000 = 0.0048 kg / s = **0.288 kg / min Answer** **(2 M)**
2	**A full journal bearing of 50 mm diameter and 100 mm long has a bearing pressure of 1.4 N/mm². The speed of the journal is 900 r.p.m. and the ratio of journal diameter to the diametral clearance is 1000. The bearing is lubricated with oil whose absolute viscosity at the operating temperature of 75°C may be taken as 0.011 kg/m-s. The room temperature is 35°C. Find :** **1. The amount of artificial cooling required, and 2. The mass of the lubricating oil required, if the difference between the outlet and inlet temperature of the oil is 10°C. Take specific heat of the oil as 1850 J / kg / °C. (Nov.2015)** BTL5 **Answer: Page : 981 – R.S.Khurmi & J.K.Gupta** **Solution.** Given : d = 50 mm = 0.05 m ; l = 100 mm = 0.1 m; p = 1.4 N/mm2 ; N = 900 r.p.m. ; d / c = 1000 ; Z = 0.011 kg / m-s ; t0 = 75°C ; ta = 35°C ; t = 10°C ; S = 1850 J/kg / °C **1. Amount of artificial cooling required** We know that the coefficient of friction, $\mu = \frac{33}{10^8}\left(\frac{ZN}{p}\right)\left(\frac{d}{c}\right) + k$ **=0.00433** **(3 M)** Load on the bearing, W = p × d.l = 1.4 × 50 × 100 = 7000 N and rubbing velocity, $v = \frac{\pi dN}{60} = \mathbf{2.36\ m/s}$ **(3 M)**

	Heat generated, Qg = µ.W.V = 0.004 33 × 7000 × 2.36 = 71.5 J/s Let tb = Temperature of the bearing surface. We know that $(t_b - t_a) = \frac{1}{2}(t_0 - t_a) = 20°C$ **(3 M)** Since the value of heat dissipation coefficient (C) for unventilated bearing varies from 140 to 420 W/m2/°C, therefore let us take C = 280 W/m2 /° C We know that heat dissipated, Qd = C.A (tb – ta) = C.l.d (tb – ta) = 280 × 0.05 × 0.1 × 20 = 28 W = 28 J/s ∴ Amount of artificial cooling required = Heat generated – Heat dissipated = Qg – Qd = 71.5 – 28 = 43.5 J/s or W **Ans.** **(3 M)** **2. Mass of the lubricating oil required** Let m = Mass of the lubricating oil required in kg / s. We know that heat taken away by the oil, Qt = m.S.t = m × 1850 × 10 = 18 500 m J/s Since the heat generated at the bearing is taken away by the lubricating oil, therefore equating Qg = Qt, 71.5 = 18 500 m ∴ m = 71.5 / 18 500 = 0.003 86 kg / s = 0.23 kg / min **Ans.** **(3 M)**
3	**A single-row deep groove ball bearing is used to support the lay shaft of a four speed automobile gear box. It is subjected to the following loads in respective speed ratios:**

Gear	Axial load (N)	Radial load (N)	% time engaged
First gear	3250	4000	1%
Second gear	500	2750	3%
Third gear	50	2750	21%
Fourth gear	Nil	Nil	75%

The lay shaft is fixed to the engine shaft and rotates at 1750 rpm. The static and dynamic load carrying capacities of the bearing are 11600 and 17600 N respectively. The bearing is expected to be in use for 4000 hours of operation. Find out the reliability with which the life could be expected. BTL5

Answer: Page : 594 – V.B.Bhandari

Given n = 1750 rpm; Co = 11 600 N; C = 17 600 N; L_h = 4000 h;

Step I *Equivalent load for complete work cycle*

Considering the work cycle of one minute duration,

$$N_1 = \frac{1}{100}(1750) = 17.50 \text{ rev.}$$

$$N_2 = \frac{3}{100}(1750) = 52.50 \text{ rev.}$$

$N_3 = \frac{21}{100}(1750) = 367.50$ rev.

$N_4 = \frac{75}{100}(1750) = 1312.50$ rev.

$(N_1 + N_2 + N_3 + N_4) = 1750$ rev.

(3 M)

First gear

$\left(\frac{F_a}{F_r}\right) = \left(\frac{3200}{4000}\right) = 0.8125$

and $\left(\frac{F_a}{C_o}\right) = \left(\frac{3200}{11600}\right) = 0.28$

From table, it is observed that the value of e will be from 0.37 to 0.44.

$\therefore \left(\frac{F_a}{F_r}\right) > e$

The value of factor *Y* is obtained by linear interpolation.

$Y = 1.2 - \frac{(1.2 - 1.0)}{(0.5 - 0.25)} \times (0.28 - 0.25) = 1.176$

and X = 0.56

$P_1 = X F_r + Y F_a = = 0.56(4000) + 1.176(3250) =$ **6062 N**

(2 M)

Second gear

$\left(\frac{F_a}{F_r}\right) = \left(\frac{500}{2750}\right) = 0.182$

and $\left(\frac{F_a}{C_o}\right) = \left(\frac{500}{11600}\right) = 0.0431$

From table, it is observed that the value of e will be from 0.24 to 0.27.

$\therefore \left(\frac{F_a}{F_r}\right) > e$

$P_2 = F_r =$ **2750 N**

(1 M)

Third gear

$\left(\frac{F_a}{F_r}\right) = \left(\frac{50}{2750}\right) = 0.0182$

and $\left(\frac{F_a}{C_o}\right) = \left(\frac{50}{11600}\right) = 0.00431$

From table, it is observed that the value of e will be 0.22 or less.

Assuming,

$\left(\frac{F_a}{F_r}\right) > e$

$P_3 = F_r =$ **2750 N**

(1 M)

Fourth gear

P4 = 0

$$P_e = \sqrt[3]{\left[\frac{N_1P_1^3 + N_1P_1^3 + N_1P_1^3 + N_4P_4^3}{N_1 + N_2 + N_3 + N_4}\right]} = \mathbf{1932.67\ N}$$

(1 M)

Step II Bearing life L10 and L

$L_{10} = \left(\frac{C}{P}\right)^3$ **= 755.2 million rev.**

$L = \frac{60nL_h}{10^6}$ **= 420 million rev.**

(3 M)

Step III Reliability of bearing

$$\left(\frac{L}{L_{10}}\right) = \left[\frac{log_e\left(\frac{1}{R}\right)}{log_e\left(\frac{1}{R_{90}}\right)}\right]^{1/b}$$

Or

$$\left(\frac{L}{L_{10}}\right)^b = \left[\frac{log_e\left(\frac{1}{R}\right)}{log_e\left(\frac{1}{R_{90}}\right)}\right]$$

Substituting L = 420 million rev., L_{10} = 755.2 million rev., R_{90} = 0.90 and b =1.17, we get
R = 0.9483 or 94.83 %

(4 M)

ME8594 **DYNAMICS OF MACHINES** **L T P C**

3 0 0 3

OBJECTIVES:

- To understand the force-motion relationship in components subjected to external forces and analysis of standard mechanisms.
- To understand the undesirable effects of unbalances resulting from prescribed motions in mechanism.
- To understand the effect of Dynamics of undesirable vibrations.
- To understand the principles in mechanisms used for speed control and stability control.

UNIT I FORCE ANALYSIS **9**

Dynamic force analysis – Inertia force and Inertia torque– D Alembert's principle –Dynamic Analysis in reciprocating engines – Gas forces – Inertia effect of connecting rod– Bearing loads – Crank shaft torque – Turning moment diagrams –Fly Wheels – Flywheels of punching presses- Dynamics of Cam follower mechanism.

UNIT II BALANCING **9**

Static and dynamic balancing – Balancing of rotating masses – Balancing a single cylinder engine –Balancing of Multi-cylinder inline, V-engines – Partial balancing in engines – Balancing of linkages –Balancing machines-Field balancing of discs and rotors.

UNIT III SINGLE DEGREE FREE VIBRATION **9**

Basic features of vibratory systems – Degrees of freedom – single degree of freedom – Free vibration – Equations of motion – Natural frequency – Types of Damping – Damped vibration– Torsional vibration of shaft – Critical speeds of shafts – Torsional vibration – Two and three rotor torsional systems.

UNIT IV FORCED VIBRATION **9**

Response of one degree freedom systems to periodic forcing – Harmonic disturbances – Disturbance caused by unbalance – Support motion –transmissibility – Vibration isolation vibration measurement.

UNIT V MECHANISM FOR CONTROL **9**

Governors – Types – Centrifugal governors – Gravity controlled and spring controlled centrifugalgovernors – Characteristics – Effect of friction – Controlling force curves. Gyroscopes Gyroscopic forces and torques – Gyroscopic stabilization – Gyroscopic effects in Automobiles, ships and airplanes.

TOTAL : 45 PERIODS

OUTCOMES:

- Upon completion of this course, the Students can able to predict the force analysis in mechanical system and related vibration issues and can able to solve the problem

TEXT BOOK:

1. Uicker, J.J., Pennock G.R and Shigley, J.E., “Theory of Machines and Mechanisms”, 3rd Edition, Oxford University Press, 2009.

2. Rattan, S.S, “Theory of Machines”, 3rd Edition, Tata McGraw-Hill, 2009.

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2. Cleghorn. W. L, “Mechanisms of Machines”, Oxford University Press, 2005

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4. Robert L. Norton, "Kinematics and Dynamics of Machinery", Tata McGraw-Hill, 2009.

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12. Khurmi, R.S.,”Theory of Machines”, 14th Edition, S Chand Publications, 2005.

Subject Code:ME8594 **Year/Semester: III /05**
Subject Name: DYNAMICS OF MACHINES **Subject Handler: Mr. S.Kannan**

UNIT I - FORCE ANALYSIS

Dynamic force analysis – Inertia force and Inertia torque– D Alembert's principle –Dynamic Analysis in reciprocating engines – Gas forces – Inertia effect of connecting rod– Bearing loads – Crank shaft torque – Turning moment diagrams –Fly Wheels – Flywheels of punching presses- Dynamics of Cam follower mechanism.

PART * A

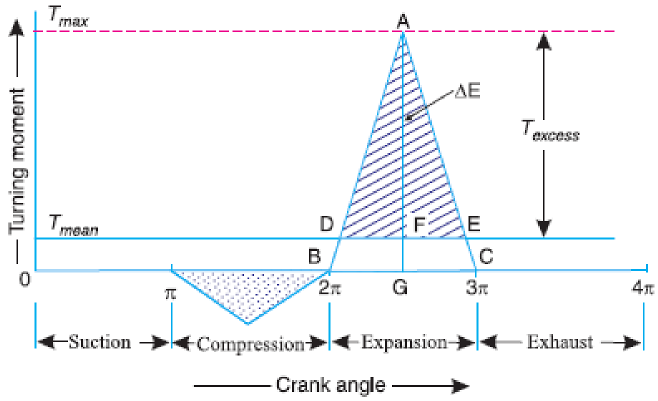
Q.No.	Questions
1.	**What do you mean by inertia? (** BTL1) The property of matter offering resistance to any change of its state of rest or of uniform motion in a straight line is known as inertia.
2	**Define inertia force. (** BTL1) The inertia force is an imaginary force, which when acts upon a rigid body, brings it in an equilibrium position. Inertia force = - Acceleration force = - m. a
3	**State D' Alembert's principle. (** BTL1) D' Alembert's principle states that the inertia forces and torques, and the external forces and torques acting on a body together result in statically equilibrium.
4	**State the principle of superposition. (** BTL1) The principle of superposition states that for linear systems the individual responses to several disturbances or driving functions can be superposed on each other to obtain the total response of the system.
5	**Define: piston effort (** BTL1) **Piston effort** is defined as the net or effective force applied on the Piston, along the line of stroke. It is also known as effective driving force (or) net load on the gudgeon pin.
6	**Define crank effort and crank-pin effort. (** BTL1) **Crank effort** is the net effort (force) applied at the crank pin perpendicular to the crank, which gives the required turning moment on the crankshaft. The component of force acting along the connecting rod (FQ) perpendicular to the crank is known as **crank-pin effort**.
7	**What do you mean by correction couple or error in torque? (** BTL1) This couple must be applied, when the masses are placed arbitrarily to make the system

	dynamically Equivalent
8	**What is meant by turning moment diagram or crank effort diagram? (** BTL2) It is the graphical representation of the turning moment or crank effort for various position of the crank In turning moment diagram, the turning moment is taken as the ordinate (Y-axis) and crank angle as abscissa (X-axis).
9	**Define inertia torque.(** BTL1) The inertia torque is an imaginary torque, which when applied upon the rigid body, brings it in equilibrium position. It is equal to the acceleration couple in magnitude but opposite in direction.
10	**Explain the term maximum fluctuation of energy in flywheel.(** BTL2) The different between the maximum and the minimum energies is known as maximum fluctuation of energy ΔE = Maximum energy – Minimum energy
11	**Define coefficient of fluctuation of energy.(** BTL1) It is the ratio of maximum fluctuation of energy to the work done per cycle. $C_E = \frac{\text{Maximum fluctuation of energy}(\Delta E)}{\text{Workdone per cycle}}$
12	**What is meant by maximum fluctuation of speed? (** BTL3) The difference between the maximum and minimum speeds during a cycle is called maximum fluctuation of speed.
13	**Define coefficient of fluctuation of speed.(** BTL1) The ratio of the maximum fluctuation of speed to the mean speed is called the coefficient of fluctuation of speed (CS). $C_S = \frac{N_1 - N_2}{N} = \frac{2(N_1 - N_2)}{(N_1 + N_2)}$ Where N_1 = Maximum speed N_2 = Minimum speed, and N = Mean speed = $\frac{N_1 + N_2}{2}$
14	**Define coefficient of steadiness. (** BTL1) The reciprocal of the coefficient of fluctuation of speed is known as coefficient of steadiness (m).

	$$m = \frac{1}{C_S} = \frac{N}{N_1 - N_2}$$
15	**List out few machines in which fly wheel is used. (** BTL4) Fly wheel is used in: a) Punching machines, b) Shearing machines,c) Riveting machines, and d) Crushing machines.
16	**Why flywheels are needed in forging and pressing operations? (** BTL4) In both forging and pressing operations, flywheels are required to control the variations in speed during each cycle of an engine.
17	**What is cam dynamics? (** BTL5) Cam dynamics is the study of cam follower system with considering the dynamic forces and torques developed in it.
18	**Define unbalance and spring surge. (** BTL1) **Unbalance**: A disc cam produces unbalance because its mass is not symmetrical with the axis of rotation. **Spring surge**: Spring surge means vibration of the retaining spring.
19	**Define windup. What is the remedy for camshaft windup. (** BTL1) Twisting effect produced in the camshaft during the raise of heavy load follower is called as windup Camshaft windup can be prevented to a large extend by mounting the flywheel as close as possible to the cam.
20	**What are the effect and causes of windup? (** BTL6) The effect of wind up will produce follower jump or float or impact. Causes of wind up are: When heavy loads are moved by the follower, When the follower moves at high speed, and When the shaft is flexible.
	PART * B
1	**A single cylinder, single acting, four stroke gas engine develops 20 kW at 300 r.p.m. The work done by the gases during the expansion stroke is three times the work done on the gases during the compression stroke, the work done during the suction and exhaust strokes being negligible. If the total fluctuation of speed is not to exceed ± 2 per cent of the mean**

speed and the turning moment diagram during compression and expansion is assumed to be triangular in shape. Find the moment of inertia of the flywheel. (13 M)(BTL5)

Answer: Page 582-R.S KHURMI



5M

<u>**Given**</u>**:** P=20kW;N=300rpm; ω=2ΠN/60=31.442rad/s

since the total fluctuation of speed (ω_1-ω_2) is not to exceed ±2 percent of the mean speed (ω),

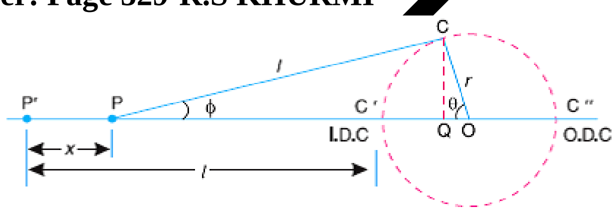
Therefore, $\omega_1-\omega_2=4\%\omega$; $C_S=\omega_1-\omega_2/\omega=0.04$

n=N/2=300/2=150; ∴Workdone/cycle=P*60/n=8000N-m

<u>Max. Fluctuation Energy $\Delta E=I\omega^2 C_S$=255.2Kg-m²</u> 8M

2 **Derive the equation of forces on the reciprocating parts of an engine, neglecting weight of the connecting rod. (13 M)**(BTL5)

Answer: Page 529-R.S KHURMI



Motion of a crank and connecting rod of a reciprocating steam engine.

Let
- l = Length of connecting rod between the centres,
- r = Radius of crank or crank pin circle,
- ϕ = Inclination of connecting rod to the line of stroke *PO*, and
- n = Ratio of length of connecting rod to the radius of crank = l/r. 3M

Force due to gas pressure: $F_L= P\times\frac{\pi}{4} d^2$

Inertia forceF_i = -(mass of piston) xAccleration of piston

1) Net Force=F_p-F_I+W_R =F_L-F_I+m_R.g 2M

2) Resultant load on the gudgeon pin: F_Q=FP/cosϕ2M

3) Thrust on the cylinder walls: F_N= FP tanϕ2M

4) Crank pin effort F_T = F_Q x cos(ϕ+ θ) and Bearing effort F_B = F_Q xSin(ϕ+ θ) 2M

6) Torque = F_Tx r 2M

3 **The torque delivered by a two-stroke engine is represented by T = (1000+300 sin 2θ – 500**

	cos 2θ) N-m.Where θ is the angle turned by the crank from the inner dead centre. the engine speed is 250 rpm.the mass of the flywheel is 400 kg and radius of gyration 400 mm. determine (i) the power developed,(ii) the total percentage fluctuation of speed,(iii) the angular acceleration of flywheel when the crank has rotated through an angle of 60° from the inner dead centre. (iv) The maximum angular acceleration and retardation of the flywheel. (13 M)(BTL5) **Answer:Page 585-R.S KHURMI** **Given:** T = (1000+300 sin 2θ – 500 cos 2 θ) N-m: N=250rpm; m=400kg; k=0.4m; ɵ=600; ω=2πx250/60=26.18rad/s; 3 M T_{mean}=Work done per cycle/Crank angle per rev=976.13N-m; $ɵ_1$=29.510$ɵ_2$=119.50; 2M Power Developed P= T_{mean}xω =25.56kW; Max. Fluctuation of Energy=ΔE=$mk^2\omega^2$cs; 2M cs=1.33%; Angular acceleration'α' when ɵ=600 ; 2M α=7.965rad/s^2 ; when 2ɵ=149.040 ; T-T_{mean}=583N-m; 2ɵ=329.04; T-T_{mean}=583N-m=-583.1N-m; 2M α_{Max} or α_{Min}= T-T_{mean}/T=9.11rad/s^2 2M
4	**In a slider crank mechanism, the length of the crank and connecting rod are150 mm and 600 mm respectively. The crank position is 60° from inner dead centre. The crank shaft speed is 450 r.p.m. clockwise. Determine 1. Velocity and acceleration of the slider, 2. Velocity and acceleration of point D on the connecting rod which is 150 mm from crank pin C, and 3. angular velocity and angular acceleration of the connecting rod. (13 M)(**BLT5) **Answer: Page 528-R.S KHURMI** **Given :** OC = 150 mm = 0.15m ; PC = 600 mm = 0.6 m ; CD = 150 mm = 0.15 m ; N = 450 r.p.m. or ω = 2π × 450/60 = 47.13 rad/s 3M 1. Velocity &Accceleration of the slider: Vp= ω xOM=6.834m/s; ap= ω 2xNO=124.4m/s^2 3M 2. Velocity and acceleration of point D on the connecting rod: V_D=ω*OD_1=6.834m/s; a_D= ω^2x OD_2=266.55m/$s^2$3M 3. Angular velocity and angular acceleration of the connecting rod: ω_{PC}= V_{pc}/PC=6.127rad/s; ω_{PC}=a^t_{PC}/PC=481.27rad/$s^2$4M
5	**A vertical petrol engine 150 mm diameter and 200 mm stroke has a connecting rod 350 mm long. The mass of the piston is 1.6 kg and the engine speed is 1800 rpm.on the expansion stroke with crank angle 30° from the top dead centre, the gas pressure is 750 kN/m^2.Determine the net thrust on the engine. (13 M)(**BTL5) **Answer: Page 537-R.S KHURMI**

	Given: D=150=0.15m; L=200mm=0.2m; Radius of the crank; r=L/2=0.1m; Connecting rod length l=0.35m 2M m=1.6kg; p=750kN/m^2 N=1800rpm; Angular velocity =188.49rad/s, 2M Crank angle θ=30^0; Gas pressure p=750kN/m^2 2M Piston Force F_p=pxarea of the piston= 13253.59N; 2M Inertia forceF_i = -(mass of piston) xAccleration of piston 2M Net thrust for vertical engine is given by F=F_P+F_i±W= 7534.396N 3M
6	**A vertical double acting steam engine develops 75 kW at 250 rpm. The maximum fluctuation of energy is 30 percent of the work done per stroke. The maximum and minimum speeds are not to vary more than 1% on either side of the mean speed. Find the mass of the flywheel required if the radius of gyration is 0.6 meters. (13 M)**(BTL5) **Answer: Page 607-R.S KHURMI** Given: Power=75kW; N=250rpm; ω_1-ω_2=1% ω=0.01ω; k=0.6m 2M Cs= ω_1-ω_2/ ω=0.01; 3M Maximum fluctuation of energy,Δ E = Work done per cycle × CE 3M We know that Δ E =mk^2 ω^2 Cs; 3M Mass of the flywheel=547kg 2M
7	**The lengths of crank and connecting rod of a horizontal reciprocating engine are 200 mm and 1 meter respectively. The crank is rotating at 400 rpm. when the crank has turned through 30° from the inner dead centre. The difference of pressure between cover and piston rod is 0.4 N/mm2.if the mass of the reciprocating parts is 100 kg and cylinder bore is 0.4 meters, then calculate: (i) inertia force, (ii) force on piston, (iii) piston effort, (iv) thrust on the sides of the cylinder walls, (v) thrust in the connecting rod, and (vi) crank effort. (13 M)(**BTL5) **Answer: Page 533-R.S KHURMI** **Given:** r=0.2m; l=1m;N=400rpm or ω=2*3.14*N/60 =41.88rad/s: ɵ=30^0; p_1-p_2=0.4N/mm^2; m=100kg; D=0.4m; n=l/r=5 1M (i)Inertia Force(Fi): Fi=-mxa [-ve sign is due to the fact that inertia force opposes the accelerating force] a=acceleration of the piston which is given as: $= r\omega^2\left(\cos\theta + \frac{\cos 2\theta}{n}\right)$ where $\theta = 30°$ =338.86m/s^2 ;

Therefore Fi=-m*a=-33886N 2M

(ii) Force of the piston: F_P=P xarea of the piston; $P=P_1-P_2=0.4\ N/mm^2$; FP=50265N 2M

(iii) Piston effort: $F=F_i+F_P=16379N$ 2M

(iv) Thrust on the sides of the cylinder walls = $F_N=F_p\tan\phi$ 2M

The thrust on the sides of cylinder walls(or normal reaction), FN is given as;

$$\sin\phi = \frac{r}{l}\sin\theta = 0.1$$
$$\phi = \sin^{-1} 0.1 = 5.739°$$
$$F_N = F\tan\phi = 16379 \times \tan 5.739°$$
$$= 16379 \times 0.1005 = 1646.1\ N.$$

ϕ=Angle made by connecting rod with line of stroke, the value of ϕ in terms of θ is given as 2M

(v) Thrust in the connecting rod:$F_Q=F/\cos\phi=16461.5N$ 2M

(vi) Crank effort (FT) or Tangential Force: $F_T=F_Q\sin(\theta+\phi)$=[illegible]615N 2M

8

The radius of gyration of a fly wheel is 1 meter and the fluctuation of speed is not to exceed 1% of the mean speed of the flywheel. If the mass of the flywheel is 3340 kg and the steam engine develops 150 kW at 135 rpm, then find (i) maximum fluctuation of energy and (ii) coefficient of fluctuation of energy.(13 M) (BLT5)

Answer: Page 533-R.S KHURMI

Given: k=1m; fluctuation of speed=1% of mean speed or $\omega_2-\omega_1$=1% of ω or $\omega_2-\omega_1/\omega=0.01$ or coefficient of fluctuation of speed, K_s=0.01; m=3340kg; P=150Kw; N=135rpm; ω=14.137rad/s

2M

(i) **maximum fluctuation of energy**

$$\Delta E = mk^2 \times \omega^2 \times K_s$$ 2M

=6675.13Nm

(ii) coefficient of fluctuation of energy

KE=Max Fluctuation of energy/Workdone per cycle

Workdone per cycle=T_{mean}x θ= T_{mean}x2π; 4M

T_{mean}= P/ω=10610.45Nm 2M

Work done per cycle=10610.45x2π=66667.42Nm/cycle.

coefficient of fluctuation of energy = 6675.1/66667.42 = 0.1 4M

9

A vertical petrol engine with cylinder of 150 mm diameter and 200 mm stroke has a connecting rod of 350 mm long. The mass of the piston is 1.6 kg and the engine speed is 1800 rpm.on the expansion stroke with crank angle 30° from TDC, the gas pressure is 750

kPa.Determine the net thrust on the piston.(13 M)(BLT5)

Answer: Page 533-R.S KHURMI

Given: D=0.15m; r=l/2=0.1m; l=0.35m;

m_k=1.6kg; N=1800rpm; ɵ=30^0;

F_{gasPr}=750x103N/m^2 2M

By Analytical Method: Net Thrust on the piston $F_P=F_{gaspr}+W_R-F_I$2M

$$F_I = m_R . a_R = m_R . \omega^2 . r \left(\cos\theta + \frac{\cos 2\theta}{n}\right)$$ 2M

F_I=5736N

$F_{gas\ pressure\ force} = F_{gaspr}$x Area = 13,254N; 2M

Weight of piston W_R=15.7N 2M

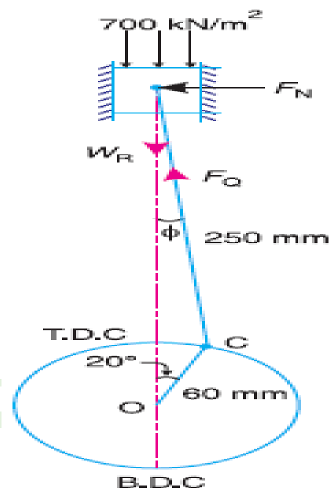
Net Thrust on the piston FP= $F_{gaspr}+W_R-F_I$=7534N 3M

PART * C

1

A single cylinder vertical engine has a bore of 100 mm and a stroke of 120 mm has a connecting rod of 250mm long. The mass of the piston is 1.1kg. The speed is 2000rpm. On the expansion stroke, with a crank at 20° from top dead center, the gas pressure is 700kN/mm2. Determine (i) Net force acting on the piston (ii) Resultant load on the gudgeon pin (iii) Thrust on the cylinder walls, and (iv) Speed above which, other things remaining the same, the gudgeon pin load would be reversed in direction. (15 M)(BTL5)

Answer: Page 528-R.S KHURMI



Given: D=0.1m; L=0.12m; r=L/2=0.06m; l=0.25m; m_R=1.1kg; N=2000rpm; ω=209.5rad/s; θ=200; p=700kN/$m^2$2M

1. Force due to gas pressure: F_L= Px3.14/4x$(0.1)^2$=5.5kN;
N=L/r=0.25/0.06=4.17

$$F_I = m_R.\omega^2.r\left(\cos\theta + \frac{\cos 2\theta}{n}\right) = 3254\ N$$ 2M

2. Net Force=F_p-F_I+W_R =F_L-F_I+m_R.g =2256.8N 2M

3. Resultant load on the gudgeon pin: FQ=FP/cosϕ=2265N 2M

4. Thrust on the cylinder walls: FN= FP tanϕ=185.5N 2M

5. Speed, above which the gudgeon pin load would be reversed in the direction 2M

6.Corresponding speed in rpm….N1>2606rpm2M

2

In a reciprocating engine mechanism, if the crank and the connecting rod are 300 mm and 1 m long respectively and the crank rotates at a constant speed of 200 rpm. determine analytically: (i) the crank angle at which the maximum velocity occurs, and (ii) the maximum velocity of the piston (iii) derive the relevant equations. (15 M)(BTL5)

Answer: Page 528-R.S KHURMI

Given : r = 300 mm = 0.3 m ; l = 1 m ; N = 200 r.p.m. or w= 2 x3.14×200/60 = 20.95 rad/s 3M

1. Crank angle at which the maximum velocity occurs, n=l/r=3.33 4M

$$v_P = \omega r\left(\sin\theta + \frac{\sin 2\theta}{2n}\right) \quad \frac{dv_P}{d\theta} = 0 \quad \theta = 75^{\circ}$$ 4M

2. Maximum velocity of the piston; v_p(max)=6.54m/s 4M

3

The turning moment diagram for a petrol engine is drawn to the following scales : Turning moment, 1 mm = 5 N-m crank angle, 1 mm = 1°. The turning moment diagram repeats itself at every half revolution of the engine and the areas above and below the mean turning moment line taken in order are 295, 685, 40, 340, 960, 270 mm². The rotating parts are equivalent to a mass of 36 kg at a radius of gyration of 150 mm. Determine the coefficient of fluctuation of speed when the engine runs at 1800 r.p.m. (15 M)(BTL5)

Answer: Page 528-R.S KHURMI

Given: m=36kg; k=0.12m; N=1800rpm; w=188.52rad/s 3M

ΔE = Maximum Energy – Minimum Energy=985mm^2

= 985x 3.14/36 = 86 N-m = 86 J 4M

Max fluctuation of energy ΔE =mk^{2}xw^{2}CS 86=36x(0.12)^{2}x(188.52)^{2}xCS 4M

Coefficient of fluctuation of speed Cs = 0.003 or 0.3 % 4M

UNIT II BALANCING

Static and dynamic balancing – Balancing of rotating masses – Balancing a single cylinder engine – Balancing of Multi-cylinder inline, V-engines – Partial balancing in engines – Balancing of linkages – Balancing machines-Field balancing of discs and rotors.

PART * A	
Q.No	**Questions**
1	**Write the importance of balancing.**BTL1 If the moving part of a machine are not balanced completely then the inertia forces are set up which may cause excessive noise, vibration, wear and tear of the system. So balancing of machine is necessary.
2	**Why rotating masses are to be dynamically balanced?** BTL4 If the rotating masses are not dynamically balanced, the unbalanced dynamic forces will cause worse effects such as wear and tear on bearings and excessive vibrations in machines. It is very common in cam shafts, steam turbine rotors, engine crank shafts, and centrifugal pumps, etc.
3	**Unbalanced effects of shafts in high speed machines are to be closely looked into – Why?** BTL4 The dynamic forces of centrifugal forces or a result of unbalanced masses are a function the angular velocity of rotation. i.e., $F_C = m\omega^2 r$
4	**Write different types of balancing.**BTL1 a) Balancing of rotating masses Static balancing Dynamic balancing b) Balancing of reciprocating masses.
5	**State the conditions for complete balance of several masses revolving in different planes of a shaft.** BTL1 (a) The resultant centrifugal force must be zero, and (b) The resultant couple must be zero.
6	**Whether grinding wheels are balanced or not? If so why?** BTL4 Yes, the grinding wheels are properly balanced by inserting some low density materials. If not the required surface finish won't be attained and the vibration will cause much noise.

7	**Whether your watch needles are properly balanced or not?** BTL4 Yes, my watch needles are properly balanced by providing some extra projection (mass) in the opposite direction.
8	**Why is only a part of the unbalanced force due to reciprocating masses balanced by revolving mass? (Or)Why complete balancing is not possible in reciprocating engine?** BTL4 Balancing of reciprocating masses is done by introducing the balancing mass opposite to the crank. The vertical component of the dynamic force of this balancing mass gives rise to "Hammer blow". In order to reduce the Hammer blow, a part of the reciprocating mass is balanced. Hence complete balancing is not possible in reciprocating engine.
10	**Differentiate between the unbalanced force caused due to rotating and reciprocating masses.** BTL5 Complete balancing of revolving mass can be possible. But fraction of reciprocating mass only balanced. The unbalanced force due to reciprocating mass varies in magnitude but constant in direction. But in the case of revolving masses, the unbalanced force is constant in magnitude but varies in direction.
11	**Why are the cranks of a locomotive, with two cylinders, placed 90° to each other?** BTL3 In order to facilitate the starting of locomotive in any position (i.e., in order to have uniformity in turning moment) the cranks of a locomotive are generally at 90° to one another.
12	**List the effects of partial balancing of locomotives.** BTL1 Variation in tractive force along the line of stroke, Swaying couple, and Hammer blow
13	**Define tractive force.** BTL1 The resultant unbalanced force due to the two cylinders along the line of stroke, is known as tractive force.
14	**Define swaying couple.** BTL1 The unbalanced force acting at a distance between the line of stroke of two cylinders, constitute a couple in the horizontal direction. The couple is known as swaying couple.
15	**Define hammer blow with respect to locomotives.** BTL1 The maximum magnitude of the unbalanced force along the perpendicular to the line of stroke is known as hammer blow.

16	**Give the effects of hammer blow and swaying couple.** BTL2 The effect of hammer blow is to cause the variation in pressure between the wheel and the rail, such that vehicle vibrates vigorously. The effect of swaying couple is to make the leading wheels sway from side to side.
17	**Give the condition to be satisfied for complete balance of in- line engine.** BTL2 The algebraic sum of the primary and secondary forces must be zero, and The algebraic sum of the couples due to primary and secondary forces must be zero.
18	**Why radial engines are preferred?** BTL2 In radial engines the connecting rods are connected to a common crank and hence the plane of rotation of the various cranks is same, therefore there are no unbalanced primary or secondary couples. Hence radial engines are preferred.
19	**List the different types of balancing machines.**BTL1 Static balancing machines, Dynamic balancing machines, and Universal balancing machines.
20	**Define swaying couple.** BTL1 The unbalanced force acting at a distance between the lines of stroke of two cylinders, constitute a couple in the horizontal direction. The couple is known as swaying couple.
	PART * B
1	**Four masses A, B, C and D revolve at equal radii and are equally spaced along a shaft. The mass B is 7 kg and the radii of C and D make angles of 90° and 240° respectively with the radius of B. Find the magnitude of the masses A, C and D and the angular position of A so that the system may be completely balanced. (13M)**BTL5 **Answer: Page : 855 - R.S.KURUMI** **Given:** mA = 7 kg ; C = 90° with B; D = 240° with B Plane Mass Radius Cent.force /ω2 Distance from Couple /ω2

	(m) kg	(r) m	(m.r) kg-m	R.P (l) m	(m.r.l) kg-m2
A	mA	rA	mA rA	1	mA rA
B	mB	rB	mBrB	1	0
C	mC	rC	mCrC	1	mCrC
D	mD	rD	mDrD	1	mDrD

(13M)

2\. **A,B,C and D are four masses carried by a rotating shaft at radii 100 , 125,200 and 150 mm respectively. The planes in which the masses revolve are spaced 600 mm apart and the masses of B ,C and D are 10 kg , 5 kg and 4kg respectively. Find the required mass A and the relative angular settingsof the four masses so that the shaft shall be in complete balance. (13M)** BTL 5

Answer: Page : 847- R.S.KURUMI

Plane	Mass (m) kg	Radius (r) m	Cent.force /ω2 (m.r) kg-m	Distance from R.P (l) m	Couple /ω2 (m.r.l) kg-m2
A	mA	0.1	0.1ma	0	0
B	10	0.125	1.25	0.6	0.75
C	5	0.2	1	1.2	1.2
D	4	0.15	0.6	1.8	1.08

(13M)

2 **The following particulars relate to an outside cylinder of uncoupled locomotive: Revolving mass per cylinder = 300kg; Reciprocating mass per cylinder = 450 kg; Length of each crank = 350 mm; Distance between wheels = 1.6 m; Distance between cylinder centers = 1.9 m; Diameter of driving wheels = 2m; Radius of balancing mass = 0.8m; angle between the cranks = 90°. If the whole of the revolving mass and 2/3 of the reciprocating masses are to be balanced in planes of driving wheels, determine;**

Magnitude and direction of the balance masses, speed at which the wheel will lift off the rails when the load on each driving wheel is 35 KN, and Swaying couple at speed arrived in (ii) above. (13M) (Dec 2013)BTL5

Answer: Page : 871- R.S.KURUMI

	Key: parts to be balanced per cylinder at the crank pin, $m = m_B = m_C = m_1 + c.m_2$

Plane	Mass (m) kg	Radius (r) m	Cent.force /ω² (m.r) kg-m	Distance from R.P (l) m	Couple /ω² (m.r.l) kg-m²
A	m_A	r_A	$m_A\ r_A$	1	$m_A\ r_A$
B	m_B	r_B	$m_B\ r_B$	1	0
C	m_C	r_C	$m_C\ r_C$	1	$m_C\ r_C$
D	m_D	r_D	$m_D\ r_D$	1	$m_D\ r_D$

Fluctuation in rail pressure or hammer blow = $B.\omega^2.b$

We know that maximum variation of tractive effort $= \pm\sqrt{2}(1-c)m_2.\omega^2.r$

We know that maximum swaying couple = $a(1-c)/(2)^{1/2} \times m_2\ \omega^2\ r$

(13M)

3	**The cranks are 3 cylinder locomotive are set at 120°. The reciprocating masses are 450 kg for the inside cylinder and 390 kg for each outside cylinder. The pitch of the cylinder is 1.2 m and the stroke of each piston 500 mm. The planes of rotation of the balance masses are 960 mm from the inside cylinder. If 40% of the reciprocating masses are to be balanced, determine: The magnitude and the position of the balancing masses required at a radial distance of 500 mm; and The hammer blow per wheel when the axle rotates at 350 rpm. (13M)**BTL5 **Answer: Page 867 (Similar Problem) - R.S.KURUMI** 1. Since 40% of the reciprocating masses are to be balanced, therefore mass of the reciprocating parts to be balanced for each outside cylinder, mA = mC = c × Mo (3M) 2. mass of the reciprocating parts to be balanced for inside cylinder, mB = c × m1 (3M) 3. Table (5M) 4. hammer blow = B.ω .b (2M)
4	**A 4 cylinder engine has the two outer cranks as 120° to each other and their reciprocating masses are each 400 kg. The distance between the planes of rotation of adjacent cranks are 400mm, 700mm, 700mm and 500mm. Find the reciprocating mass and the relative angular position for each of the inner cranks, if the engine is to be in completely balance. Also find the maximum unbalanced secondary force, if the length of each crank is 350 mm, the length of each connecting rod 1.7m and the engine speed 500 rpm. (Nov / Dec 2012) (13M)**BTL5 **Answer: Page : 881 -R.S.KURUMI**

Key: Given : $m_1 = m_4 = 400$ kg ; r = 300 mm = 0.3 m ; l = 1.2 m ; N = 240 r.p.m.

Plane	Mass (m) kg	Radius (r) m	Cent.force /ω^2 (m.r) kg-m	Distance from R.P (l) m	Couple /ω^2 (m.r.l) kg-m^2
A	m_A	r_A	$m_A\ r_A$	1	$m_A\ r_A$
B	m_B	r_B	$m_B\ r_B$	1	0
C	m_C	r_C	$m_C\ r_C$	1	$m_C\ r_C$
D	m_D	r_D	$m_D\ r_D$	1	$m_D\ r_D$

(13M)

5 **A 4 cylinder vertical engine has cranks 150 mm long. The planes of rotation of first, second and fourth cranks are 400 mm, 200 mm and 200 mm respectively from the third crank and their respective masses are 50kg, 60kg, and 50 kg respectively. Find the mass of the reciprocating mass for the third cylinder and the relative angular positions of the cranks in order that the engine may be in computer primary balance. (13M)**BTL5

Answer: Page: 879 - R.S.KURUMI

Given r1 = r2 = r3 = r4 = 150 mm = 0.15 m ; m1 = 50 kg ; m2 = 60 kg ;m4 = 50 kg

Plane	Mass (m) kg	Radius (r) m	Cent.force /ω^2 (m.r) kg-m	Distance from R.P (l) m	Couple /ω^2 (m.r.l) kg-m^2
A	m_A	r_A	$m_A\ r_A$	1	$m_A\ r_A$
B	m_B	r_B	$m_B\ r_B$	1	$m_B\ r_B$
C (R.P)	m_C	r_C	$m_C\ r_C$	0	0
D	m_D	r_D	$m_D\ r_D$	1	$m_D\ r_D$

Ans: $\theta_2 = 160°$, $\theta_4 = 26°$ $m_3 = 60$ kg

(13M)

6 **A 3-cylinder radial engine driven by a common crank has the cylinders spaced at 120°. The stroke is 125 mm; the length of the connecting rod is 225 mm and the reciprocating mass per cylinder 2 kg. Calculate the primary and secondary forces at crank shaft speed of 1200 rpm. (13M) (Dec 2013)** BTL5

Answer: Page : 907 -R.S.KURUMI

Given: L = 125 mm ; l = 225 mm; m = 2 kg ; N = 1200 r.p.m.

1. Maximum Primary Force = 3m/2 x ω2 r (6M)

2. Maximum Secondary force = 2m/2(2 ω2)(r/4n). (7M)

PART* C

1 **The reciprocating mass per cylinder in a 60° V-twin engine is 1.5 kg. The stroke is 100 mm for each cylinder. If the engine runs at 1800 rpm, determine the maximum and**

	minimum values of the primary forces and find out the corresponding crank position. (15M)BTL5 **Answer: Page: 903 -R.S.KURUMI** ϴ= 30°, m = 1.5 kg, l = 100 mm ; N = 1800 r.p.m. Maximum and minimum values of primary forces = m/2 x ω2 r (9cos2ϴ+sin2ϴ)1/2; $=\frac{\sqrt{3}}{2}\times\frac{m}{n}\times\omega^2 r$ (15M)
2	**The firing order of a six cylinder, vertical, four stroke, in-line engine is 1-4-2-6-3-5. The piston stroke is 80 mm and length of each connecting rod is 180 mm. The pitch distances between the cylinder centre lines are 80 mm, 80 mm, 120 mm, 80 mm and 80 mm respectively. The reciprocating mass per cylinder is 1.2 kg and the engine speed is 2400 rpm. Determine the out-of-balance primary and secondary forces and couples on the engine taking a plane mid-way between the cylinders 3 and 4 as the reference plane. (15M)**BTL5 **Answer: Page: 891 -R.S.KURUMI** Given Data (2M) Formula (3M) Solution (7M) Result(3M) Given : L = 80 mm or r = L / 2 = 40 mm = 0.04 m ; l = 180 mm ; m = 1.2 kg ; N = 2400 r.p.m.

Plane	Mass (m) kg	Radius (r) m	Cent.force /ω^2 (m.r) kg-m	Distance from R.P (l) m	Couple /ω^2 (m.r.l) kg-m^2
1	1.2	0.04	0.04	l1	0.04l1
2	1.2	0.04	0.04	l2	0.04l2
3	1.2	0.04	0.04	l3	0.04l3
4	1.2	0.04	0.04	l4	0.04l4
5	1.2	0.04	0.04	l5	0.04l5
6	1.2	0.04	0.04	l6	0.04l6

Draw force polygon and couple polygon.

3	**A 3 cylinder radial engine driven by a common crank has the cylinders spaced at 120°. The stroke is 125 mm; the length of the connecting rod is 225 mm and the reciprocating mass per cylinder 2 kg. Calculate the primary and secondary forces at crank shaft speed**

	of 1200 rpm. (15M) (Dec 2013) BTL5 **Answer: Page: 907 -R.S.KURUMI** Given Data (2M) Formula (4M) Solution (6M) Result (3M) Given : L = 125 mm ; l = 225 mm; m = 2 kg ; N = 1200 r.p.m. 1. Maximum Primary Force = 3m/2 x ω2 r 2. Maximum Secondary force = 2m/2(2 ω2)(r/4n).

UNIT III FREE VIBRATION

Basic features of vibratory systems – Degrees of freedom – single degree of freedom – Free vibration – Equations of motion – Natural frequency – Types of Damping – Damped vibration– Torsional vibration of shaft – Critical speeds of shafts – Torsional vibration – Two and three rotor torsional systems.

PART * A

Q.No.	Questions
1.	**What are the different types of vibrations? (**BTL2) Free vibrations, Forced vibrations, and Damped vibration
2	**State different methods of finding natural frequency of a system. (**BTL1) Equilibrium (or Newton's) method, Energy method, and Rayleigh method.
3	**What is meant by free vibration and forced vibrations? (**BTL1) Free or natural vibrations: When no external force acts on the body, after giving it an initial displacement, then the body is said to be under free or natural vibrations. **Forced vibrations:** When the body vibrates under the influence of external force, then the body is said to be under forced vibrations.
4	**What do you mean by damping and damped vibration? (**BTL2) Damping: The resistance against the vibration is called damping. Damped vibration:When there is a reduction in amplitude over every cycle of vibration, then the motion is said to be damped vibration.
5	**Define resonance. (**BTL1) When the frequency of external force is equal to the natural frequency of a vibrating body, the amplitude of vibration becomes excessively large. This phenomenon is known as resonance.
6	**What are the various types of damping? (**BTL1) (a) Viscous damping (b) coulomb or dry friction damping (c) Solid or structural damping, and (d) slip or interfacial damping.
7	**What is the limit beyond which damping is detrimental and why? (**BTL3) When damping factor > 1, the a periodic motion is resulted. That is, a periodic motion means the

	system cannot vibrate due to over damping. Once the system is disturbed, it will take infinite time to come back to equilibrium position.
8	**When do you say a vibration system in under-damped? (**BTL2) The equation of motion of a free damped vibration is given by $\frac{d^2x}{dt^2} + \frac{c}{m}\frac{dx}{dt} + \frac{s}{m}x = 0$ If $\frac{s}{m} > \left(\frac{c}{2m}\right)^2$, then radical becomes negative. The two roots k_1 and k_2 are known as complex conjugate. Then the vibration system is known as under-damping.
9	**What is meant by critical damping? (**BTL2) The system is said to be critically damped when the damping factor $\zeta = 1$. If the system is critically damped, the mass moves back very quickly to its equilibrium position within no time.
10	**Explain the Dunkerley's method used in natural transverse vibration.(**BTL2) The natural frequency of transverse vibration for a shaft carrying a number of point loads and uniformly distributed load is obtained by Dunkerley's formula. **Dunkerley's formula**
11	**Define critical or whirling or whipping speed of a shaft.(**BTL1) The speed at which resonance occurs is called critical speed of the shaft. In other words, the speed at which the shaft runs so that the additional deflection of the shaft from the axis of rotation becomes infinite is known as critical speed.
12	**What are the factors that affect the critical speed of a shaft? (**BTL2) The critical speed essentially depends on: The eccentricity of the C.G of the rotating masses from the axis of rotation of the shaft, Diameter of the disc, Span of the shaft, and Type of supports connections at its ends.
13	**Critical speed of shaft is the same as the natural frequency of transverse vibration. Justify.(**BTL5) We know that critical or whirling speed, $\omega_{cr} = \omega_n = \sqrt{\frac{s}{m}} = \sqrt{\frac{g}{\delta}}$ Hz If N_C is the critical speed in rps, then $2\pi N_{cr} = \sqrt{\frac{g}{\delta}} \Rightarrow N_{cr} = \frac{1}{2\pi}\sqrt{\frac{g}{\delta}} = \frac{0.4985}{\delta}$ rps Hence proved.
14	**What are the causes of critical speed? (Or) Why is critical speed encountered? (**BTL2) The critical speed may occur due to one or more of the following reasons: Eccentric mountings like gears, flywheels, pulleys, etc., Bending of the shaft due to self-weight, Non-uniform distribution of rotor material, etc.
15	**Define torsional vibration.(**BTL1) When the particles of a shaft or disc move in a circle about the axis of the shaft, then the

	vibrations are known as torsional vibrations.
16	**Differentiate between transverse and torsional vibration.**(BTL5) In transverse vibrations, the particles of the shaft move approximately perpendicular to the axis of the shaft. But in torsional vibrations, the particles of the shaft move in a circle about the axis of the shaft. Due to transverse vibrations, tensile and compressive stresses are induced. Due to torsional vibrations, torsional shear stresses are induced in the shaft.
17	**Define torsional equivalent shaft.**(BTL1) A shaft having diameter for different lengths can be theoretically replaced by an equivalent shaft of uniform diameter such that they have the same total angle of twist when equal opposing torques are applied at their ends. Such a theoretically replaced shaft is known as torsion ally equivalent shaft.
18	**What are the conditions to be satisfied for an equivalent system to that of geared system in torsional vibrations?** (BTL2) Two conditions are: The kinetic energy of the equivalent system must be equal to the kinetic energy of the original system. The strain energy of the equivalent system must be equal to the strain energy of the original system.
19	**What is meant by degrees of freedom in a vibrating system?** (BTL2) The number of independent coordinates required to completely define the motion of a system is known as degree of freedom of the system
20	**What is the limit beyond which damping is detrimental and why?** (BTL2) When damping factor > 1, the a periodic motion is resulted. That is, a periodic motion means the system cannot vibrate due to over damping. Once the system is disturbed, it will take infinite time to come back to equilibrium position.
	PART * B
1	**The measurement on mechanical vibrating system show that it has a mass of 8 kg and that the springs can be combined to give an equivalent spring of stiffness 5.4 N/mm. if the vibrating system have a dashpot attached which exerts a force of 40 N when the mass has a velocity of 1 m/s, find 1. Critical damping coefficient, 2. Damping factor, 3. Logarithmic decrement and 4. Ratio of two consecutive amplitude.** (**13 M**)(BTL5) **Answer: Page :944-R.S KHURMI** Given : $m = 8$ kg ; $s = 5.4$ N/mm = 5400 N/m 1M Since the force exerted by dashpot is 40 N, and the mass has a velocity of 1 m/s , therefore Damping coefficient (actual), $c = 40$ N/m/s *1. Critical damping coefficient* We know that critical damping coefficient, $c_c = 2m.\omega_n = 2m\times\sqrt{\frac{s}{m}} = 2\times8\sqrt{\frac{5400}{8}} = 416$ N/m/s **Ans.** 3M

2. Damping factor

We know that damping factor

$$= \frac{c}{c_c} = \frac{40}{416} = 0.096 \textbf{ Ans.}$$

3M

3. Logarithmic decrement

We know that logarithmic decrement,

$$\delta = \frac{2\pi c}{\sqrt{(c_c)^2 - c^2}} = \frac{2\pi \times 40}{\sqrt{(416)^2 - (40)^2}} = 0.6 \textbf{ Ans.}$$

3M

4. Ratio of two consecutive amplitudes

Let x_n and x_{n+1} = Magnitude of two consecutive amplitudes,

We know that logarithmic decrement,

$$\delta = \log_e \left[\frac{x_n}{x_{n+1}}\right] \text{ or } \frac{x_n}{x_{n+1}} = e^{\delta} = (2.7)^{0.6} = 1.82 \textbf{ Ans.}$$

3M

2

Derive the expression for the natural frequency of free transverse or longitudinal vibrations by using any two methods. (13 M) (BTL5)

Answer: Page: 913-R.S KHURMI

1. Equilibrium Method
2. Energy Method 2M

Equilibrium Method

Consider a constraint (i.e. spring) of negligible mass in an unstrained position,

Let s = Stiffness of the constraint. It is the force required to produce unit displacement in the direction of vibration. It is usually expressed in N/m.

m = Mass of the body suspended from the constraint in kg,

W = Weight of the body in newtons = m.g,

δ= Static deflection of the spring in metres due to weight W newtons, and

x = Displacement given to the body by the external force, in metres. 2M

$$f_n = \frac{0.4985}{\sqrt{\delta}}$$

4M

Energy Method

$m.d^2x/dt^2 + s.x = 0$ 5M

3

A shaft of 100 mm diameter and 1 m long is fixed at one end and other end carries a flywheel of mass 1 tonne. Taking young's modulus for the shaft material as 200 GN/m^2; find the natural frequency of longitudinal and transverse vibrations.(13 M) (BTL5)

Answer: Page: 968-R.S KHURMI

cross sectional area of the shaft A = (π/4) d^2

Moment of Inertia I = (π/64) d^4 3M

Static deflection of cantilever beam

$$\delta = \frac{W.l}{A.E}$$

Natural frequency of longitudinal vibration

$$f_n = \frac{0.4985}{\sqrt{\delta}}$$

= 200 HZ 5M

Natural Frequency of Transverse vibrations

Using the below formula, find f_n – which is natural frequency of transverse vibration

Static deflection of cantilever beam for transverse vibrations is

$$\delta = \frac{W.l^3}{3E.I}$$

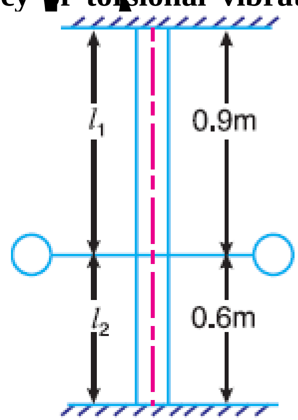
Natural frequency of transverse vibration

$$f_n = \frac{0.4985}{\sqrt{\delta}}$$

= 8.6 HZ 5M

4

A flywheel is mounted on a vertical shaft as shown in figure. The both ends of the shaft are fixed and its diameter is 50 mm. The flywheel has a mass of 500 kg and its radius of gyration is 0.5 m. Find the natural frequency of torsional vibrations. If the modulus of



rigidity for the shaft material is E = 80GN/m². **(13 M)** (BTL5)

Answer: Page 974-R.S KHURMI

Given : d = 50 mm = 0.05 m ; m = 500 kg ; E = 200 GN/m² = 200 × 10^9 N/m²

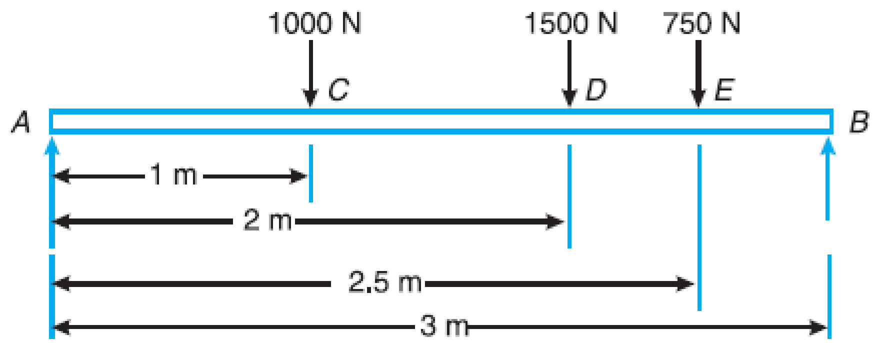
$$A = \frac{\pi}{4} \times d^2 = \frac{\pi}{4}(0.05)^2 = 1.96 \times 10^{-3} \text{ m}^2$$

$$I = \frac{\pi}{64} \times d^4 = \frac{\pi}{64}(0.05)^4 = 0.307 \times 10^{-6} \text{m}^4$$

3M

	$$= \frac{W_1.l_1}{A.E} = \frac{m_1.g.l_1}{A.E} \quad \ldots (i)$$ Similarly, compression of length l_2 $$= \frac{(W - W_1)\, l_2}{A.E} = \frac{(m - m_1)\, g.l_2}{A.E} \quad \ldots (ii)$$ $$m_1.l_1 = (m - m_1) l_2$$ $$m_1 \times 0.9 = (500 - m_1) 0.6 = 300 - 0.6 m_1 \text{ or } m_1 = 200 \text{ kg}$$ $\therefore$ Extension of length l_1, $$\delta = \frac{m_1.g.l_1}{A.E} = \frac{200 \times 9.81 \times 0.9}{1.96 \times 10^{-3} \times 200 \times 10^9} = 4.5 \times 10^{-6} \text{ m}$$ We know that natural frequency of longitudinal vibration, $$f_n = \frac{0.4985}{\sqrt{\delta}} = \frac{0.4985}{\sqrt{4.5 \times 10^{-6}}} = 235 \text{ Hz} \quad \textbf{Ans.}$$ 5M *Natural frequency of transverse vibration* We know that the static deflection for a shaft fixed at both ends and carrying a point load is given by $$\delta = \frac{Wa^3b^3}{3EIl^3} = \frac{500 \times 9.81 (0.9)^3 (0.6)^3}{3 \times 200 \times 10^9 \times 0.307 \times 10^{-6} (1.5)^3} = 1.24 \times 10^{-3} \text{ m}$$ . . . (Substituting $W = m.g$; $a = l_1$, and $b = l_2$) $$f_n = \frac{0.4985}{\sqrt{\delta}} = \frac{0.4985}{\sqrt{1.24 \times 10^{-3}}} = 14.24 \text{ Hz} \quad \textbf{Ans.}$$ 5M	
5	**A shaft 1.5 m long is supported by two short bearings and carries two wheels each of 50 kg mass. One wheel is situated at the centre of the shaft and other at a distance of 0.4 m from the centre towards right. The shaft is hollow of external diameter 75 mm and inner diameter 37.5 mm. The density of the shaft material is 8000 kg/m^3. The young's modulus for the shaft material is 200 GN/m^2. Find the frequency of free transverse vibration. (13 M)** (BTL5) **Answer: Page: 929-R.S KHURMI** **Solution.** Given : d = 50 mm = 0.05 m ; l = 3 m, W_1 = 1000 N ; W_2 = 1500 N ; W_3 = 750 N; E = 200 GN/m^2 = 200 × 10^9 N/m^2 $$I = \frac{\pi}{64} \times d^4 = \frac{\pi}{64} (0.05)^4 = 0.307 \times 10^{-6} \text{m}^4$$ 3M	

$$\delta = \frac{Wa^2b^2}{3\,EIl}$$



3M

∴ Static deflection due to a load of 1000 N,

$$\delta_1 = \frac{1000 \times 1^2 \times 2^2}{3 \times 200 \times 10^9 \times 0.307 \times 10^{-6} \times 3} = 7.24 \times 10^{-3} \text{ m}$$

. . . (Here a = 1 m, and b = 2 m)

2M

Similarly, static deflection due to a load of 1500 N,

$$\delta_2 = \frac{1500 \times 2^2 \times 1^2}{3 \times 200 \times 10^9 \times 0.307 \times 10^{-6} \times 3} = 10.86 \times 10^{-3} \text{ m}$$

. . . (Here a = 2 m, and b = 1 m)

and static deflection due to a load of 750 N,

$$\delta_3 = \frac{750\,(2.5)^2\,(0.5)^2}{3 \times 200 \times 10^9 \times 0.307 \times 10^{-6} \times 3} = 2.12 \times 10^{-3} \text{ m}$$

. . . (Here a = 2.5 m, and b = 0.5 m)

We know that frequency of transverse vibration,

$$f_n = \frac{0.4985}{\sqrt{\delta_1 + \delta_2 + \delta_3}} = \frac{0.4985}{\sqrt{7.24 \times 10^{-3} + 10.86 \times 10^{-3} + 2.12 \times 10^{-3}}}$$

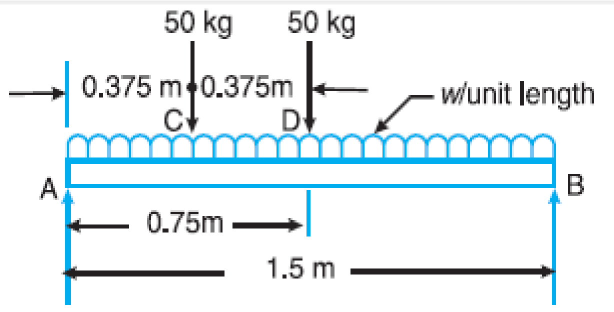
$$= \frac{0.4985}{0.1422} = 3.5 \text{ Hz}$$ **Ans.**

5M

PART * C

1	**A shaft 1.5 m long, Supported in flexible bearing at the ends carries two wheels each of 50 kg mass. One wheel is situated at the centre of the shaft and other at a distance of 375 mm from the centre towards left. The shaft is hollow of external diameter 75 mm and internal diameter 40 mm. the density of the shaft material is 7700 kg/m^3 and its modulus of elasticity is 200 GN/m^2. Find the lowest whirling speed of the shaft, taking into account the mass of the shaft. (15 M)** (BTL5) **Answer: Page:933-R.S KHURMI**

Solution. $l = 1.5$ m ; $m_1 = m_2 = 50$ kg ;
$d_1 = 75$ mm $= 0.075$ m ; $d_2 = 40$ mm $= 0.04$ m ;
$\rho = 7700$ kg/m^3 ; $E = 200$ GN/m^2 $= 200 \times 10^9$ N/m^2 3M



3M

$$I = \frac{\pi}{64}\left[(d_1)^4 - (d_2)^4\right] = \frac{\pi}{64}\left[(0.075)^4 - (0.04)^4\right] = 1.4 \times 10^{-6} \text{m}^4$$

m_S = Area × length × density

$$= \frac{\pi}{4}\left[(0.075)^2 - (0.04)^2\right]1 \times 7700 = 24.34 \text{ kg/m}$$

2M

static deflection due to a load W

$$= \frac{Wa^2b^2}{3EIl} = \frac{m.ga^2b^2}{3EIl}$$

2M

Static deflection due to a mass of 50 kg at C,

$$\delta_1 = \frac{m_1 ga^2b^2}{3EIl} = \frac{50 \times 9.81(0.375)^2(1.125)^2}{3 \times 200 \times 10^9 \times 1.4 \times 10^{-6} \times 1.5} = 70 \times 10^{-6} \text{ m}$$

. . . (Here $a = 0.375$ m, and $b = 1.125$ m)

static deflection due to a mass of 50 kg at D

$$\delta_2 = \frac{m_1 ga^2b^2}{3EIl} = \frac{50 \times 9.81(0.75)^2(0.75)^2}{3 \times 200 \times 10^9 \times 1.4 \times 10^{-6} \times 1.5} = 123 \times 10^{-6} \text{ m}$$

static deflection due to uniformly distributed load or mass of the shaft,

$$\delta_S = \frac{5}{384} \times \frac{wl^4}{EI} = \frac{5}{384} \times \frac{24.34 \times 9.81(1.5)^4}{200 \times 10^9 \times 1.4 \times 10^{-6}} = 56 \times 10^{-6} \text{ m}$$

. . . (Substituting, $w = m_S \times g$)

frequency of transverse vibration,

$$f_n = \frac{0.4985}{\sqrt{\delta_1 + \delta_2 + \frac{\delta_S}{1.27}}} = \frac{0.4985}{\sqrt{70\times10^{-6} + 123\times10^{-6} + \frac{56\times10^{-6}}{1.27}}} \text{ Hz}$$

$= 32.4$ Hz

$= 32.4$ Hz

Since the whirling speed of shaft (N_c) in r.p.s. is equal to the frequency of transverse vibration in Hz, therefore

$N_c = 32.4$ r.p.s. $= 32.4 \times 60 = 1944$ r.p.m. **Ans.**

5M

2

A machine of mass 75 kg is mounted on springs and is fitted with a dashpot to damp out vibrations. there are three springs each of stiffness 10 N/mm and it is found that the amplitude of vibration diminishes from 38.4 mm to 6.4 mm in two complete oscillations. Assuming that the damping force varies as the velocity determine: 1. The resistance of dashpot at unit velocity; 2. The ratio of the frequency of the damped vibration to the frequency of the un damped vibration; and 3. The periodic time of the damped vibration.(15 M)(BTL5)

Answer: Page: 947-R.S KHURMI

Solution. Given : $m = 75$ kg ; $s = 10$ N/mm $= 10 \times 10^3$ N/m ; $x_1 = 38.4$ mm $= 0.0384$ m ; $x_3 = 6.4$ mm $= 0.0064$ m

2M

Since the stiffness of each spring is 10×10^3 N/m and there are 3 springs, therefore total stiffness,

$$s = 3\times10\times10^3 = 30\times10^3 \text{ N/m}$$

We know that natural circular frequency of motion,

$$\omega_n = \sqrt{\frac{s}{m}} = \sqrt{\frac{30\times10^3}{75}} = 20 \text{ rad/s}$$

2M

We know that $\frac{x_1}{x_2} = \frac{x_2}{x_3}$

$$\therefore \quad \left(\frac{x_1}{x_2}\right)^2 = \frac{x_1}{x_3} \quad \ldots \left[\because \frac{x_1}{x_3} = \frac{x_1}{x_2}\times\frac{x_2}{x_3} = \frac{x_1}{x_2}\times\frac{x_1}{x_2} = \left(\frac{x_1}{x_2}\right)^2\right]$$

$$\frac{x_1}{x_2} = \left(\frac{x_1}{x_3}\right)^{1/2} = \left(\frac{0.0384}{0.0064}\right)^{1/2} = 2.45$$

	$$\log_e\left(\frac{x_1}{x_2}\right) = a \times \frac{2\pi}{\sqrt{(\omega_n)^2 - a^2}}$$ 2M $$\log_e 2.45 = a \times \frac{2\pi}{\sqrt{(20)^2 - a^2}}$$ $$0.8951 = \frac{a \times 2\pi}{\sqrt{400 - a^2}} \quad \text{or} \quad 0.8 = \frac{a^2 \times 39.5}{400 - a^2} \quad \text{. . . (Squaring both sides)}$$ $$a^2 = 7.94 \quad \text{or} \quad a = 2.8$$ $$a = c / 2m$$ $$c = a \times 2m = 2.8 \times 2 \times 75 = 420 \text{ N/m/s}$$ **Ans.** 3M ***2. Ratio of the frequency of the damped vibration to the frequency of undamped vibration*** Let f_{n1} = Frequency of damped vibration = $\frac{\omega_d}{2\pi}$ f_{n2} = Frequency of undamped vibration = $\frac{\omega_n}{2\pi}$ $$\therefore \quad \frac{f_{n1}}{f_{n2}} = \frac{\omega_d}{2\pi} \times \frac{2\pi}{\omega_n} = \frac{\omega_d}{\omega_n} = \frac{\sqrt{(\omega_n)^2 - a^2}}{\omega_n} = \frac{\sqrt{(20)^2 - (2.8)^2}}{20} = 0.99$$ **Ans.** 3M ***3. Periodic time of damped vibration*** We know that periodic time of damped vibration $$= \frac{2\pi}{\omega_d} = \frac{2\pi}{\sqrt{(\omega_n)^2 - a^2}} = \frac{2\pi}{\sqrt{(20)^2 - (2.8)^2}} = 0.32 \text{ s}$$ **Ans.** 3M	
3	**A mass of 10 kg is suspended from one end of a helical spring. The other end being fixed. The stiffness of the spring is 10 N/mm. the viscous damping causes the amplitude to decrease to one – tenth of the initial value in four complete oscillations. If a periodic force of 150 cos t N is applied at the mass in the vertical direction, find the amplitude of the forced vibrations. What is value of resonance? (15 M)**(BTL5)	

Answer: Page: 957-R.S KHURMI

Solution. Given : $m = 10$ kg ; $s = 10$ N/mm $= 10 \times 10^3$ N/m ; $x_5 = \frac{x_1}{10}$

2M

Since the periodic force, $F_x = F \cos \omega t = 150 \cos 50 t$, therefore

Static force, $F = 150$ N

and angular velocity of the periodic disturbing force,

$$\omega = 50 \text{ rad/s}$$

We know that angular speed or natural circular frequency of free vibrations,

$$\omega_n = \sqrt{\frac{s}{m}} = \sqrt{\frac{10 \times 10^3}{10}} = 31.6 \text{ rad/s}$$

2M

$$\frac{x_1}{x_5} = \frac{x_1}{x_2} \times \frac{x_2}{x_3} \times \frac{x_3}{x_4} \times \frac{x_4}{x_5} = \left(\frac{x_1}{x_2}\right)^4 \quad \ldots \left(\because \frac{x_1}{x_2} = \frac{x_2}{x_3} = \frac{x_3}{x_4} = \frac{x_4}{x_5}\right)$$

$$\frac{x_1}{x_2} = \left(\frac{x_1}{x_5}\right)^{1/4} = \left(\frac{x_1}{x_1/10}\right)^{1/4} = (10)^{1/4} = 1.78 \quad \ldots \left(x_5 = \frac{x_1}{10}\right)$$

$$\log_e\left(\frac{x_1}{x_2}\right) = a \times \frac{2\pi}{\sqrt{(\omega_n)^2 - a^2}}$$

$$\log_e 1.78 = a \times \frac{2\pi}{\sqrt{(31.6)^2 - a^2}} \quad \text{or} \quad 0.576 = \frac{a \times 2\pi}{\sqrt{1000 - a^2}}$$

2M

Squaring both sides and rearranging,

$$39.832\, a^2 = 332 \quad \text{or} \quad a^2 = 8.335 \quad \text{or} \quad a = 2.887$$

We know that $a = c/2m$ or $c = a \times 2m = 2.887 \times 2 \times 10 = 57.74$ N/m/s

deflection of the system produced by the static force F,

$$x_o = F/s = 150/10 \times 10^3 = 0.015 \text{ m}$$

amplitude of the forced vibrations,

$$x_{max} = \frac{x_o}{\sqrt{\frac{c^2.\omega^2}{s^2} + \left[1 - \frac{\omega^2}{(\omega_n)^2}\right]^2}}$$

$$= \frac{0.015}{\sqrt{\frac{(57.74)^2(50)^2}{(10\times10^3)^2} + \left[1 - \left(\frac{50}{31.6}\right)^2\right]^2}} = \frac{0.015}{\sqrt{0.083+2.25}}$$

$$= \frac{0.015}{1.53} = 9.8\times10^{-3} \text{ m} = 9.8 \text{ mm } \textbf{Ans.}$$

5M

Amplitude of forced vibrations at resonance

We know that amplitude of forced vibrations at resonance,

$$x_{max} = x_0 \times \frac{s}{c.\omega_n} = 0.015\times\frac{10\times10^3}{57.54\times31.6} = 0.0822 \text{ m} = 82.2 \text{ mm } \textbf{Ans.}$$

4M

UNIT IV FORCED VIBRATION

Response of one degree freedom systems to periodic forcing – Harmonic disturbances –Disturbance Caused by unbalance – Support motion –transmissibility – Vibration isolation vibration measurement.

Q.No	PART – A
1	**Define damping ratio or damping factor.** BTL1 It is defined as the ratio of actual damping coefficient (c) to the critical damping coefficient (CC) Mathematically, Damping ratio, $\zeta = \frac{c}{c_c} = \frac{c}{2m\omega_n}$
2	**Define logarithmic decrement.** BTL1 Logarithmic decrement is defined as the natural logarithm of the amplitude reduction factor.

	The amplitude reduction factor is the ratio of any two successive amplitudes on the same side of the mean position
3	**Give the equation for damping factor and damped frequencyω_d.** BTL2 (i) Damping factor, $\zeta = \frac{c}{c_c} = \frac{c}{2m\omega_n}$ (ii) Damped frequency, $\omega_d = f_d = \sqrt{1-\zeta^2} \times \omega_n$ Where c = Damping coefficient, C_C = Critical damping coefficient, and ω_n = Natural or Undamped frequency.
4	**Write a short note on harmonic forcing.** BTL2 The term harmonic refers to a spring-mass system with viscous damping, excited by a sinusoidal harmonic force. $F = F_0 \sin\omega t$
5	**Give the relationship between frequencies of undamped and damped vibrations.** BTL2 $$\frac{f_d}{f_n} = \frac{\left(\frac{\omega_d}{2\pi}\right)}{\left(\frac{\omega_n}{2\pi}\right)} = \frac{\omega_d}{\omega_n} = \sqrt{1-\zeta^2}$$
6	**Write about dynamic magnifier or magnification factor? Mention the factors on which it depends.** BTL2 It is the ratio of maximum displacement of the forced vibration (Xmax) to the deflection due to the static force F (x0)

	$$D = \frac{x_{max}}{x_0} = \frac{1}{\sqrt{\left[1-\left(\frac{\omega}{\omega_n}\right)^2\right]^2 + \left[2\zeta\frac{\omega}{\omega_n}\right]^2}} = \frac{1}{\sqrt{(1-r^2)^2+(2\zeta r)^2}}$$ It depends on: (i) the ratio of circular frequencies($\frac{\omega}{\omega_n}$), and (ii)the damping factor(ζ)
7	**Define transmissibility.**BTL1 When a machine is supported by a spring, the spring transmits the force applied on the machine to the fixed support or foundation. This is called transmissibility.
8	**Define transmissibility ratio or isolation factor.** BTL1 The ratio of force transmitted (FT) to the force applied (F) is known as transmissibility ratio $$\varepsilon = \frac{F_T}{F_0} = \frac{\sqrt{1+(2\zeta r)^2}}{\sqrt{(1-r^2)^2+(2\zeta r)^2}}$$ Where r = Frequency ratio = ($\frac{\omega}{\omega_n}$)
9	**Define elastic suspension.**BTL2 When machine components are suspended from elastic members, the vibrational force produced by the machine components will not be transmitted to the foundation. This is called elastic suspension.
10	**Specify any two industrial application where the transmissibility effects of vibration are important.** BTL2 (a) All machine tools, and (b) All turbo machines.

11	**Define vibration isolation.** BTL2 The term vibration isolation refers to the prevention or minimization of vibrations and their transmission due to the unbalanced machines.
12	**Specify the importance of vibration isolation.**BTL2 When an unbalanced machine is installed on the foundation, it produces vibration in the foundation. So, in order to prevent these vibrations or to minimize the transmission of forces to the foundation, vibration isolation is important.
13	**Give the methods of isolating the vibration.** BTL2 High speed engines/machines mounted on foundation and supports cause vibrations of excessive amplitude because of the unbalanced forces. It can be minimized by providing "spring-damper"etc. The materials used for vibration isolation are rubber, felt cork, etc. These are placed between the foundation and vibrating body.
14	**Give the Examples of forced vibrations.** BTL2 Ringing of electrical bell The vibrations of air compressors, internal combustion engines, machine tools and various other machinery.
15	**Mention the types of external excitation.** BTL2 Periodic forces Impulsive forces and Random forces.
16	**Give the governing equation of damped forced vibrations.**BTL2 $\frac{d^2x}{dt^2}+\frac{c}{m}\frac{dx}{dt}+\frac{s}{m}x=\left(\frac{F_0}{m}\right)\sin\omega t$
17	**List the isolating materials.** BTL2 Rubber Felt Cork

	Metallic Springs
18	**Define vibration isolation.** BTL1 The process of reducing the vibrations of machines and hence reducing the transmitted force to the foundation using vibration isolating materials is called vibration isolation.
19	**Mention the types of isolation.** BTL1 Isolation of force Isolation of motion.
20	**Define Amplitude Transmissibility.** BTL1 Amplitude transmissibility is defined as the ratio of absolute amplitude of the mass (*x*max) to the base excitation amplitude(y).
Part – B	
1	**Machine has a mass of 125 kg and unbalanced reciprocating mass 3 kg which moves through a vertical stroke of 90 mm with SHM. The machine is mounted upon 5 springs. Neglecting damping, calculate the combined stiffness of the spring in order that force transmitted is 1/20th of the applied force, when the speed of the machine crank shaft is 1200 rpm. When the machine is actually supported on the springs, it is found that damping reduces the amplitude of successive free vibration by 30% Determine; (1) Force transmitted to the foundation at 1200 rpm (2) Force transmitted to the foundation at resonance.** BTL[illegible] **Answer : Page [illegible]444 - Dr.A.Baskar** Step 1: Determine the angular velocity [circular frequency] using the equation $\omega = 2\pi N/60$ (2M) and Determine the Eccentricity e = Stroke / 2 (2M) Step 2: Determine circular natural frequency using transmissibility ratio. Transmissibility ratio **ε = +/-** [1/ (1-r2)](2M) where $r = \omega/\omega n$

	Since force transmitted is 1/20th of applied force ε = 1/20 In the transmissibility ratio equation put **(1-r_2) as (r_2-1) to get positive root** Find combined stiffness using **ωn = Sqrt [s/m]** (2M) Step 3: To determine the Force transmitted to the foundation at 1200 rpm Find frequency ratio **r = ω/ωn**

	Given that percentage of successive amplitude is 30%, hence $X_1 = 0.70\ X_o$ Logarithmic Decrement is $\ln[X_o/X_1] = 2\pi c/\mathrm{Sqrt}\ [c_c^2 - c^2]$ **Find critical damping coefficient from $c_c = 2m\omega_n$,** **Find the value of damping coefficient c from the above expression.** **Actual value of transmissibility is** $$\varepsilon = \frac{\sqrt{1+\left(\frac{2c.\omega}{c_c.\omega_n}\right)^2}}{\sqrt{\left(\frac{2c.\omega}{c_c.\omega_n}\right)^2+\left(1-\frac{\omega^2}{(\omega_n)^2}\right)^2}}$$ Step 4 The maximum unbalance force due to reciprocating parts is given by $F = m_u\omega^2 r$ where m_u is mass of reciprocating part = 3 kg Force transmitted to the foundation is $F_T = \varepsilon F$ Step 5 Force transmitted to the foundation at resonance, At resonance $\omega = \omega_n$ Hence the expression is reduced to $$\varepsilon = \frac{\sqrt{1+\left(\frac{2c}{c_c}\right)^2}}{\sqrt{\left(\frac{2c}{c_c}\right)^2}}$$ Find F_T in same manner as above [$F = m_u\omega^2 r$ where m_u is mass of reciprocating part = 3 kg Force transmitted to the foundation is $F_T = \varepsilon F$] (5M)
2	**A vibrating system having a mass of 1.5 kg is suspended by a spring of stiffness 1200N/m and it is put to harmonic excitation of 12 N. Assuming viscous damping, Determine, (1) Resonant Frequency (2) Phase angle at resonance (3) Amplitude at resonance (4) Damped frequency; Take c = 48 NS/m .**BTL5 **Answer : Page:10.19- V.Jayakumar** Step 1: 3M + Step 2: 3M + Step 3: 3M + Step 4: 4M

	Step 1 Determine circular natural frequency ω_n = Sqrt [s/m] [s & m are given] At resonance $\omega = \omega_n$ i) Find Resonant frequency using $f_n = \omega_n/2\pi$ Step 2 ii)Determine the phase angle φ at resonance using [At resonance $\omega = \omega_n$] $\phi = \tan^{-1}\left(\frac{c.\omega}{s - m.\omega^2}\right)$ [c- given in the question] Step 3 (iii) Amplitude at resonance Max amplitude can be determined using below expression [Force F=12N,$\omega=\omega_n$ at resonance] $x_{max} = \frac{F}{\sqrt{c^2.\omega^2 + (s - m.\omega^2)^2}}$ Step 4: Damped frequency $f_d = \omega_d/2\pi$ where $\omega_d = \text{sqrt}\ [\omega_n^2 - a^2]$ and $a = c/2m$ Substitute and find frequency of damped vibration
3	**A machine supported symmetrically on five springs, has a mass of 90 kg. The mass of the reciprocating parts is 3 kg which moves through a vertical stroke of 90 mm with SHM. Neglecting damping determine the combined stiffness of the springs so that force transmitted to the foundation is 1/30th of impressed force. The machine crank shaft rotates at 750 rpm. If the under actual working conditions the damping reduces the amplitude of successive vibration by 25%, find:** **(i) Force transmitted to the foundation at 900 rpm**

(ii)Force transmitted to the foundation at resonance.

(iii)The amplitude of vibration at resonance. BTL5

Answer : Page:10.38 – V.Jayakumar

Step 1:

Determine the angular velocity [circular frequency] using the equation

ω = 2πN/60

Determine the Eccentricity e = Stroke / 2 (2M)

Step 2: Determine circular natural frequency using transmissibility ratio.
Transmissibility ratio **ε = +/- [1/ (1-r2)]**

where **r = ω/ωn**

Since force transmitted is 1/30th of applied force ε = 1/30

In the transmissibility ratio equation put **(1-r) as (r2-1) to get positive root**

Find combined stiffness using **ωn = Sqrt[s/m]** ([illegible]M)

Step 3:

To determine the Force transmitted to the foundation at 900 rpm

Find **frequency ratio r = ω/ωn**

Given that percentage of successive amplitude is 25%, hence X1 = 0.75 Xo

Logarithmic Decrement is **ln[Xo/X1] = 2πc/Sqrt [cc2-c2]** (3M)

Find critical damping coefficient from cc = 2mωn,

Find the value of damping coefficient c from the above expression.

Actual value of transmissibility is

$$\varepsilon = \frac{\sqrt{1+\left(\frac{2c.\omega}{c_c.\omega_n}\right)^2}}{\sqrt{\left(\frac{2c.\omega}{c_c.\omega_n}\right)^2+\left(1-\frac{\omega^2}{(\omega_n)^2}\right)^2}}$$

Step 4

	The maximum unbalance force due to reciprocating parts is given by **F = muω2r** where mu is mass of reciprocating part = 3 kg Force transmitted to the foundation is FT = ε F (2M) Step 5 Force transmitted to the foundation at resonance, At resonance **ω = ωn** Hence the expression is reduced to $\varepsilon = \dfrac{\sqrt{1+\left(\frac{2c}{c_c}\right)^2}}{\sqrt{\left(\frac{2c}{c_c}\right)^2}}$ Find FT in same manner as above **[F = muω2r** where mu is mass of reciprocating part = 3 kg Force transmitted to the foundation is FT = ε F] (2M) Step 6: Determine the Amplitude using : Amplitude = Force transmitted at the resonance / Combined Stiffness (2M)
4	**A 75 kg machine is mounted on springs of stiffness K= 11.76 X 10 5 N/m with an assumed damping factor of 0.2. A 2 kg piston within the machine has a reciprocating motion with a stroke of 0.08 m and a speed of 3000 rpm. Assuming the motion of the piston to be harmonic, determine the amplitude of vibration of the machine and the vibratory force transmitted to the foundation.** BTL5 **Answer : Page:10.33 – V.Jayakumar** Step 1: Determine the angular velocity of unbalance force using

ω = 2πN/60

Circular Natural frequency **ωn = Sqrt [s/m]** [s is stiffness which is denoted as k in question]

Eccentricity e = stroke / 2

Frequency ration r = ω/ωn(4M)

Step 2

Determine the exciting force F = mu.ω2.e [where mu – mass of reciprocating part – piston]

Max amplitude of vibration will be given by

$$x_{max} = \frac{F/s}{\sqrt{\frac{c^2.\omega^2}{s^2} + \frac{(s - m.\omega^2)^2}{s^2}}}$$

Damping factor c/cc is given in question.

cc = 2mωn

From this find c = [cc.][Damping factor] (4M)

Step 3:

Determine transmissibility ratio ε from the below expression

$$\varepsilon = \frac{\sqrt{1 + \left(\frac{2c.\omega}{c_c.\omega_n}\right)^2}}{\sqrt{\left(\frac{2c.\omega}{c_c.\omega_n}\right)^2 + \left(1 - \frac{\omega^2}{(\omega_n)^2}\right)^2}}$$

Also $\varepsilon = F_T/F$

Since F is known, determine F_T from the above expression, which is force transmitted to the foundation. (5M)

5 **A body of mass 70 kg is suspended from a spring which deflects 2 cm under the load. It is subjected to a damping effect adjusted to a value of 0.23 times that required for critical damping. Find the natural frequency of the un-damped and damped vibrations and ratio of successive amplitudes of damped vibrations. If the body is subjected to a**

periodic disturbing force of 700 N and of frequency equal to 0.78 times the natural frequency, find the amplitude of forced vibrations and the phase difference with respect to the disturbing force.BTL5

Answer : Page:10.12 – V.Jayakumar

Step 1:

Determine the natural frequency of free vibration [without damping] using

fn = 0.4985/Sqrt[δ] where δ – Deflection of spring due to load = 20cm = 0.2 m[given]

Damping coefficient **c = 0.23 cc** [given- damping coeff is 0.23 times of critical damping coeff]

Circular natural frequency **ωn = 2πfn**

Critical Damping coefficient **cc = 2mωn** (4M)

Determine damping coefficient c from the above expressions

Step 2 :

Natural frequency of undamped vibration is fn.

Natural frequency of damped vibration

fd = ωd/2π

where **ωd = Sqrt[ωn2- a2] and a = c/2m** (4M)

Step 3:

For forced vibration [excitation] in the same setup

Frequency f = 0.78fn [given in question as frequency is 0.78 times of natural frequency]

Hence **ω = 2πf**

Max amplitude of forced vibration can be determined by

$$x_{max} = \frac{F/s}{\sqrt{\frac{c^2.\omega^2}{s^2} + \frac{(s - m.\omega^2)^2}{s^2}}}$$

Phase difference φ can be determined by

$$\phi = \tan^{-1}\left(\frac{c.\omega}{s - m.\omega^2}\right)$$

Determine s by using ω_n = sqrt [s/m], [since ω_n and m is known, s can be determined]

(5M)

6 **The support of a spring mass system is vibrating with amplitude of 6 mm and a frequency of 1200 cycles/min. If a mass is 95 kg and the spring has a stiffness of 1950 N/m, determine the amplitude of vibration of the mass. If a damping factor of 0.2 is include, what would be the amplitude?** BTL5

Answer : Page:10.22 – V.Jayakumar

Step 1:

Determine the frequency of the support ω = 2πf

Determine the natural frequency ω_n = Sqrt [s/m] (4M)

Step 2:

Amplitude of Support Y = 6mm = 0.006m

Amplitude of forced vibration due to excitation of support is

Xmax = Y. [sqrt{s2+(cω2)}2] / [sqrt { (s – mω2)2 +(cω)2]

Intially without damping,damping coefficient **c = 0** (4M)

Step 3:

If a damping factor of 0.2 is included, c/cc = 0.2

Determine **cc = 2mωn** and find xmax with same above expression

Xmax = Y. [sqrt{s2+(cω2)}2] / [sqrt { (s – mω2)2 +(cω)2](5M)

Part– C

1

A machine has a mass of 100 kg and unbalanced reciprocating parts of mass 2 kg which move through a vertical stroke of 80 mm with SHM. The machine is mounted on 4 springs, symmetrically arranged with respect to center of the mass, in such a way that the machine has one degree of freedom and can undergo vertical displacements only. Neglecting damping, calculate the combined stiffness of the spring in order that the force transmitted to the foundation is 1/25th of the applied force, when the speed of the rotation of machine crank shaft is 1000 rpm. When the machine is actually supported on the springs it is found that the damping reduces the amplitude of successive five vibrations by 25%. Find:(i)The force transmitted to the foundation at 1000 rpm; (ii)The force transmitted to the foundation at resonance; (iii) The amplitude of the forced vibration of the machine at resonance. BTL5

Answer : Page:10.45 – V.Jayakumar

Step 1:

Determine the angular velocity [circular frequency] using the equation

ω = 2πN/60 and

Determine the Eccentricity e = Stroke / 2 (2M)

Step 2:

Determine circular natural frequency using transmissibility ratio.

Transmissibility ratio **ε = +/- [1/ (1-r2)]**

where **r = ω/ωn**

Since force transmitted is 1/25th of applied force ε = 1/25

In the transmissibility ratio equation put **(1-r) as $(r_2$-1) to get positive root**

Find combined stiffness using **ωn = Sqrt [s/m]** (2M)

Step 3:

To determine the Force transmitted to the foundation at 1000 rpm

Find **frequency ratio r = ω/ωn**

Given that percentage of successive amplitude is 25%, hence X1 = 0.75 Xo

Logarithmic Decrement is

ln[Xo/X1] = 2πc/Sqrt [cc2-c2]

Find critical damping coefficient from **cc = 2mωn,** Find the value of damping coefficient c from the above expression.

Actual value of transmissibility is

$$\varepsilon = \frac{\sqrt{1+\left(\frac{2c.\omega}{c_c.\omega_n}\right)^2}}{\sqrt{\left(\frac{2c.\omega}{c_c.\omega_n}\right)^2+\left(1-\frac{\omega^2}{(\omega_n)^2}\right)^2}}$$

(3M)

Step 4 :

The maximum unbalance force due to reciprocating parts is given byStep 4
The maximum unbalance force due to reciprocating parts is given by**F = muω2r** where mu is mass of reciprocating part = 3 kg
Force transmitted to the foundation is

FT = ε F (3M)

Step 5 :

Force transmitted to the foundation at resonance,

At resonance **ω = ωn**

Hence the expression is reduced to

$$\varepsilon = \frac{\sqrt{1+\left(\frac{2c}{c_c}\right)^2}}{\sqrt{\left(\frac{2c}{c_c}\right)^2}}$$

Find FT in same manner as above

F = muω2r where mu is mass of reciprocating part = 2 kg

Force transmitted to the foundation is

FT = ε F] (3M)

Step 6:

Determine the Amplitude using :

	Amplitude = Force transmitted at the resonance / Combined Stiffness (2M)
3	**A single cylinder engine of total mass 200 kg is to be mounted on an elastic support which permits vibratory movement in vertical direction only. The mass of the piston is 3.5 kg and has a vertical reciprocating motion which may be assumed simple harmonic with a stroke of 150 mm. It is desired that the maximum vibratory force transmitted through the elastic support to the foundation shall be 600 N when the engine speed is 800 rpm and less than this at all high speeds. Find: (i) the necessary stiffness of the elastic support, and the amplitude of vibration at 800 rpm, and (ii) if the engine speed is reduced below 800 rpm at what speed will the transmitted force again becomes 600N.** BTL5 **Answer : Page:10.37 – V.Jayakumar** Step 1 Determine the unbalanced force on the piston F = muω2e [where e = stroke /2 and mu is the mass of reciprocating parts] (3M) Step 2 Max vibratory force transmitted to the foundation will be given by FT = [Stiffness of elastic support].[Max amplitude of vibration] Since FT is given in the question, determine s from the above expression (5M) Step 3 Determine the Maximum Amplitude of vibration using

$$x_{max} = \frac{F}{m.\omega^2 - s}$$

Step 4

To find the speed at which the transmitted force again becomes 600 N

Find Disturbing force $F = m_u \omega_1^2 e$ [Keep the value in terms of ω_1]

Step 5

Since the engine speed is reduced, find amplitude with same above concept [as given formulae]

$$x_{max} = \frac{F}{m\left[(\omega_n)^2 - (\omega_1)^2\right]} = \frac{F}{m\left[\frac{s}{m} - (\omega_1)^2\right]} = \frac{F}{s - m(\omega_1)^2}$$

Force transmitted F_T = [Stiffness]. x_{max} [F_T = 600 N – known value]

$$= s \times \frac{F}{s - m(\omega_1)^2}$$

Determine ω_1 from the above expression and hence find N_1- that is speed required

(7M)

UNIT V MECHANISM FOR CONTROL

Governors – Types – Centrifugal governors – Gravity controlled and spring controlled centrifugal governors – Characteristics – Effect of friction – Controlling force curves. Gyroscopes –Gyroscopic forces and torques – Gyroscopic stabilization – Gyroscopic effects in Automobiles, ships andairplanes.

PART * A

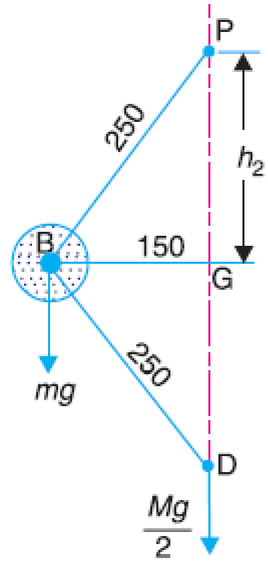
Q.No.	Questions
1.	**Differentiate between governor and fly wheel.** BTL5

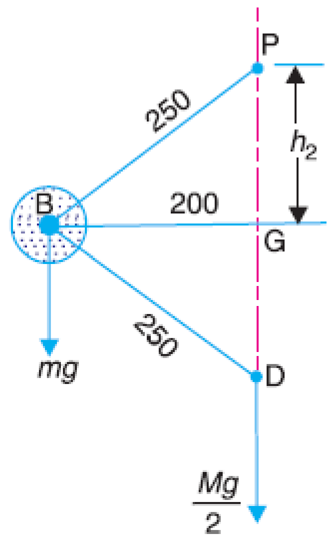
SL. NO	Governor	Flywheel
1	The function of a governor is to regulate the mean speed of an engine, when there are variations in the load.	The function of a flywheel is to reduce the fluctuations of speed caused by the engine turning moment during each cycle of operation.
2	It is provided or, prime movers such as engines and turbines.	It is provided on engine and fabricating machines viz., rolling mills, punching machines, shear machines, presses, etc.
3	It works intermittently, i.e., only when there is change in load.	It works continuously from cycle to cycle.
4	It has no influence over cyclic speed fluctuation	It has no influence on mean speed of the prime mover

2	**What do you mean by governor effort?** BTL2 The mean force acting on the sleeve for a given percentage change of speed for lift of the sleeve

	is known as the governor effort.
3	**Define power of a governor.**BTL1 The power of a governor is the work done at the sleeve for a given percentage change of speed. It is the product of the mean value of the effort and the distance through which the sleeve moves. Power = Mean effort x Lift of sleeve.
4	**What is meant by sensitiveness of a governor?** BTL2 The sensitiveness the difference between the maximum and minimum speeds. A governor is said to be sensitive, when it really responds to a small change of speed.
5	**Define coefficient of sensitiveness.**BTL1 It is the ratio between range of speed and mean speed.
6	**What is meant by hunting?** BTL1 The phenomenon of continuous fluctuation of the engine speed above and below the mean speed is termed as hunting. This occurs in over-sensitive governors.
7	**Explain the term stability of governor.**BTL2 A governor is said to be stable if there is only one radius of rotation for all equilibrium speeds of the balls within the working range. If the equilibrium speed increases the radius of governor ball must also increase
8	**What is meant by isochronous condition in governors?** BTL2 A governor with zero range of speed is known as an isochronous governor. Actually the isochronisms is the stage of infinite sensitivity. i.e., when the equilibrium speed is constant for all radii of rotation of rotation of the balls within the working range, the governor is said to be in isochronisms.
9	**Give the application of gyroscopic principle.**BTL2 In instrument or troy known as gyroscope, In ships in order to minimize the rolling and pitching effects of waves, and In aero plane, monorail cars, gyrocompasses, etc.
10	**What is gyroscopic torque?** BTL2 Whenever a rotating body changes its axis of rotation, a torque is applied on the rotating body. This torque is known as gyroscopic torque.
11	**Define steering, pitching and rolling.**BTL1 **Steering** is the turning of a complete ship in a curve towards left or right, while it moves forward. **Pitching** is the movement of a complete ship up and down in a vertical plane about transverse axis. **Rolling** is the movement of a ship in a linear fashion.
12	**What is the effect of gyroscopic couple on rolling of ship? Why?** BTL2 We know that, for the effect of gyroscopic couple to occur, the axis of precession should always be perpendicular to the axis of spin. In case of rolling of a ship, the axis of precession is always parallel to the axis of spin for all positions. Hence there is no effect of the gyroscopic couple acting on the body of the ship during rolling.
13	**How the left and right hand sides of the ship are named when viewed from the stern?**BTL2 Left hand side is named as port; Right hand side star-board.
14	**Discuss the effect of the gyroscopic couple on a two wheeled vehicle when taking a turn.**BTL2 The gyroscopic couple will act over the vehicle outwards. The tendency of this couple is to overturn the vehicle in outward direction.

15	**The engine of an aeroplane rotates in clockwise direction when seen from the tail end and theaeroplane takes a turn to the left. What will be the effect of the gyroscopiccouple on the Aeroplane?** BTL2 The effect of gyroscopic couple will be to raise the nose and dip the tail.
16	**Define gyroscopic couple.**BTL1 If a body having moment of inertia I and rotating about its own axis at ω rad/sec is also caused to turn at $\omega_P$rad/sec about an axis perpendicular to axis of spin, then it experiences a gyroscopic couple of magnitude (I ω ω_P) in an axis which is perpendicular to both the axis of spin and axis of Precession.
17	**Write the expression for gyroscopic couple.**BTL5 Gyroscopic couple, $C = I \bullet \omega \bullet \omega_P$ Where I = Moment of inertia of the disc, ω = Angular velocity of the engine, and ω_P = Angular velocity of precession.
18	**Define power of a governor.**BTL1 The power of a governor is the work done at the sleeve for a given percentage change of speed. It is the product of the mean value of the effort and the distance through which the sleeve moves. Power = Mean effort x Lift of sleeve.
19	**Define coefficient of sensitiveness.**BTL1 It is the ratio between range of speed and mean speed.
20	**What is gyroscopic torque?** BTL2 Whenever a rotating body changes its axis of rotation, a torque is applied on the rotating body. This torque is known as gyroscopic torque.
	PART * B
1	**The arms of a porter governor are each 250 mm long and pivoted on the governor axis. The mass of the each belt is 5 kg and the mass of the central sleeve is 30 kg. the radius of rotation of the balls is 150 mm when the sleeve begins to rise and reaches a valve of 200 mm for maximum speed. Determine the speed range of the governor. If the friction at the sleeve is equivalent of 20 N of load at the sleeve, determine how the speed range is modified.(13 M)**BTL5 **Answer: Page :662-R.S KHURMI** **Solution.** Given : $BP = BD = 250$ mm ; $m = 5$ kg ; $M = 30$ kg ; $r_1 = 150$ mm ; $r_2 = 200$ mm N_1 = Minimum speed when $r_1 = BG = 150$ mm, and N_2 = Maximum speed when $r_2 = BG = 200$ mm.





4M

$$h_1 = PG = \sqrt{(PB)^2 - (BG)^2} = \sqrt{(250)^2 - (150)^2} = 200 \text{ mm} = 0.2 \text{ m}$$

$$(N_1)^2 = \frac{m + M}{m} \times \frac{895}{h_1} = \frac{5 + 30}{5} \times \frac{895}{0.2} = 31\,325$$

$$N_1 = 177 \text{ r.p.m.}$$

$$h_2 = PG = \sqrt{(PB)^2 - (BG)^2} = \sqrt{(250)^2 - (200)^2} = 150 \text{ mm} = 0.15 \text{ m}$$

$$(N_2)^2 = \frac{m + M}{m} \times \frac{895}{h_2} = \frac{5 + 30}{5} \times \frac{895}{0.15} = 41\,767$$

$$N_2 = 204.4 \text{ r.p.m.}$$

$$= N_2 - N_1 = 204.4 - 177 = 27.4 \text{ r.p.m.}$$ **Ans.**

4M

$$(N_1)^2 = \frac{m.g + (M.g - F)}{m.g} \times \frac{895}{h_1}$$

$$= \frac{5 \times 9.81 + (30 \times 9.81 - 20)}{5 \times 9.81} \times \frac{895}{0.2} = 29\,500$$

$$\therefore \qquad N_1 = 172 \text{ r.p.m.}$$

$$(N_2)^2 = \frac{m.g + (M.g + F)}{m\,.\,g} \times \frac{895}{h_2}$$

$$= \frac{5 \times 9.81 + (30 \times 9.81 + 20)}{5 \times 9.81} \times \frac{895}{0.15} = 44\,200$$

$\therefore$ $N_2 = 210$ r.p.m.

$= N_2 - N_1 = 210 - 172 = 38$ r.p.m. **Ans.**

5M

2

A proell governor has equal arms of length 300 mm. the upper and lower ends of the arms are pivoted on the axis of the governor. The extension arms of the lower links are each 80 mm long and parallel to the axis when the radii of rotation of the balls are 150 mm and 200 mm. the mass of each ball is 10 kg and the mass of the central load is 100 kg. determine the range of speed of the governor.(13 M)BTL5

Answer: Page:671-R.S KHURMI

Solution. Given : $PF = DF = 300$ mm ; $BF = 80$ mm ; $m = 10$ kg ; $M = 100$ kg ; $r_1 = 150$ mm; $r_2 = 200$ mm

$$h_1 = PG = \sqrt{(PF)^2 - (FG)^2} = \sqrt{(300)^2 - (150)^2} = 260 \text{ mm} = 0.26 \text{ m}$$

$FM = GD = PG = 260$ mm $= 0.26$ m

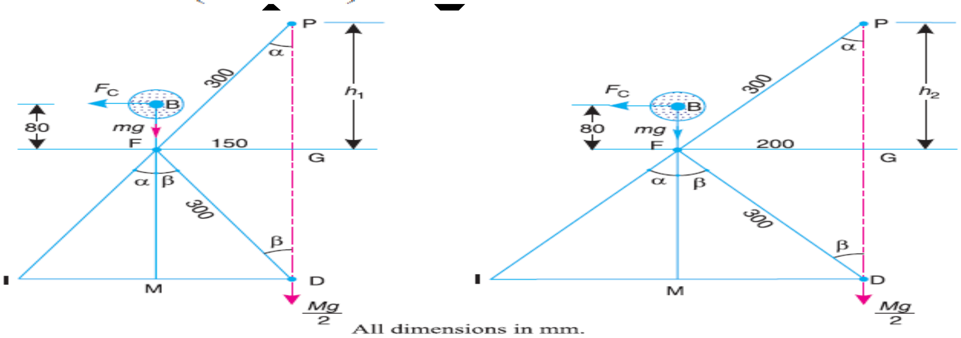
$BM = BF + FM = 80 + 260 = 340$ mm $= 0.34$ m

2M

$$(N_1)^2 = \frac{FM}{BM}\left(\frac{m+M}{m}\right)\frac{895}{h_1} \quad \ldots (\because \alpha = \beta \text{ or } q = 1)$$

$$= \frac{0.26}{0.34}\left(\frac{10+100}{10}\right)\frac{895}{0.26} = 28\,956 \quad \text{or} \quad N_1 = 170 \text{ r.p.m.}$$

4M



All dimensions in mm.

(a) Minimum position. (a) Maximum position.

3M

$$h_2 = PG = \sqrt{(PF)^2 - (FG)^2} = \sqrt{(300)^2 - (200)^2} = 224 \text{ mm} = 0.224 \text{ m}$$

$FM = GD = PG = 224$ mm $= 0.224$ m

$BM = BF + FM = 80 + 224 = 304$ mm $= 0.304$ m

We know that $(N_2)^2 = \frac{FM}{BM}\left(\frac{m+M}{m}\right)\frac{895}{h_2}$ . . . ($\because$ $\alpha = \beta$ or $q = 1$)

$$= \frac{0.224}{0.304}\left(\frac{10+100}{10}\right)\frac{895}{0.224} = 32\,385 \quad \text{or} \quad N_2 = 180 \text{ r.p.m.}$$

We know that range of speed

$$= N_2 - N_1 = 180 - 170 = 10 \text{ r.p.m. } \textbf{Ans.}$$

4M

3

A Hartnell governor having a central sleeve spring and two right angled bell crank levers moves between 290 r.p.m and 310 r.p.m. for a sleeve lift of 15 mm. the sleeve arms and the ball arms are 80 mm and 120 mm respectively. The levers are pivoted at 120 mm from the governor axis and mass of the each ball is 2.5 kg. the ball arms are parallel to the governor axis at the lowest equilibrium speed. Determine : 1. Loads on the springs at the lowest and the highest equilibrium speed, and 2. Stiffness of the spring.(13 M)BTL

Answer: Page: 680-R.S KHURMI

Solution. Given : $N_1 = 290$ r.p.m. or $\omega_1 = 2\pi \times 290/60 = 30.4$ rad/s ; $N_2 = 310$ r.p.m. or $\omega_2 = 2\pi \times 310/60 = 32.5$ rad/s ; $h = 15$ mm $= 0.015$ m ; $y = 80$ mm $= 0.08$ m ; $x = 120$ mm $= 0.12$ m ; $r = 120$ mm $= 0.12$ m ; $m = 2.5$ kg

$$r = r_1 = 120 \text{ mm} = 0.12 \text{ m}$$

$$F_{C1} = m\,(\omega_1)^2\, r_1 = 2.5\,(30.4)^2\;\; 0.12 = 277 \text{ N}$$

2M

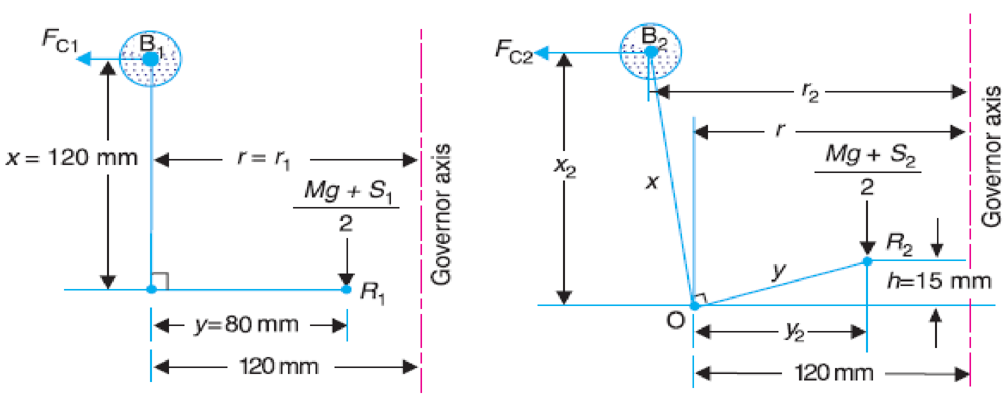
We know that $h = (r_2 - r_1)\,\frac{y}{x}$

$$r_2 = r_1 + h\left(\frac{x}{y}\right) = 0.12 + 0.015\left(\frac{0.12}{0.08}\right) = 0.1425 \text{ m}$$

$\therefore$ Centrifugal force at the maximum speed,

$$F_{C2} = m\,(\omega_2)^2\, r_2 = 2.5 \times (32.5)^2 \times 0.1425 = 376 \text{ N}$$

2M



(*a*) Lowest position. (*b*) Highest position.

4M

$$M.g + S_1 = 2F_{C1} \times \frac{x}{y} = 2 \times 277 \times \frac{0.12}{0.08} = 831 \text{ N}$$

$S_2 = 831$ N **Ans.** ($\because$ $M = 0$)

$$M.g + S_2 = 2F_{C2} \times \frac{x}{y} = 2 \times 376 \times \frac{0.12}{0.08} = 1128 \text{ N}$$

$S_1 = 1128$ N **Ans.** ($\because$ $M = 0$)

	We know that stiffness of the spring, $$s = \frac{S_2 - S_1}{h} = \frac{1128 - 831}{15} = 19.8 \text{ N/mm}$$ **Ans.** 5M
4	**An aeroplane makes a complete half circle of 50 metres radius, towards left, when flying at 200 km per hr. the rotary engine and the propeller of the plane has a mass of 400 kg and aradius of gyration of 0.3 m. the engine rotates at 2400 r.p.m. clockwise when viewed from the rear. Find the gyroscopic couple on the aircraft and state its effect on it. (13 M)**BTL5 **Answer: Page: 487-R.S KHURMI** **Solution.** Given : $R = 50$ m ; $v = 200$ km/hr $= 55.6$ m/s ; $m = 400$ kg ; $k = 0.3$ m ; $N = 2400$ r.p.m. or $\omega = 2\pi \times 2400/60 = 251$ rad/s mass moment of inertia of the engine and the propeller, $I = m.k^2 = 400(0.3)^2 = 36$ kg-m^2 4M angular velocity of precession, $\omega_P = v/R = 55.6/50 = 1.11$ rad/s 2M gyroscopic couple acting on the aircraft, $C = I.\ \omega.\ \omega_P = 36 \times 251.4 \times 1.11 = 100\ 46$ N-m $= 10.046$ kN-m **Ans.** 4M when the aeroplane turns towards left, the effect of the gyroscopic couple is to lift the nose upwards and tail downwards. **Ans.** 3M
5	**A four – wheeled trolley car of mass 2500 kg runs on rails, which are 1.5 m apart and travels around a curve of 30 m radius at 24 km/h. the rails are at same level. Each wheel of the trolley is 0.75 m in diameter and each of the trolley is 0.75 m in diameter and each of the two axles is driven by a motor running in a direction opposite to that of the wheels at a speed of five times the speed of rotation of the wheels. The moment of inertia of each axle with gear and wheel is 18 kg-m^2. Each motor with shaft and gear pinion has a moment of inertia of 12 kg-m^2. The centre of gravity of the car is 0.9m above the rail level. Determine the vertical force exerted by each wheel on the rail taking into consideration on the centrifugal and gyroscopic effects on the trolley. (13 M)**BTL5 **Answer: Page: 497-R.S KHURMI** **Solution.** Given : $m = 2500$ kg ; $x = 1.5$ m ; $R = 30$ m ; $v = 24$ km/h $= 6.67$ m/s ; $d_W = 0.75$ m or $r_W = 0.375$ m ; $G = \omega_E/\omega_W = 5$; $I_W = 18$ kg-m^2 ; $I_E = 12$ kg-m^2 ; $h = 0.9$ m The weight of the trolley ($W = m.g$) will be equally distributed over the four wheels, which will act downwards. The reaction between the wheels and the road surface of the same magnitude will act upwards. 4M $\therefore$ Road reaction over each wheel $= W/4 = m.g/4 = 2500 \times 9.81/4 = 6131.25$ N We know that angular velocity of the wheels, $\omega_W = v/r_W = 6.67/0.375 = 17.8$ rad/s angular velocity of precession, $\omega_P = v/R = 6.67/30 = 0.22$ rad/s

∴ Gyroscopic couple due to one pair of wheels and axle,

$$C_W = 2\, I_W.\omega_W.\omega_P = 2 \times 18 \times 17.8 \times 0.22 = 141 \text{ N-m}$$

and gyroscopic couple due to the rotating parts of the motor and gears,

$$C_E = 2\, I_E.\omega_E.\omega_P = 2\, I_E.G.\omega_W.\omega_P \quad \ldots (\because\ \omega_E = G.\,\omega_W)$$

$$= 2 \times 12 \times 5 \times 17.8 \times 0.22 = 470 \text{ N-m}$$

∴ Net gyroscopic couple, $C = C_W - C_E = 141 - 470 = -329$ N-m

... (–ve sign is used due to opposite direction of motor)

4M

Due to this net gyroscopic couple, the vertical reaction on the rails will be produced. Since C_E is greater than C_W, therefore the reaction will be vertically downwards on the outer wheels and vertically upwards on the inner wheels. Let the magnitude of this reaction at each of the outer or inner wheel be $P/2$ newton.

∴ $P/2 = C/2x = 329 / 2 \times 1.5 = 109.7$ N

We know that centrifugal force, $F_C = m.v^2/R = 2500\,(6.67)^2/30 = 3707$ N

∴ Overturning couple, $C_O = F_C \times h = 3707 \times 0.9 = 3336.3$ N-m

This overturning couple is balanced by the vertical reactions which are vertically upwards on the outer wheels and vertically downwards on the inner wheels. Let the magnitude of this reaction at each of the outer or inner wheels be $Q/2$ newton.

∴ $Q/2 = C_O / 2x = 3336.3 / 2 \times 1.5 = 1112.1$ N

We know that vertical force exerted on each outer wheel,

$$P_O = \frac{W}{4} - \frac{P}{2} + \frac{Q}{2} = 6131.25 - 109.7 + 1112.1 = 7142.65 \text{ N}$$ **Ans.**

vertical force exerted on each inner wheel,

$$P_I = \frac{W}{4} + \frac{P}{2} - \frac{Q}{2} = 6131.25 + 109.7 - 1112.1 = 5128.85 \text{ N}$$ **Ans.**

5M

PART * C

1

In a spring Hartnell type governor, the extreme radii of rotation of balls are 80 mm and 120 mm. the ball arm and the sleeve arm of the bell crank lever are equal in length. The mass of each ball is 2 kg. if the speeds at the two extreme positions are 400 and 420 r.p.m., find : 1. The initial compression of the central spring, and 2. The spring constant. (15 M) BTL5

Answer: Page 681-R.S KHURMI

Solution. Given : $r_1 = 80$ mm = 0.08 m ; $r_2 = 120$ mm = 0.12 m ; $x = y$; $m = 2$ kg ; $N_1 = 400$ r.p.m. or $\omega = 2\,\pi \times 400/60 = 41.9$ rad/s ; $N_2 = 420$ r.p.m. or $\omega_2 = 2\,\pi \times 420/60 = 44$ rad/s

We know that the centrifugal force at the minimum speed,

$$F_{C1} = m\,(\omega_1)^2\, r_1 = 2\,(41.9)^2\ \ 0.08 = 281 \text{ N}$$

2M

centrifugal force at the maximum speed,

$$F_{C2} = m\,(\omega_2)^2\, r_2 = 2\,(44)^2\ \ 0.12 = 465 \text{ N}$$

$$M.g + S_1 = 2\,F_{C1} \times \frac{x}{y}$$

$$S_1 = 2\,F_{C1} = 2 \times 281 = 562 \text{ N} \qquad \ldots (\because M = 0 \text{ and } x = y)$$

$$M.g + S_2 = 2\,F_{C2} \times \frac{x}{y}$$

$$S_2 = 2\,F_{C2} = 2 \times 465 = 930 \text{ N}$$

5M

lift of the sleeve,

$$h = (r_2 - r_1)\,\frac{y}{x} = r_2 - r_1 = 120 - 80 = 40 \text{ mm} \qquad \ldots (\because x = y)$$

Stiffness of the spring,

$$s = \frac{S_2 - S_1}{h} = \frac{930 - 562}{40} = 9.2 \text{ N/mm}$$

initial compression of the central spring

$$= \frac{S_1}{s} = \frac{562}{9.2} = 61 \text{ mm} \quad \textbf{Ans.}$$

5M

2. ***Spring constant***

We have calculated above that the spring constant or stiffness of the spring,

$$s = 9.2 \text{ N/mm} \quad \textbf{Ans.}$$

3M

2

The turbine rotor of a ship has a mass of 3500 kg. it has a radius of gyration of 0.45 m and a speed of 3000 r.p.m. clockwise when looking from stern. Determine the gyroscopic couple and its effect upon the ship:
1. when the ship is steering to the left on the curve of 100 m radius at a speed of 36 km/h.
2. when the ship is pitching in a simple harmonic motion, the bow falling with its maximum velocity. The period of pitching is 40 seconds and the total angular displacement between the two extreme positions of pitching is 12 degrees. (15 M)BTL5
Answer: Page: 492-R.S KHURMI

Solution. Given : $m = 3500$ kg ; $k = 0.45$ m; $N = 3000$ r.p.m. or $\omega = 2\pi \times 3000/60 = 314.2$ rad/s

1. ***When the ship is steering to the left***

Given: $R = 100$ m ; v = km/h = 10 m/s

We know that mass moment of inertia of the rotor,

$$I = m.k^2 = 3500\,(0.45)^2 = 708.75 \text{ kg-m}^2$$

3M

angular velocity of precession,

$$\omega_P = v/R = 10/100 = 0.1 \text{ rad/s}$$

$\therefore$ Gyroscopic couple,

$$C = I.\omega.\omega_P = 708.75 \times 314.2 \times 0.1 = 22\,270 \text{ N-m}$$

$$= 22.27 \text{ kN-m } \textbf{Ans.}$$

when the rotor rotates clockwise when looking from the stern and the ship takes a left turn, the effect of the reactive gyroscopic couple is to raise the bow and lower the stern. **Ans.** 5M

2. When the ship is pitching with the bow falling

Given: $t_p = 40$ s

Since the total angular displacement between the two extreme positions of pitching is 12° (*i.e.* $2\phi = 12°$), therefore amplitude of swing,

$$\phi = 12 / 2 = 6° = 6 \times \pi/180 = 0.105 \text{ rad}$$

and angular velocity of the simple harmonic motion,

$$\omega_1 = 2\pi / t_p = 2\pi / 40 = 0.157 \text{ rad/s}$$

We know that maximum angular velocity of precession,

$$\omega_P = \phi.\omega_1 = 0.105 \times 0.157 = 0.0165 \text{ rad/s}$$ 5M

$\therefore$ Gyroscopic couple,

$$C = I.\omega.\omega_P = 708.75 \times 314.2 \times 0.0165 = 3675 \text{ N-m}$$

$$= 3.675 \text{ kN-m } \textbf{Ans.}$$ 2M

3

All the arms of a porter governor are 178 mm long and are hinged at a distance of 38 mm from the axis of the rotation. The mass of the each ball is 1.15 kg and mass of sleeve is 20 kg. the governor sleeve begins to rise at 280 r.p.m. when the links are at an angle of 30^0 to the vertical. Assuming the friction force to be constant, determine the minimum and maximum speed of rotation when the inclination of the arms to the vertical is 45^0(15 M)BTL5

Answer: Page:669-R.S.KHURMI

Solution. Given : $BP = BD = 178$ mm ; $PQ = DH = 38$ mm ;

$m = 1.15$ kg ; $M = 20$ kg ; $N = 280$ r.p.m. ; $\alpha = \beta = 30°$

$r = BG = BF + FG = BP \times \sin\alpha + FG$

$= 178 \sin 30° + 38 = 127$ mm

$h = BG / \tan\alpha$

$= 127 / \tan 30° = 220$ mm $= 0.22$ m

$$N^2 = \frac{m.g + (Mg \pm F)}{m.g} \times \frac{895}{h}$$

. . . ($\therefore$ tan α = tan β or $q = 1$)

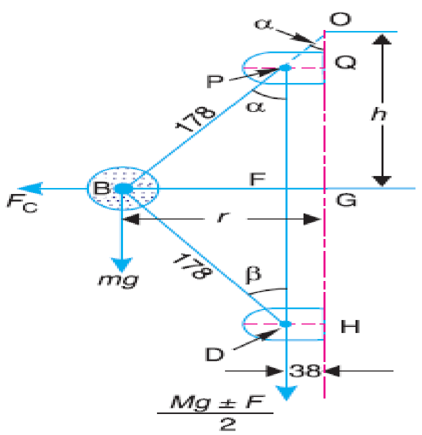
$$(280)^2 = \frac{1.15 \times 9.81 + 20 \times 9.81 \pm F}{1.15 \times 9.81} \times \frac{895}{0.22}$$

3M

$$\pm F = \frac{(280)^2 \times 1.15 \times 9.81 \times 0.22}{895} - 1.15 \times 9.81 - 20 \times 9.81$$

$$= 217.5 - 11.3 - 196.2 = 10 \text{ N}$$

2M



All dimensions in mm.

3M

We know that radius of rotation when inclination of the arms to the vertical is 45 (*i.e.* when $\alpha = \beta = 45°$),

$$r = BG = BF + FG = BP \times \sin\alpha + FG$$

$$= 178 \sin 45° + 38 = 164 \text{ mm}$$

$$h = BG / \tan\alpha = 164 / \tan 45° = 164 \text{ mm} = 0.164 \text{ m}$$

2M

$$(N_1)^2 = \frac{m.g + (M.g - F)}{m.g} \times \frac{895}{h}$$

$$= \frac{1.15 \times 9.81 + (20 \times 9.81 - 10)}{1.15 \times 9.81} \times \frac{895}{0.164} = 95\ 382$$

$\therefore$ $N_1 = 309$ r.p.m. **Ans.**

$$(N_2)^2 = \frac{m.g + (M.g + F)}{m.g} \times \frac{895}{h}$$

$$= \frac{1.15 \times 9.81 + (20 \times 9.81 + 10)}{1.15 \times 9.81} \times \frac{895}{0.164} = 105\ 040$$

$N_2 = 324$ r.p.m. **Ans.**

5M

ME8595 THERMAL ENGINEERING – II L T P C

3 0 0 3

OBJECTIVES:

- ✓ To apply the thermodynamic concepts for Nozzles, Boilers, Turbines, and Refrigeration & Air Conditioning Systems.
- ✓ To understand the concept of utilising residual heat in thermal systems.

UNIT I STEAM NOZZLE 9

Types and Shapes of nozzles, Flow of steam through nozzles, Critical pressure ratio, Variation of mass flow rate with pressure ratio. Effect of friction. Metastable flow.

UNIT II BOILERS 9

Types and comparison. Mountings and Accessories. Fuels - Solid, Liquid and Gas. Performance calculations, Boiler trial.

UNIT III STEAM TURBINES 9

Types, Impulse and reaction principles, Velocity diagrams, Work done and efficiency – optimal operating conditions. Multi-staging, compounding and governing.

UNIT IV COGENERATION AND RESIDUAL HEAT RECOVERY 9

Cogeneration Principles, Cycle Analysis, Applications, Source and utilisation of residual heat. Heat pipes, Heat pumps, Recuperative and Regenerative heat exchangers. Economic Aspects.

UNIT V REFRIGERATION AND AIR – CONDITIONING 9

Vapour compression refrigeration cycle, Effect of Superheat and Sub-cooling, Performance calculations, Working principle of air cycle, vapour absorption system, and Thermoelectric refrigeration. Air conditioning systems, concept of RSHF, GSHF and ESHF, Cooling load calculations. Cooling towers – concept and types.

TOTAL: 45 PERIODS

OUTCOMES:

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

CO1 Solve problems in Steam Nozzle.

CO2 Explain the functioning and features of different types of Boilers and auxiliaries and calculate performance parameters.

CO3 Explain the flow in steam turbines, draw velocity diagrams for steam turbines and solve problems.

CO4 Summarize the concept of Cogeneration, Working features of Heat pumps and Heat Exchangers.

CO5 Solve problems using refrigerant table / charts and psychrometric charts.

TEXT BOOKS:

1. Kothandaraman, C.P. Domkundwar .S and Domkundwar A.V.,"A course in Thermal Engineering", Dhanpat Rai & Sons, 2016.
2. Mahesh.M. Rathore,"Thermal Engineering", 1st Edition, Tata Mc Graw Hill Publications, 2010.

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- ✓ Arora .C.P., "Refrigeration and Air Conditioning", Tata Mc Graw Hill, 2008.
- ✓ Ballaney. P.L ." Thermal Engineering", Khanna publishers, 24th Edition 2012.
- ✓ Charles H Butler : Cogeneration" McGraw Hill, 1984.
- ✓ Donald Q. Kern, " Process Heat Transfer", Tata Mc Graw Hill, 2001.
- ✓ Sydney Reiter "Industrial and Commercial Heat Recovery Systems" Van Nostrand Reinhols,
- ✓ 1985.

Subject Code: ME8595 **Year/Semester: III/05**

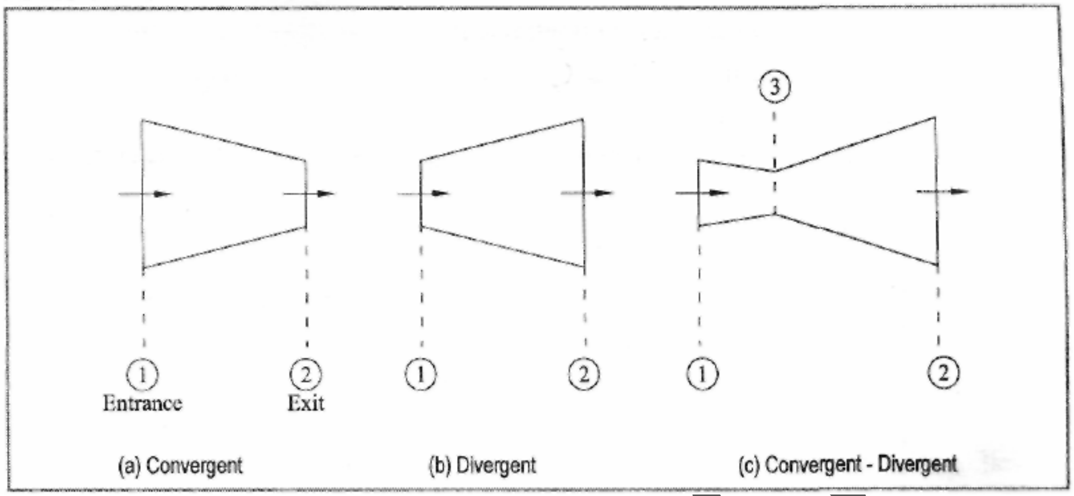
Subject Name : Thermal Engineering - II

Subject Handler : Mr.J.RAVIKUMAR & Mrs.S.A.AROKYA ANICIA

UNIT I STEAM NOZZLE	
Types and Shapes of nozzles, Flow of steam through nozzles, Critical pressure ratio, Variation of mass flow rate with pressure ratio. Effect of friction. Metastable flow.	
PART * A	
Q.No.	**Questions**
1.	**Define nozzles and their functions.** BTL 1 Nozzle is a duct of varying cross-sectional area in which the velocity increases with the corresponding drop in pressure. A steam nozzle is a duct or passage of smoothly varying cross sectional area which converts heat energy of steam into kinetic energy. The shape of

	nozzle is designed such that it will perform this conversion of energy with minimum loss.
2	**Enlist the effects of friction on the flow through a steam nozzle.** BTL 1 1. The final fraction of the steam is increased as the part of the kinetic energy gets converted into heat due to friction and absorbed by steam with n increase in enthalpy. 2. The expansion is no more isentropic and enthalpy drop is reduced thereby resulting in lower exit velocity. 3. The specific volume of steam is increased as the steam becomes drier due to this frictional reheating.
3	**Define nozzle efficiency and critical pressure ratio.** BTL 1 **Nozzle efficiency:** It is defined as the ratio of actual enthalpy drop to the isentropic enthalpy drop **Nozzle efficiency** = Actual enthalpy drop / Isentropic enthalpy drop . **Critical pressure ratio**: There is only one value of the ratio (P2/P1) which produces maximum discharge from the nozzle. The ratio is called critical pressure ratio. Critical pressure ratio P_2 /P_1 = (2/n+1) n/n+1 Where, P_1= Initial pressure P_2= Throat pressure
4	**Explain the phenomenon of super saturated expansion in steam nozzle.** **Or What is Metastable flow**? BTL 2 When the supersaturated steam is expanded in the nozzle, the condensation should occur in the nozzle. Since the steam has a great velocity, the condensation does not take place at the expected rate. So the equilibrium between the liquid and vapour phase is delayed and the steam continues to expand in a dry state. The steam in such set of condition is said to be supersaturated or meta stable flow.
5	**Mention the conditions that produce super saturation of steam in nozzles.** BTL 1 When the superheated steam expands in the nozzle, the condensation will occur in the nozzle. Since, the steam has more velocity, the condensation will not take place at the expected rate. So, the equilibrium between the liquid and vapour phase is delayed and the steam continues to expand in a dry state. The steam in such set of condition is said to be supersaturated or meta stable flow.
6	**State the effects of super saturation in a steam nozzle.** BTL 2 The following effects in a nozzle on steam, in which super saturation occurs, may be summarized as follows. 1. The dryness fraction of the steam is increased. 2. Entropy and specific volume of the steam are increased. 3. Exit velocity of the steam is reduced. 4. Mass of stream discharged is increased.
7	**What is the critical pressure ratio initially of a dry saturated steam?** BTL 1

	$P_2/P_1= 0.577$
11	**What is super saturated flow?** BTL 2 When the saturated steam is expanded in the nozzle, the condensation should occur in the nozzle. Since the steam has a great velocity, the condensation does not takes place at the expected rate. So, the equilibrium between liquid and vapour phase is delayed and the steam continues to expand in a dry state. The steam in such set of condition is said to be supersaturated or metastable flow.
12	**List the different cross-sections of the nozzle.** BTL 1 The cross section of the nozzles may be circular, rectangular, elliptical or square.The z smallest section in the nozzle is known as throat**.**
13	**Mention the applications of Steam nozzles.** BTL 3 The nozzles are used in steam and gas turbines, jet engines, for propulsion of rocket motors, flow measurements, in injectors for pumping water, in ejectors for removing air from condensers etc.
14	**What is the major function of the nozzle?** BTL 1 The major function of nozzles is to produce a jet of steam or gas with high velocity to drive steam or gas turbines. So, the nozzles are located just before the steam or gas turbines. When the nozzles velocity gas is produced and there will be no question of condensation and hence dryness fraction
15	**Describe the functions of the nozzle when used in steam turbines .** BTL 3 When the nozzles are used with steam turbines, they perform the following functions. 1. They convert part of heat energy of steam (obtained from boiler) into kinetic energy. 2. In case of impulse turbines (steam turbines), the nozzles direct the jet of high velocity steam against the blades of rotor which then convert the kinetic energy of steam into mechanical (shaft) work.
	PART * B
1	**Explain the different types of nozzles with neat sketches.** BTL 2 **Answer : Page-1.1 Dr.G.K.Vijayaragavan** There are three important types of steam nozzles : 1. Convergent nozzie. 2. Divergent nozzle. 3. Convergent - divergent nozzle. (3M)



Types of Steam Nozzles (5M)

- If the cross section of the nozzle decreases continuously from entrance to exit; then it is called convergent nozzle.
- If the cross section of a nozzle increases continuously from entrance to exit then it is called Divergent nozzle.
- If the cross section of a nozzle decreases first upto certain length and then increases upto exit; then it is called - Convergent - Divergent nozzle. This is used mostly in various types of steam turbines. (5M)

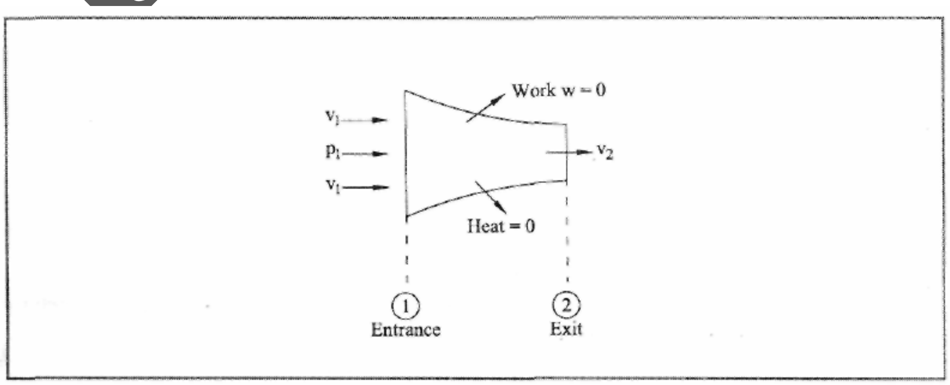
2 **Briefly explain the phenomenon of Super saturated flow.** BTL 2

Answer: Page – 1.10 Dr.G.K.Vijayaragavan

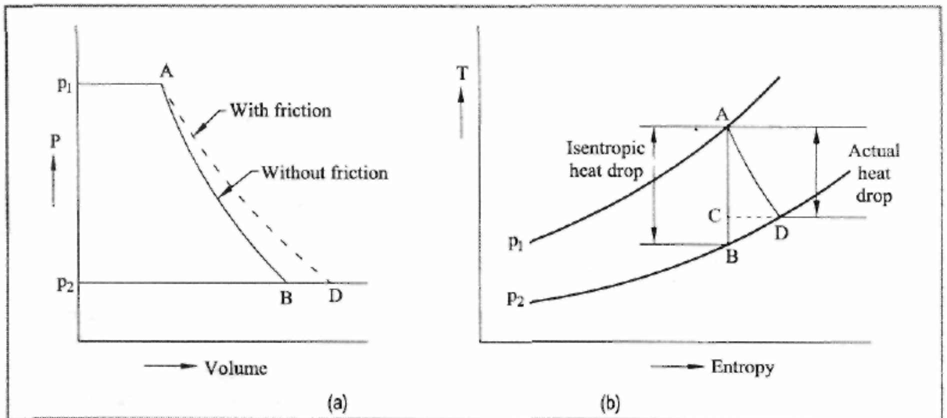
The phenomenon known as - super saturation that occurs in the flow of steam through nozzles. This is due to time lag in the condensation of steam during expansion. This super saturated flow affects mass and condition of the steam discharged. So, the flow of steam through a nozzle may be regarded as either :

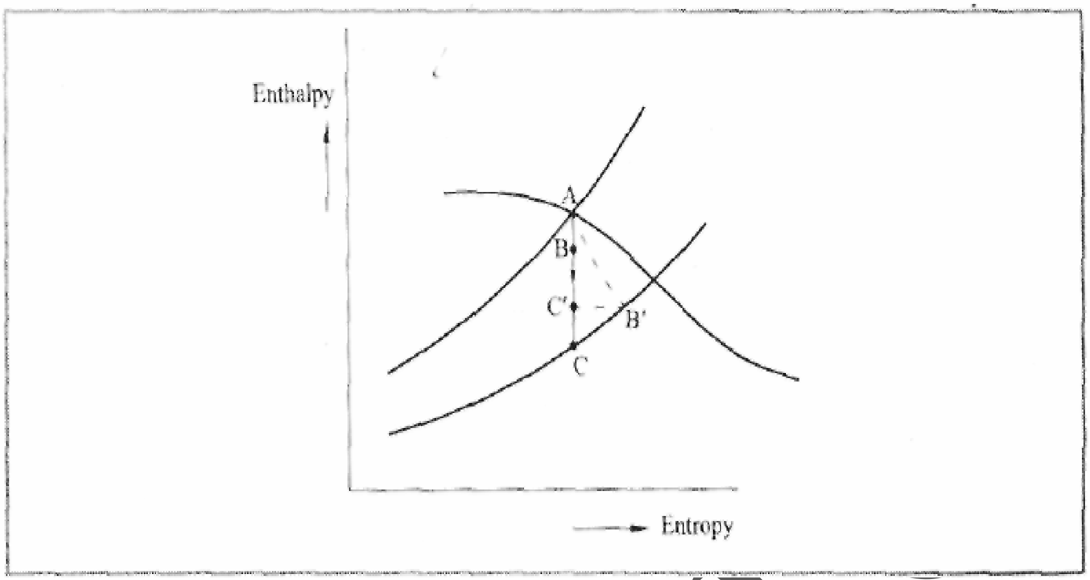
1. Reversible adiabatic or isentropic flow.
2. Adiabatic flow modified by friction.
3. Super saturated flow. (5M)

The nozzle as a system where plane 1 is the entrance of the nozzle and plane 2 is the exit of the nozzle.



(2M)

	Figure: A Nozzle at entrance and exit  Figure : Expansion of Steam (4M) The analysis of steam nozzles is also valid for gas nozzles (Nozzles in which the working fluid is a gas) where dryness fraction $x=1$. Super saturation is limited to flow of steam only and it doesn't occur in gas nozzles. (2M)
3	**Explain the effect of friction in a nozzle.** BTL2 **Answer : Page – 1.8 Dr.G.K.Vijayaragavan** When steam flows through a nozzle, for a given pressure drop, the final velocity of steam gets reduced because of the following losses : 1. The friction between steam and walls of nozzle. 2. Internal friction of steam itself. 3. Shock losses. (3M) Most of the friction in a convergent divergent nozzle occurs in the divergent portion - between throat and exit. Due to the effect of friction, the actual flow through a nozzle is not isentropic but still approximately adiabatic. The effects of friction are : 1. The enthalpy drop is reduced and hence the final velocity. 2. The kinetic energy gets converted into heat due to friction and is absorbed by the steam. Due to this, the final dryness fraction of steam increases. 3. Steam becomes more dry due to increased dryness fraction and hence specific volume of steam increases and mass flow rate decreases. (5M)



- Point A represents the initial condition of steam which enters the nozzle in a dry saturated state. If the effect of friction is neglected, the expansion of steam from entrance to throat is represented by *A-B* and that from throat to exit by *B-C*.
- The whole expansion from *A* to C is isentropic. The heat drop $(h_A - h_c)$ is known as - Isentropic heat drop or Rankine heat drop.
- The heat drop (h_A - h_B ') is the actual enthalpy drop during the expansion of steam when effect of friction is considered and is known as - useful heat drop. The useful heat drop is less than the isentropic heat drop.
- If the steam enters the nozzle in a super heated condition, then during expansion, the friction tends to super heat the steam

(5M)

4 **Write a short note on Nozzle efficiency.** BTL2

Answer: Page – 1.8 Dr.G.K.Vijayaragavan

The ratio of actual or useful heat drop to isentropic heat drop is known as - Coefficient of nozzle or nozzle efficiency. *K*. (4M)

$\eta_{nozzle} = K$ = Nozzle efficiency

$$= \frac{\text{Actual/useful heat drop}}{\text{Isentropic heat drop}}$$

The efficiency of a nozzle generally varies from 0.85 to 0.95. The efficiency of a nozzle depends upon the following factors :

1. Material of the nozzle.
2. Size and shape of the nozzle.
3. Finish of the nozzle.
4. Angle of divergence.
5. Nature of the fluid and its state,

6. Friction.
7. Fluid velocity.
8. Turbulence in the flow passages. (9M)

5 **Derive the expression for velocity of steam flow through a nozzle.** BTL2

Answer: Page – 1.2 Dr.G.K.Vijayaragavan

Steam enters the nozzle with high pressure and low velocity and leaves the nozzle with high velocity and low pressure. The initial velocity compared to exit velocity is so small and is generally neglected.

Let V_1 = Velocity of steam at entrance of nozzle - *m/sec.*

V_2 = Velocity of steam at any section - *m/sec*

h_1 = Enthalpy of entering steam - *J/kg*

h_2 = Enthalpy of steam at the section considered - *J/kg*

(4M)

For unit mass flow of steam, we have the steady flow energy equation :

$$h_1 + \frac{V_1^2}{2} = h_2 + \frac{V_2^2}{2}$$

$$\frac{V_2^2}{2} = \frac{V_1^2}{2} + (h_1 - h_2)$$

(2M)

The gain in kinetic energy between any two sections is equal to loss of enthalpy. Enthalpy drop $h_d = (h_l - h_2)$

$$\therefore \qquad \frac{V_2^2}{2} = \frac{V_1^2}{2} + h_d$$

Neglecting the velocity of entering steam or velocity of approach;

$$\therefore \qquad V_2 = \sqrt{2000\, h_d} = 44.72\sqrt{h_d}\ m/sec.$$

$$\frac{V_2^2}{2} = h_d$$

$V_2^2 = 2\, h_d = 2000\, h_d KJ/kg$ (4M)

In actual practice, always certain amount of friction exits between steam and the surfaces of the nozzle. This reduces the enthalpy drop by 10-15 percent and hence the exit velocity of steam is also reduced correspondingly.

Considering the effect of friction;

$$V_2 = 44.72\sqrt{K \cdot h_d}, \text{ Where}$$

K = Nozzle efficiency or coefficient of nozzle. (3M)

PART * C

1 **Derive the expression foe mass of steam discharged through a nozzle.** BTL 4

Answer: Page – 1.3 Dr.G.K.Vijayaragavan

The steam flowing through a nozzle approximately follows the equation pV^n = constant.

Where n = 1.135 for saturated steam

= 1.300 for superheated steam**.**

For wet steam, from Zenner's equations; $n = 1.035 + 0.1\, x_x$. (2M)

Where

x_1= Initial dryness fraction of steam

Let p_1 = Initial pressure of steam- N/m^2 .

v_1 = Initial volume of 1 *kg* of steam - m^3

p_2 = Pressure of steam at throat - N/m^2

v_2 - Volume of steam at pressure - m^3

A = Cross sectional area of nozzle - m^2

V_2 = Velocity of leaving steam - m/sec. (2M)

Work done during Rankine cycle

= Drop in enthalpy

$$= \frac{n}{n-1}(p_1 v_1 - p_2 v_2)$$

Gain in kinetic energy = $\frac{V_2^{\,2}}{2}$ (Neglecting initial velocity)

Gain in kinetic energy is equal to enthalpy drop.

$$\therefore \quad \frac{V_2^{\,2}}{2} = \frac{n}{n-1}(p_1 v_1 - p_2 v_2)$$

$$= \frac{n}{n-1} p_1 \cdot v_1 \left(1 - \frac{p_2 v_2}{p_1 v_1}\right) \qquad \ldots\ldots\ldots (1)$$

(2M)

$$\therefore \quad \frac{v_2}{v_1} = \left(\frac{p_1}{p_2}\right)^{1/n} \qquad \ldots\ldots\ldots (2)$$

$$\therefore \quad \frac{v_2}{v_1} = \left(\frac{p_1}{p_2}\right)^{1/n} \qquad \ldots\ldots\ldots (2)$$

$$\therefore \quad \frac{v_2}{v_1} = \left(\frac{p_1}{p_2}\right)^{1/n} \qquad \ldots\ldots\ldots (2)$$

$$v_2 = v_1 \left(\frac{p_1}{p_2}\right)^{1/n} \qquad \ldots\ldots\ldots (3)$$

$$V_2^{\,2} = \frac{n}{n-1} p_1 v_1 \left[1 - \frac{p_2}{p_1}\left(\frac{p_1}{p_2}\right)^{1/n}\right]$$

$$= \frac{n}{n-1} p_1 v_1 \left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right]$$

$$\therefore \quad V_2 = \sqrt{2\left(\frac{n}{n-1}\right) p_1 v_1 \left\{1 - \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right\}}$$

(2M)

Volume of steam flowing / *sec.* = Cross sectional area of nozzle x velocity

$= A.\ V_2$

Volume of 1 *kg* of steam i.e., specific volume of steam at pressure $p_2 = v_2$ nr'/kg

Then, mass of steam discharged through the nozzle per second

$$m = \frac{\text{Volume of steam flowing}/sec}{\text{Specific volume of steam at } p_2}$$

	$$= \frac{A \cdot V_2}{v_2}$$ $$\therefore \quad m = \frac{A}{v_2} \cdot \sqrt{2\left(\frac{n}{n-1}\right) p_1 v_1 \left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right]}$$ (3M) Substituting the value of v_2 from equation (3); $$m = \frac{A}{v_1 \left(\frac{p_1}{p_2}\right)^{1/n}} \sqrt{2\left(\frac{n}{n-1}\right) p_1 V_1 \left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right]}$$ $$= \frac{A}{v_1}\left(\frac{p_2}{p_1}\right)^{\frac{1}{n}} \sqrt{2\left(\frac{n}{n-1}\right) p_1 V_1 \left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right]}$$ $$= A \cdot \sqrt{\left(\frac{p_2}{p_1}\right)^{\frac{2}{n}} \cdot \frac{2n}{n-1} \frac{p_1}{v_1} \left[1 - \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}\right]}$$ $$= A \sqrt{\frac{2n}{n-1} \cdot \frac{p_1}{v_1} \left[\left(\frac{p_2}{p_1}\right)^{2/n} - \left(\frac{p_2}{p_1}\right)^{\frac{n+1}{n}}\right]} \quad \ldots\ldots\ldots (4)$$ This equation gives mass of steam in *kgs/sec* flowing through a nozzle for a pressure drop from p_1 to p_2. (4M)
2	**Derive the expression for Critical pressure ratio for flow of steam in a nozzle.** BTL 4 **Answer: Page – 1.9 Dr.G.K.Vijayaragavan** the rate of mass flow of steam per unit are is given by $$\frac{m}{A} = \sqrt{\frac{2n}{n-1} \frac{p_1}{v_1} \left[\left(\frac{p_2}{p_1}\right)^{2/n} - \left(\frac{p_2}{p_1}\right)^{\frac{n+1}{n}}\right]} \quad \ldots\ldots\ldots (5)$$ (2M) The mass flow per unit are has maximum value at 'throat' which has minimum area.The value of pressure ratio *(p_2/p_1)* at throat can becalculated from equation (5) corresponding to maximum value of *m/A*. Except the ratio *(p_2/p_1)*, all other terms in this equation are constant. So, *m/A* will be maximum when $$\left[\left(\frac{p_2}{p_1}\right)^{2/n} - \left(\frac{p_2}{p_1}\right)^{\frac{n+1}{n}}\right]$$ (2M)

Differentiating the above expression with respect to *(p_2/p_1)* and equating to zero for a maximum discharge per unit area.

$$\frac{d}{d(p_2/p_1)}\left[\left(\frac{p_2}{p_1}\right)^{2/n} - \left(\frac{p_2}{p_1}\right)^{\frac{n+1}{n}}\right] = 0$$

$$\therefore \quad \frac{2}{n}\left[\frac{p_2}{p_1}\right]^{\frac{2}{n}-1} - \frac{n+1}{n}\left[\frac{p_2}{p_1}\right]^{\frac{n+1}{n}-1} = 0$$

(5M)

$$\therefore \quad \left(\frac{p_2}{p_1}\right)^{\frac{2-n}{n}} = \frac{n+1}{2}\left(\frac{p_2}{p_1}\right)^{1/n} \quad \text{(or)}$$

$$\left(\frac{p_2}{p_1}\right)^{2-n} = \left[\frac{n+1}{2}\right]^{n}\left(\frac{p_2}{p_1}\right)$$

$$\therefore \quad \left(\frac{p_2}{p_1}\right)^{1-n} = \left[\frac{n+1}{2}\right]^{n}$$

$$\therefore \quad \frac{p_2}{p_1} = \left[\frac{2}{n+1}\right]^{\frac{n}{n-1}} \qquad \ldots\ldots\ldots (6)$$

(4M)

The ratio *(p_2/p_1)* is known as - Critical pressure ratio and its value depends upon the value of index *n*. The pressure at throat is known as - Critical pressure and the ratio of pressure at minimum cross section i.e., throat *(p_2)* to initial pressure - pressure at entrance *(p_1)* is known as critical pressure ratio. The area of throat of all steam nozzles should be designed on this ratio. (2M)

4 **Summarise the effects of supersaturation for a metastable flow in a nozzle.**

Answer: Page – 1.10 Dr.G.K.Vijayaragavan

The following are the important effects that occur during super saturated flow of steam in a nozzle.

1. As the condensation doesn't take place during super saturated expansion, the

	temperature at which super saturation occurs will be less than the super saturation temperature corresponding to the pressure. So, the density of super saturated steam will be more than that for equilibrium conditions. (Generally 8 times that of ordinary saturated vapour at the corresponding pressure). Which gives increase in the mass of steam discharged. 2. Due to super saturation, the entropy and specific volume increase. 3. Super saturation increases slightly the dryness fraction. 4. For some pressure limits, super saturation reduces enthalpy drop slightly. As velocity is proportional to square root of enthalpy drop; exit velocity is also reduced slightly. When meta stable conditions exist in the nozzle; Mollier chart (H-S chart) should not be used and the expansion must be considered to follow the law $pv^{1.3} = C$ i.e., with index of expansion for super heated steam. The problems on super saturated flow can't be solved by Mollier chart unless Wilson line is drawn on it. (8M) WILSON LINE Generally, there is a limit upto which super saturated flow is possible. This limit of super saturation is represented by a curve known as - Wilson line, on the Mollier diagram. Above this curve, steam is super saturated and super heated. Beyond Wilson line, there is no super saturation. At Wilson line condensation occurs suddenly and irreversibly at constant enthalpy and then remains in stable condition. The result is to reduce heat drop slightly during expansion causing corresponding reduction in exit velocity and final dryness fraction increases slightly. The limiting condition of under cooling at which condensation begins and restores the conditions of thermal equilibrium is called Wilson line. Generally, Wilson line closely follows 0.96 dryness fraction line. In nozzles, this limit may be with in the nozzle or after the vapour leaves the nozzle. (7M)

UNIT II BOILERS	
Types and comparison. Mountings and Accessories. Fuels - Solid, Liquid and Gas. Performance calculations, Boiler trial.	
PART * A	
Q.No.	**Questions**
1.	**Define a boiler.** BTL1 A simple boiler is a closed vessel strongly constructed of steel in which steam is generated from water by the application of heat. The function of steam boiler is to convert chemical energy of fuel into heat by combustion and thus to produce steam which is then available

for different purposes.

2 **Write a note on boiler mountings.** BTL1

Mountings : These are the elements mounted directly on the boiler for its safe and proper functioning.They include –safety valve, pressure gauges,stop valves,feed check valve etc.

3 **Write a note on boiler accessories.** BTL1

Accessories : These elements from an integral part of the boiler; but not mounted on it. They include Economiser, Superheater, feed pump etc. They increase the efficiency of the boiler.

4 **List out the requirements of a good boiler.** BTL1

A good boiler should meet the following requirements.

1. It should provide maximum quantity of steam at required pressure and temperature and at required quality (dryness fraction) with minimum fuel consumption.
2. It should be safe in working and should confirm to safety regulations.
3. Initial, installation and maintenance costs should be low enough.
4. It should be capable of quick starting,rapidly meet the fluctuations of load.
5. All components should be easily accessible for inspection and repair.
6. It should be light in weight and occupy less space.
7. Minimum refractory material should be used.
8. The heating surface should be from any type of deposits.
9. The water and flue gas circuits should allow maximum fluid velocity without excessive frictional losses.

5 **Enlist the classification of boilers.** BTL1

Generally, boilers are classified based on the following factors :

1. Tubecontents
2. Use
3. Tube shape andposition
4. Furnaceposition
5. Number oftubes
6. Heatsource
7. Circulation

6 **Define Boiler Efficiency.** BTL2

Generally, boilers are classified based on the following factors :

It is an other tool to know the performance of a boiler. It is defined as the ratio of heat

	actually utilised in generating steam to heat liberated by the complete combustion of fuel (Based on H.C.V) in the same period. $$\text{Boiler efficiency} = \frac{m_a \cdot (hs - hw)}{C.V}$$ Boiler efficiency depends upon 2 factors : (a) Fixed factors (b) Variable factors.
7	**Summarise on Boiler Trial.** BTL 2 In order to study the efficiency, heat losses and performance of a boiler, a trail is taken on a boiler. During trail, the boiler is run on 'test conditions' for few hours to obtain steady state conditions and necessary data is recorded. The objects of a boiler trail are : (a) To estimate the evaporative capacity of boiler. (b) To determine the thermal efficiency of boiler. (c) To prepare a heat balance sheet for the boiler.
8	**Mention the function of safety valve .** BTL 1 The main function of a safety valve is to discharge excess pressure generated in the boiler than the designed or working pressure. This is done automatically by discharging the excess steam to atmosphere as soon as maximum pressure is reached"and brings down the pressure to the normal working limit.
9	**List the types of safety valves.** BTL 1 There are four types of safety valves : • Dead weight safety valve. • Lever safety valve. • Spring loaded safety valve. • High steam and low water safety valve.

10	**Describe the function of pressure gauge .** BTL2 The function of pressure gauge is to indicate the pressure of the steam generated. The pressure should be nearly constant and shouldn't change with fluctuations of load. The pressure gauge is generally constructed to indicate upto double the maximum working pressure. The pressure gauge is mounted on the top front of the boiler shell or drum.
11	**List the types of pressure gauges.** BTL1 There are two types of pressure gauges : 1. Bourdon tube pressure gauge. 2. Diaphragm type pressure gauge.
12	**Mention the function of Blow Off Cock.** BTL2 1. To blow out sand,sediment,mud and other impurities collected at the bottom of the boiler that deposit from feedwater. 2. To empty the boiler whenever required for cleaning and when water level in the boiler becomes high enough and when boiler is to be kept out of operation.
13	**What is the function of feed pump?** BTL2 The function of a feed pump is to deliver feed water to the boiler under pressure. These pumps may be of reciprocating type or rotary type. The rotary pumps are generally of centrifugal type and they're used when a large quantity of feed water is to be supplied to the boiler. The reciprocating pumps are used for boilers of small capacity.
14	**Enlist the ways to preheat the feed water given to the boiler..** BTL1 Feed water to the boiler can be preheated in two ways. 1. Using exhaust steam from an condensing unit of fresh steam direct from the boiler. 2. Taking heat from flue gases.
15	**State the purpose of an Economiser and give its types.** BTL1 An economiser is a feed water heater that utilises the heat of flue gases. It is placed between boiler and chimney. A saving of about 10% (5-6°(rise in temperature of feed water) is achieved by the use of the economiser. There are two types of economisers - Independent type and Integral type. Independent economisers are installed apart from the boiler setting whereas integral economisers are installed with in the boiler setting.

	PART * B
1	**Summarize the classification of boilers.** BTL 2 **Answer: Page – 2.1 Dr.G.K.Vijayaragavan** 1. According to contents in the tube, boilers are classified as : (a) Fire tube boilers (b) Water tube boilers • In fire tube boilers, the flue gases pass through the tubes while water surrounds the tubes. Cochran, Lancashire, Cornish, locomotive boilers are examples of fire tube boilers. • In water tube boilers, water flows through the tubes while products of combustion (Fluegases) pass over external surface of tubes. Babcock and wilcox, Stirling boilers are examples of water tube boilers. 2. According to use, boilers are classified as : (a) Stationary boilers (b) Portable boilers (c) Mobile boilers • Stationary boilers are generally of large capacity and are used for power generation. Portable boilers can be readily dismantled and transported from one place to another. • Mobile boilers are boilers fitted on vehicles that move from one place to another place. Marine and locomotive boilers are examples of mobile boilers. 3. According to shape and position of tubes, boilers are classified as : (a) Straight tube boilers (b) Bent tube boilers (c) Horizontal tube boilers (d) Vertical tube boilers (e) Inclined tube boilers 4. According to furnace position and method of firing, boilers are classified as : (a) External combustion boilers or externally fired boilers (b) Internal combustion boilers or internally fired boilers • In externally fired boilers, furnace is arranged underneath a brick work setting water tube boilers are always externally fired. • In internally fired boilers, furnace is provided inside the boilers shell and is completely surrounded by water cooled surfaces. 5. Depending upon number of tubes, boilers may be classified as:

(a) Single tube boilers

(b) Multi tubular boilers

- In single tube boilers, there is only one water or fire tube. Simple vertical and cornish boilers are single tube boilers.
- In multi tubular boilers,there are 2 or more fire tubes or water tubes.Lancashire,Locomotive, cochran, Babcock & Wilcox boilers are multitubular boilers.

6. According to the source of heat supply

(a) Combustion of solid, liquid and gaseousfuels.

(b) Electrical or Nuclear energy

(c) Hot waste gases which are by-products of other chemical processes.

7. According to method of circulation of water,boilers may be classified as:

(a) Natural circulation boilers

(b) Forced circulation boilers

- In Natural circulation steam boilers, circulation of water is by natural convection currents produced by application of heat. In most of the boilers,there is a natural circulation of water. Lancashire ,locomotive, Babcock & Wilcox boilers belong to this category.
- In Forced circulation boilers, pumps are used to increase the circulation. Forced circulation is used in high pressure boilers as-LaMont,Benson&Velox boilers etc.

8. According to axis of shell, boilers are classified as :

(a) Vertical boilers

(b) Horizontal boilers

- In Vertical boilers,axis of shell is vertical .Simple vertical boiler, Cochran boilers are vertical boilers.
- InHorizontal boilers, axis of shell is horizontal. Lancashire, Locomotive, Babcock & Wilcox boilers are Horizontal boilers.

9. According to the pressure of steam generated, boilers may be classified as:

(a) Low Pressure boilers

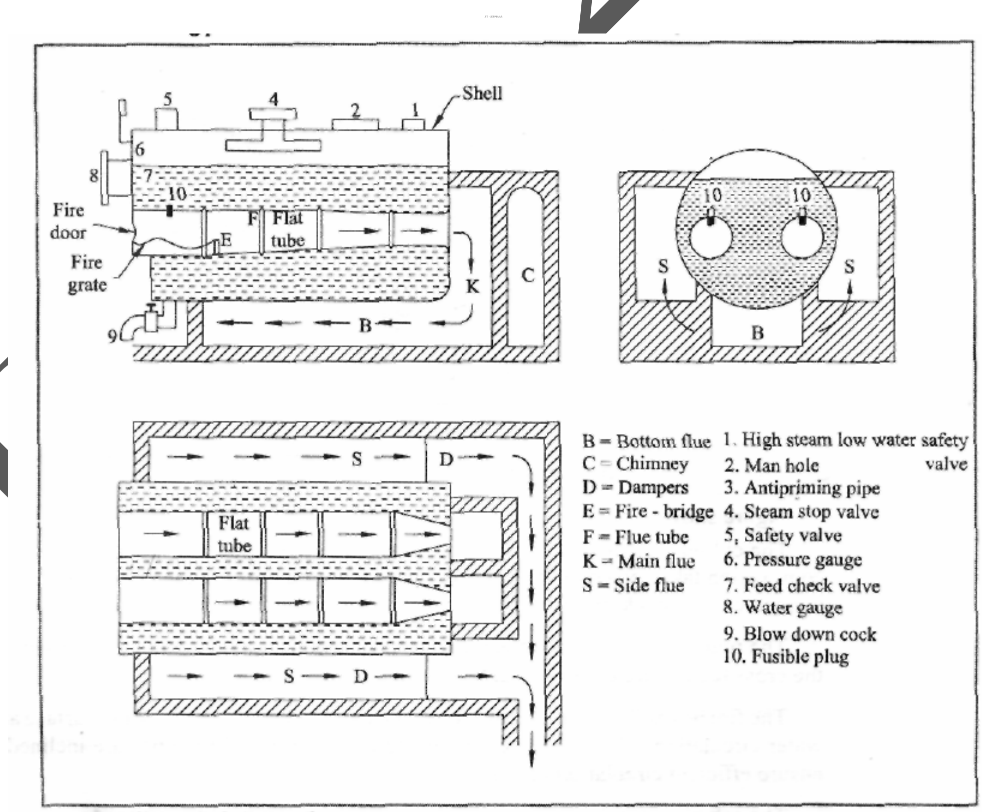
(b) Medium Pressure boilers

(c) High Pressure boilers

- A boiler which generates steam at a pressure upto 30 bar is called low pressure boiler. Cornish, Cochran, locomotive boilers etc. are low pressure boilers.
- A boiler which generates steam at a pressure higher than 80 bar is called - High pressure boiler. Lamont, Velox boilers etc. are high pressure boilers.

10. According to the design of gas passage, boilers may be classified as :

(a) Single pass boilers

	(b) Multi pass boilers 11. Depending upon the type of draught provided, boilers are classified as: (a) Natural draught boilers (b) Forced draught boilers • In Natural draught boilers, the draught is produced by natural circulation of air or gas. • In Forced draught boilers, draught is produced by Mechanical means -Fans etc. 12. On the basis of material used for shell, boilers are classified as: (a) Cast Iron boilers (b) Steel boilers (c) Copper and Stainless steel boilers.
2	**Paraphise the working principle of Lanchashire boiler with neat sketch.** BTL2 **Answer: Page – 2.6 Dr.G.K.Vijayaragavan** **Diagram :** (3M) 

Construction Details : (6M)

- Feed water is supplied to the boiler under pressure and feed checkvalve stops feed water coming back.
- Fire bridge is used for deflecting the gases of combustion (Flue gases) upwards.
- Flue tubes are the channels or passages metallic tubes through which the flue gases flow. Water surrounds these tubes in the shell.
- Flues are the passages of flue gases. (Generally made of bricks).
- Anti priming device is meant for separating moisture from dry steam and allows dry steam only to pass through the stop valve.
- Fusible plug is for safety of boiler- to protect the boiler from excessive heat when water level falls too low.
- Dampers are meant for controlling the flow of flue gases. Generally, they are iron doors which slide up and down by means of chains, pulleys etc.
- The flue gases pass front to back through 2 internal flue tubes, back to front through one bottom flue, and front to back through 2 side flues.While flowing through flue tubes,bottom and side flues, the flue gases give up heat to the shell.
- Finally, the flue gases meet again in main flue, pass through the damper from where they are discharged to atmosphere through the chimney.
- The flues are built of ordinary brick work. The damper controls the flow of flue gases by restricting the passage of flow; and this controls the rate of steam generation.

<u>Advantages</u>: (2M)

1. It can burn coal of inferior quality also.
2. It is reliable,simple in design,easy to operate and so operating and maintenance costs are less.
3. Easy to clean and inspect
4. It can meet sudden heavy demands of load without appreciable pressure drop.

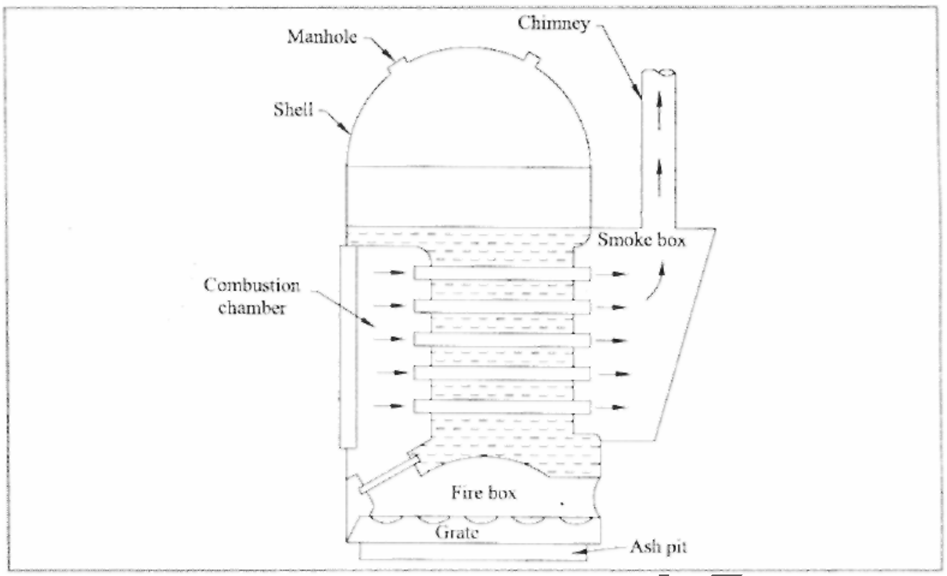
<u>Disadvantages :</u>

1. Maximum working pressure is limited to 20 bar
2. More floor area is required due to brick work settings
3. Cracks in setting due to large temperature difference between inside and outside may cause leakages.
4. If overload is continued for some time, boiler may stop working. (2M)

3	**Explain the working of Cochran boiler with neat sketch.** BTL2 **Answer: Page – 2.5 Dr.G.K.Vijayaragavan**

COCHRAN OR VERTICAL MULTITUBULAR BOILER

It is a vertical, multitubular, internally fired, natural circulation boiler. It is an improvement over simple vertical boiler and provides greater heating surface. The steam pressure is about 6.5 bar and steaming capacity is 3500 kgs/ hr.



(5M)

- It consists of a vertical cylindrical shell with hemispherical dome. The fire box is also of hemispherical form. Adjacent to the fire box or furnace, a combustion chamber is provided.
- Close to the combustion chamber, number of horizontal smoke tubes of equal length are provided.
- The tubes are arranged with space in between them and the shell to help convection currents.
- A smoke box is provided on the other side of the smoke tubes.The stack or chimney is provided on the top of the smoke box.
- The furnace is surrounded by water on all sides except at opening of fire door and the combustion chamber. The smoke tubes are completely surrounded by water. (5M)

Working: The hot flue gases from the combustion of fuel on the grate rise up and come into the combustion chamber. The hemispherical form of the furnace gives maximum volume of space for given mass of material and also permits maximum absorption of radiant heat.

The flue gases from combustion chamber pass through the smoke tubes and smoke box and finally are discharged through the chimney. (3M)

4 **Write a short note on Water tube boilers with one example.**

Answer: Page – 2.10 Dr.G.K.Vijayaragavan

WATER TUBE BOILERS

In these boilers, water passes inside the tubes while hot gases surround the tubes. These are extensively used because they are built for high pressures and large evaporative capacities. They are safe, quick steaming, flexible in construction and operation.

They consists of small drums which form small part of the total heating surface and greater part of heating surface is provided by number of water tubes fitted outside the drum in the furnace.

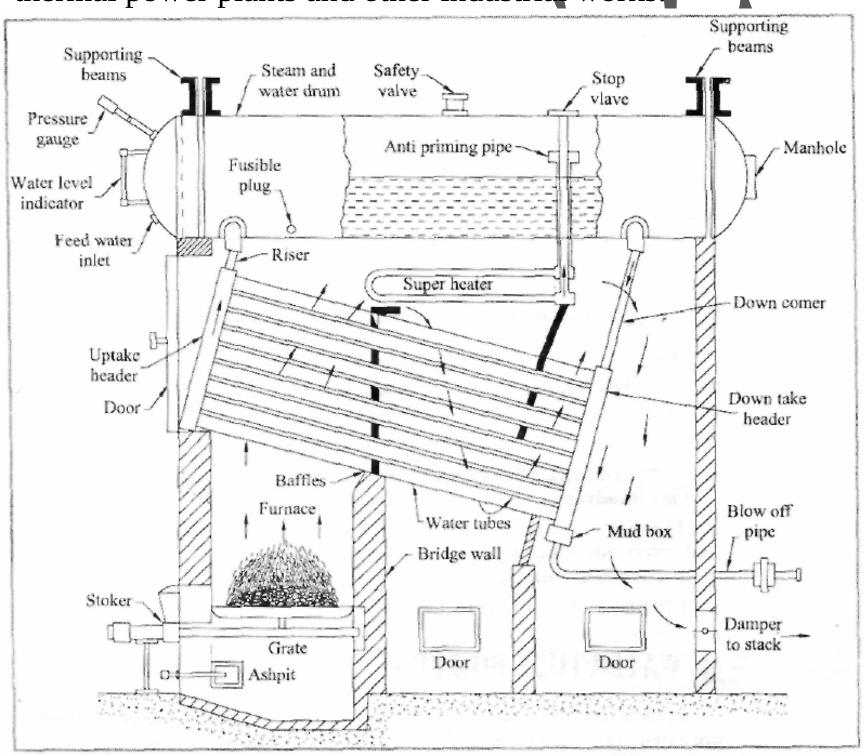
Water tube boilers may be mainly classified into 2 groups:

1. Straight horizontal tube boilers
2. Bent tube boilers (3M)

Babcock & Wilcox boiler is an example of straight tube boilers and Stirling boiler is an example of bent tube boilers.

BABCOCK & WILCOX BOILER

This is best known type of water tube boilers. The maximum working pressure is 40 bar and maximum steaming capacity is 40,000 kgs/hr. It is suitable for small size thermal power plants and other industrial works.



(5M)

- The boiler has 3 main parts. Steam and water drum, water tubes and furnace.

The drum is connected to headers by short tubes known as - Riser tubes. The headers are common collecting chambers. A series of inclined tubes connect the uptake header to

	downtake header. There are many rows of tubes. The inclination of the tubes promote water circulation. The headers are curved and the tubes are expanded into headers which are provided with zig-zag holes.This arrangement allows surfaces of all tubes to be exposed to hot gases. • The heating surface is the outer surface of the tubes and half of the cylindrical surface of the drum. • A mud box is attached to the bottom of the down take header where foreign matter in the water gets collected and can be blown off from time to time. • Below the uptake header,the furnace of the boiler is arranged. A damper is provided at the inlet of the chimney to regulate the draught. The bridge wall deflector deflects the flue gases upwards. • Baffles are provided across the water tubes to act as deflectors for the flue gases and to provide them with gas passes. Here, 2 baffles are provided which provide 3 passes of the flue gases. • Superheater tubes are provided for producing superheated steam.The superheater consists of 2 boxes:superheated steam box and saturated steam box. Steam generated above water level in the drum flows to a dry pipe and into superheated steam box. • It then passes into saturated steam box. The steam during its passage through the tubes gets further heated and becomes superheated.Now,the steam is taken through the outlet pipe. • The soot (particles carried by flue gases from combustion) from the flue gases that accumulate on the surface of the water tubes is removed at frequent intervals either by mechanical scrapers or blown off by high pressure steam blowers. This is necessary to keep the heat transfer effective. (3M) Working : The feed water enters the drum, from drum to uptake header, into tubes and from tubes to downtake header and again to drum. Water circulates in this fashion and during its travel, takes up heat and gets evaporated. The hot flue gases are deflected upwards and pass over the tubes between the baffles.Baffles are obstructions in the passage of flue gases provided to transfer heat to all tubes. The circulation of water in the boiler is natural set up by convective currents. The steam formed rises to uptake header and then through the riser enters the boiler drum. The steam escapes through the water to the upper half of the drum. Finally, the flue gases go to chimney through the dampers. (2M)
5	**Write a short note on Boiler Mountings and accessories.** BTL2 **Answer: Page – 2.9 Dr.G.K.Vijayaragavan** Boiler mountings are different fittings and appliances generally mounted over the boiler shell directly and they form an integral part of the boiler. They are necessary for the safety of the boiler and to have control on the working of the boiler.

	Boiler mountings can be divided into two types : (a) Safety fittings. (b) Control fittings. Safety fittings are meant for the safety of boiler. They are : (i) Safety valve: (ii) Water level indicator, (iii) Fusible plug. (4M) Control fittings are meant for having control on the working of the boiler. They are : (i) Pressure gauge. (ii) Feed check valve, (iii) Junction or stopvalve, (iv) Blow off cock box. (v) Man hole and mud. (vi) Anti-priming pipe. (4M) Boiler accessories are fittings or devices attached to a boiler. They increase the efficiency and help in smooth working of the boiler plant. They are not necessary for the operation of a boiler but incorporated to increase the efficiency of the plant and its proper working. They are not integral with the boiler and are installed either outside or inside the boiler. The important boiler accessories are: (a) Feed water pump. (b) Superheater. (c) Economiser. (d) Air preheater. (e) Injector. (f) Steam drier or separator. (g) Steam trap. (h) Pressure reducing valves. (5M)
	PART * C
1	**Explain the working of any two safety valves.** BTL 2 **Answer: Page – 2.32 Dr.G.K.Vijayaragavan**

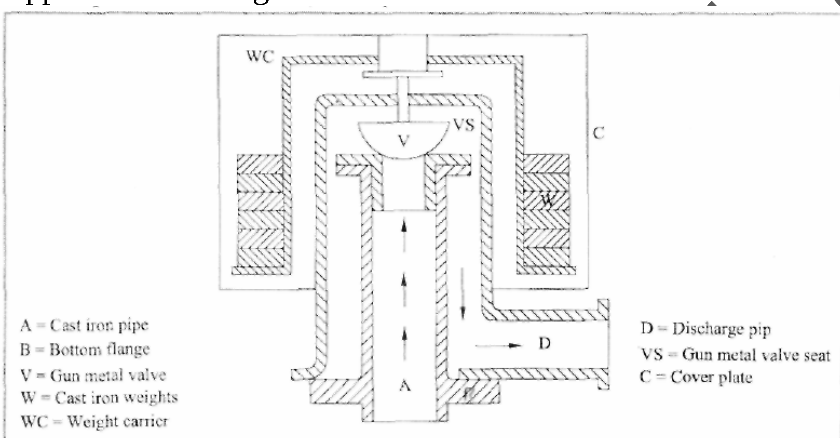
There are four types of safety valves :

- Dead weight safety valve.
- Lever safety valve.
- Spring loaded safety valve.
- High steam and low water safety valve. (3M)

The principle of operation of a safety valve depends on the fact that a valve is pressed against as through some agency-also called as method of loading the valve such as spring,screw or external weight. When the force of steam generated in the boiler exceeds the external force imposed by the agency, the valve gets lifted off from its seat and allows steam to escape out until the pressure is restored again.

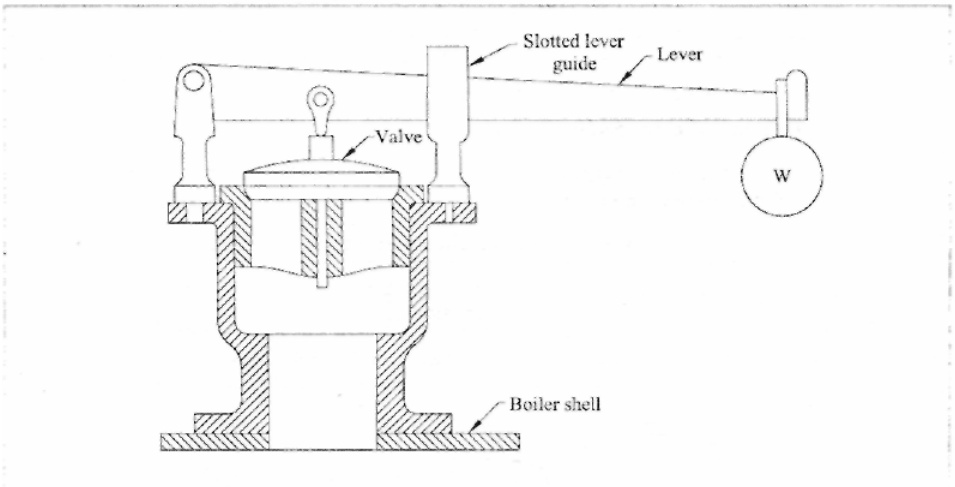
1. Dead Weight Safety Valve:

It is the simplest type of safety valves in which the valve is loaded by direct application of weights above the valve.

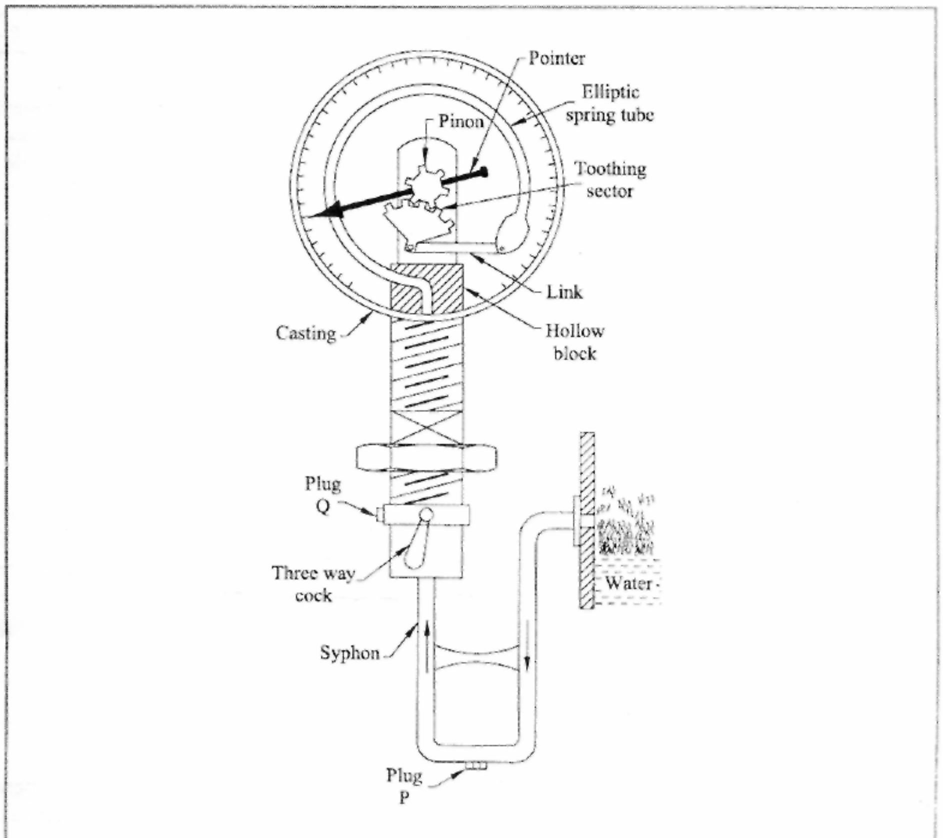


(4M)

- It consists of a large vertical cast iron pipe through which steam pressure acts. The bottom flange of the pipe is bolted to the mounting block on the boiler shell communicating to steam space.
- On the top of the pipe,a valves eat is fixed and the valve rests on it. A weight carrier is suspended from the top of the valve. The dead weight consisting of cast iron rings are placed the weight carrier.
- The total load on the valve includes the weights of carrier,dead weights.,of cover and weight of the valve itself.
- During normal operation, the upward force exerted by the steam is balanced by the down ward force equivalent to load on the valve.
- When steam pressure exceeds the total weight, the valve lifts in the guides and the excess steam escapes to the enclosed discharge casing to the atmosphere. The blowing off of the valves is prevented by stop screw fitted on the discharge casing.
- It is the most reliable safety valve, simple in design and gives satisfactory performance during operation. It can't be easily tempered.
- It is unsuitable for use on boilers where extensive vibrations and movements

	are encountered as in locomotive and marine boilers. • This valve has very limited range of application. It is mainly used for low pressure, low capacity stationary boilers like - Cornish and Lancashire boilers. **2.** Lever Safety Valve: The principle of operation of this type of safety valve depends upon the second system of levers.  (3M) • The flange of the cast iron body is bolted to the mounting of the boiler to communicate with steam in the boiler. • The valve rests on the valves eat which is screwed in the body.The valve is held by a mild steel or wrought iron lever fulcrumed at one end and loaded at the other end by an external weight w. • The thrust is applied to the valve through a strut against the steam pressure.The guide prevents the lateral movement to fit the valve and also prevents its blowing off. The weight can be moved on the lever and its position depends upon the boiler pressure. • To avoid tempering by unauthorised persons, the weight is firmly secured to the lever by a pin and locked.As the weight is placed on a longer arm,a smaller weight gives a large thrust. • When the pressure of the steam in the boiler is equal to the working pressure, the valve remains at its position firmly.When the pressure of steam becomes higher,the valve is lifted with the lever and the weight. • Consequently, the excess steam escapes through the passages between the valve and seat and hence the pressure of steam decreases to normal working pressure. (5M)
2	**Explain the working of Bourdon tube pressure gauge.** BTL2 **Answer: Page – 2.29 Dr.G.K.Vijayaragavan** • The flange of the cast iron body is bolted to the mounting of the boiler to communicate with steam in the boiler. The valve rests on the valves eat which

		is screwed in the body. • The valve is held by a mild steel or wrought iron lever fulcrumed at one end and loaded at the other end by an external weight *w*. The thrust is applied to the valve through a strut against the steam pressure. • The guide prevents the lateral movement of the valve and also prevents its blowing off. • The weight can be moved on the lever and its position depends upon the boiler pressure. To avoid tempering by unauthorised persons, the weight is firmly secured to the lever by a pin and locked. • As the weight is placed on a longer arm,a smaller weight gives a large thrust. • When the pressure of the steam in the boiler is equal to the working pressure, the valve remains at its position firmly. • When the pressure of steam becomes higher,the valve is lifted with the lever and the weight. Consequently, the excess steam escapes through the passages between the valve and seat and hence the pressure of steam decreases to normal working pressure. • It consists of an elliptical spring tube called-Bourdon tube,one end of which is plugged and the other end communicates with the steam space through a syphon. • The U-tune syphon contains water which fills the Bourdon tube.The steam pressure acting though the water causes the tube to become circular. As the tube is fixed at one end; the other end moves outwards. • The movement of the free end is proportional to the difference between internal and external pressure on the tube and this motion is magnified by a mechanism consisting of a connecting link and toothed sector. • The sector meshes with a pinion mounted on the spindle carries the pointer.So,any slight movement of the Bourdon tube is magnified considerably and the pointer gives a maximum deflection that can be read easily. • As the outside pressure on the tube is atmospheric; the movement of free end is a measure of the boiler pressure above atmospheric- Gauge pressure. (9M)



(6M)

3 **Enumerate the performance and heat loss occurring in a boiler.** BTL 5

Answer: Page – 2.63 Dr.G.K.Vijayaragavan

The difference between heat liberated in the furnace to heat utilized by the tubes in generating steam is known as-Heat lost in the boiler. This heat is lost in different ways:

(a) Heat lost in dry flue gases.

(b) Heat lost due to moisture present in the fuel.

(c) Heat lost due to formation of steam by combustion of hydrogen.

(d) Heat lost due to incomplete combustion.

(e) Heat lost due to unburnt fuel.

(f) Heat lost due to radiation.

(a) Heat Lost in Dry Flue Gases:
This is the largest loss.

$$\text{Heat lost in dry flue gases/kg of fuel} = m_g\, Cp_g\, (t_g - t_b)$$

Where m_g= Mass of dry flue gases -Kgs
Cp_g= Specific heat of dry flue gases - kJ/kg K

t_g= Temperature of flue gases leaving the chimney
t_b = Temperature of boiler room. (3M)

(b) Heat Lost Due to Moisture Present in the Fuel:
It is assumed that moisture is converted into superheated steam at atmospheric pressure.

Heat lost/kg of fuel = $m_m[h_g + Cp\,(t_g - t_s) - h_b]$

$= m_m[2676 + Cp(t_g-100)-h_b]$

[From steam tables, corresponding to 1.013 bar,
h_g = Enthalpy of dry saturated steam
= 2676 kJ/kg

t = Saturation temperature].
m_m = Mass of moisture/kg of fuel.
h_b = Enthalpy of water at boiler room temperature.

Cp = Mean specific heat of superheated steam (3M)

(c) Heat Lost Due to Formation of Steam by Combustion of Hydrogen :
We have $2\,H_2 + 0_2 \rightarrow 2\,H_2O$.
(1x2)+(16x2) =2(1x2+16)
4 + 32 =36
1+8 =9.

One 1 kg of hydrogen unites with 8 kgs of oxygen to produce 9 kgs of steam. Let H_2= Mass of hydrogen present in the fuel/kg of fuel.
Mass of steam formed = 9 H_2
Heat lost to steam/kg of fuel = $9\,H_2[2676 + Cp\,(t_g - 100) - h_b]$
(3M)

(d) Heat Lost Due to Incomplete Combustion:
This loss occurs due to insufficient air supply. When \kg of carbon burns to Co-carbon monoxide, it releases about 11,000 kJ and when burns to $C0_2$-carbon dioxide, releases about 32,500 kJ So, if carbon is burnt to carbon monoxide only then the difference 21,500 kJ of heat is going to be wasted. So, presence of carbon monoxide in flue gases is a loss due to incomplete combustion.

Heat lost/kg of fuel = m1 x C.V.

Where m_1 = Mass of co-carbon monoxide in flue gases/kg of fuel
C.V = Calorific value of CO. (3M)

(e) Heat Lost Due to UnburntFuel:
When solid fuels are used, some of the fuel falls through the grate bars and is lost with ash.

	Heat lost/kg of fuel = m_2 x C.V Where m_2 = Mass of fuel escaped/kg offuel C.V = Calorific value of fuel **(f)** Heat Lost Due to Radiation: There is no direct method for finding out the heat lost due to radiation. This is obtained by difference from heat supplied by fuel to total of above heat losses. (3M)

UNIT III STEAM TURBINES

Types, Impulse and reaction principles, Velocity diagrams, Work done and efficiency – optimal operating conditions. Multi-staging, compounding and governing

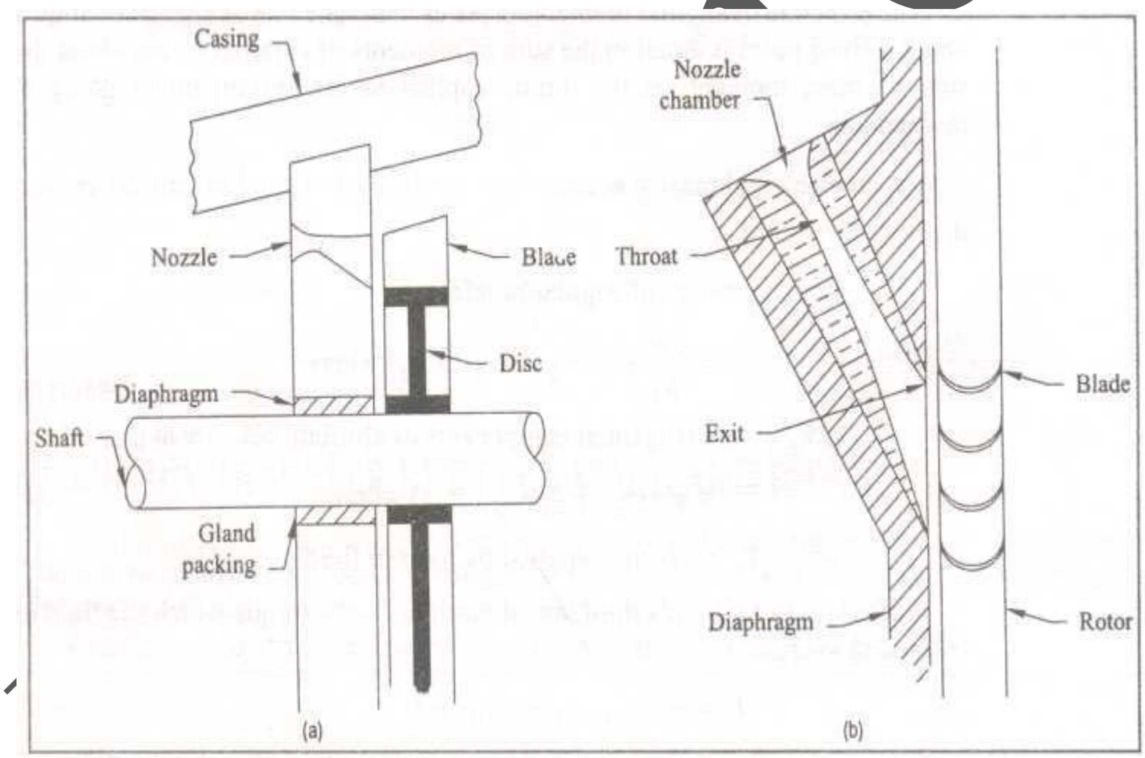
PART * A

Q.No.	Questions
1	**State the principle of an impulse turbine.** BTL1 In impulse turbines, the high velocity jet of steam which is obtained from the nozzle impinges on blades fixed on a rotor. The blade changes the direction of the steam flow without changing its pressure. It causes the change in momentum and the force developed drives the turbine rotor.
2	**Define Steam turbine.** BTL1 A steam turbine is a turbo-machine and a prime mover in which potential energy of steam is transformed into kinetic energy and this kinetic energy is then transformed into mechanical energy of rotation of shaft of turbine**.**
3	**State the advantages of steam turbines over steam nozzles.** BTL1 A steam turbine offers the following advantages over a conventional steam engine. 1. With turbines, higher speeds can be developed and greater speed range is possible. 2. For same power, turbine units are smaller. 3. As turbine is a rotary unit; perfect balancing is possible and so vibrations are less. 4. Due to greater range of expansion, steam consumption is less. So, they are more efficient arid economical.
4	**Write the types of Steam turbines.** BTL2 Steam turbines may be classified in many ways. Considering the action of steam which is most important factor, steam turbines are mainly classified as: • Impulse turbines. • Impulse reaction turbines
5	**Recognize the effect of blade friction.** BTL1 In an impulse turbine, the relative velocity remains same as steam passes over the

	blades if friction is neglected. In actual practice, the flow of steam the blades is resisted by friction. The effect of this friction is to reduce the relative velocity of steam while passing over the blades - Generally, there is a loss of 10-15% in relative velocity. Owing to friction in blades. V_{r2} is less than V_{r1} .
6	**Explain the need of compounding in steam turbines.** BTL3 **(Or)** **Explain the purpose of compounding in steam turbines.** In simple impulse turbine, the expansion of steam from the boiler pressure to condenser pressure takes place in a single stage turbine. The velocity of steam at the exit of turbine is very high. Hence, there is a considerable loss of kinetic energy (i.e. about 10to 12%). Also the speed of the rotor is very high (i.e. up to 30000rpm). There are several methods of reducing this speed to lower value. Compounding is a method of absorbing the jet velocity in stages when the steam flows over moving blades.
7	**List the different methods of compounding.** BTL1 1. Velocity compounding 2. Pressure compounding 3.Pressure-velocity compounding
8	**What is meant by carry over loss?** BTL2 The velocity of steam at exit is sufficiently high thereby resulting in a kinetic energy loss called "Carry over loss" or "Leading velocity loss".
9	**Interpret the need for compounding in steam turbines?** BTL2 A compounded steam turbine has multiple stages i.e. it has more than one set of nozzles and rotors, in series, keyed to the shaft or fixed to the casing, so that either the steam pressure or the jet velocity is absorbed by the turbine in number of stages.
10	**Define Degree of reaction.** BTL2 The energy transfer is by change of dynamic pressure and by change of dynamic pressure in rotor passage. The ratio of energy transfer by means of change of static pressure in the rotor to total energy static pressure in the rotor to total energy transfer in the rotor is called the degree of reaction.
	PART - B
1	**List the classification of Steam turbines.** BTL 2 **Answer : Page – 3.1 Dr.G.K.Vijayaragavan** **1.** According to Direction of Steam Flow : (a) Axial flow turbine. (b) Radial flow turbine. (c) Tangential flow turbine. **2.** According to Steam Conditions at Inlet to Turbine : (a) Low pressure turbines.

	(b) Medium pressure turbines. (c)High pressure turbines 3.According to Condition of Exhaust Steam: (a) Condensing turbine. (b) Non condensing turbine 4.According to Number of Stages : (a) Single stage turbine. (b) Multi stage turbine. 5.According to Number of Cylinders : (a) Single cylinder turbine. (b) Multi cylinder turbine 6.According to Way of Governing : (a) Turbines with throttle governing. (b) Turbines with nozzle governing. (c) Turbine with bypass governing. 7.According to General Direction of Steam Flow : (a) Single flow turbine. (b) Double flow turbine. (c) Reversed flow turbine. 8. On the Basis of Number of Shafts : (a) Tandem compound turbines (b) Cross compound turbines 9. On the Basis of Rotational Speed : • Constant speed turbines. • Variable speed turbines.
2	**Explain the operation of a simple impulse turbine with a neat sketch.** BTL2 **Answer : Page – 3.3 Dr.G.K.Vijayaragavan** • The turbines in which complete process of expansion of steam takes place in stationary nozzles and the kinetic energy is converted into mechanical work on the turbine blades are known as - Impulse turbines. • In impulse turbines, the entire pressure drop takes place in nozzles only. The pressure drops from steam chest pressure to condenser or exhaust pressure. The pressure in the blade passages remains approximately constant and is equal to condenser pressure.

- An impulse turbine for its operation, depends wholly on the impulsive force of high velocity steam jets, which are obtained by expansion of steam in nozzles. The action of steam jet impinging on the blades is said to be impulse and the rotation of rotor is due to impulsive forces of steam jets.
- Generally, converging - diverging nozzles are used. Due to relatively large expansion ratio, steam leaves the nozzles at a very high velocity (Even supersonic).
- The steam at high velocity impinges over blades, both pressure and enthalpy remain constant, work transfer takes place, velocity reduces gradually and steam comes out with appreciable velocity . The nozzle angle is inclined at a fixed angle to tangent of rotor wheel.
- Mostly, impulse turbines are axial flow turbines and they have zero degree of reaction (discussed later). The entire pressure drop takes place in nozzles resulting in enthalpy drop. The energy transfer is derived from a change of absolute velocity. (6M)

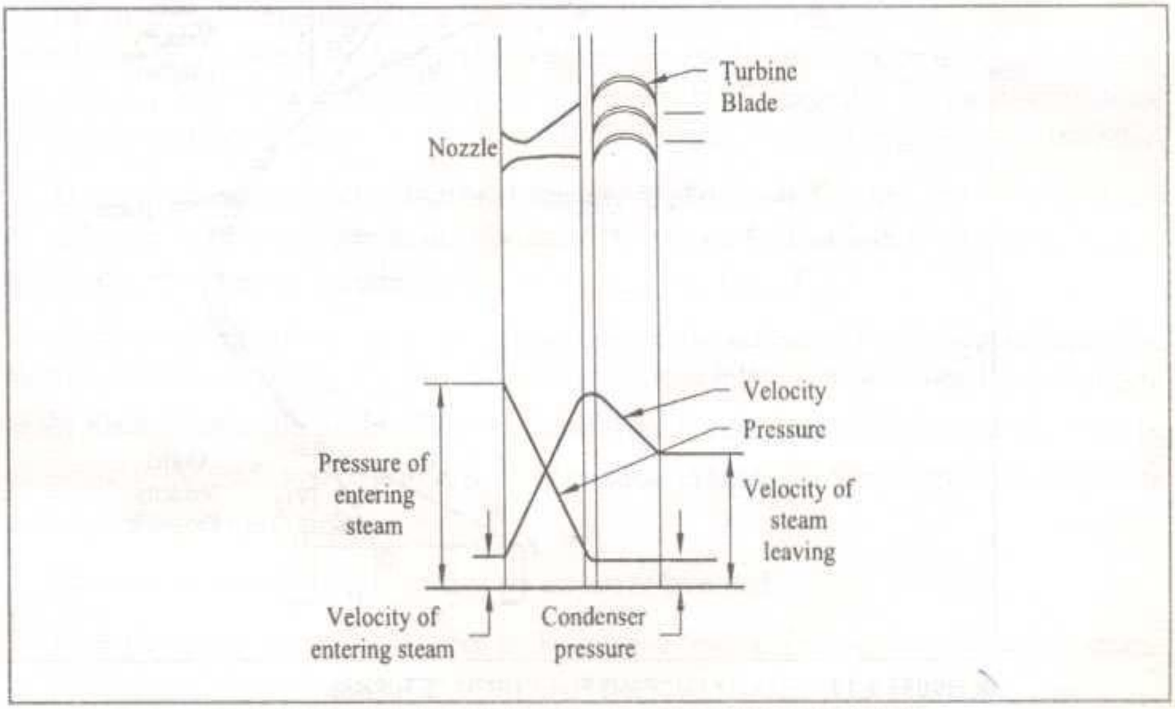


- Impulse turbines are generally employed where relatively small amounts of power are required and where rotor diameter is fairly small.
  - Mostly, impulse turbines are axial flow turbines and they have zero degree of reaction (discussed later). The entire pressure drop takes place in nozzles resulting in enthalpy drop. The energy transfer is derived from a change of absolute velocity.
  - Impulse turbines are generally employed where relatively small amounts of power are required and where rotor diameter is fairly small. (7M)

3.

Write a short note on variation of pressure and velocity in a Impulse turbine. BTL2

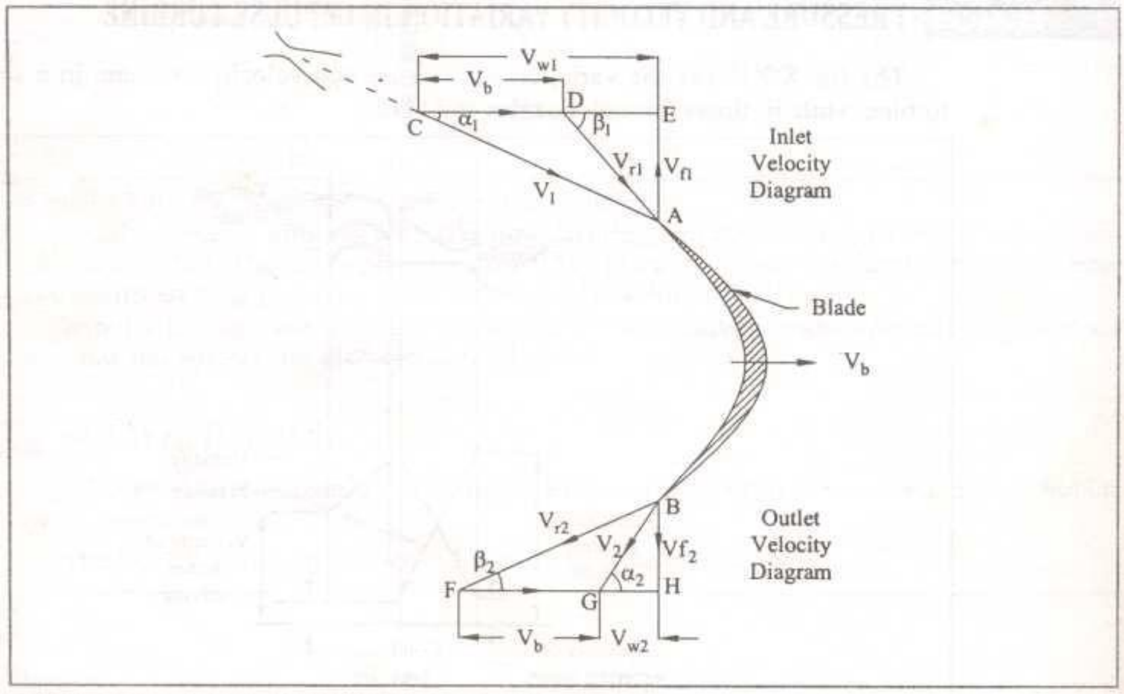
Answer : Page – 3.8 Dr.G.K.Vijayaragavan



- The entire pressure drop takes place in nozzles and the pressure remains constant while passing through the blades.
- As enthalpy drop takes place in nozzles the heat energy is converted into kinetic energy and so velocity of steam increases in the nozzle and is reduced gradually while flowing through the blades.
- From the velocity graph; it is clear that the velocity of steam leaving the blades consists of a large portion of velocity of steam leaving the nozzle. This results in loss of energy and this loss of energy due to higher exit velocity is called - carry over loss or leaving energy loss. (5M)

VELOCITY DIAGRAM FOR AN IMPULSE TURBINE

- Since force is due to change of momentum mainly caused by change in the direction of flow of steam, it is essential to draw velocity diagram that shows how velocity of steam varies during its passage through the blades.
- Velocity is a vector quantity as it has both magnitude and direction. So, we can represent velocity by a straight line and the length of the straight line indicates its magnitude and its direction is indicated by the direction of the line with reference to some fixed direction.



(6M)

The steam jet after leaving the nozzle, impinges on one end the blade, glides over the inside surface of the blade and finally leaves from the other edge.

Let V_b = Linear velocity of moving blade.

V_1 = Absolute velocity of steam at inlet to moving blade i.e., exit velocity of nozzle.

V_{w1} = Tangential component of entering steam. V_{w1} Also known as velocity of whirl at entrance.

V_{r1} = Relative velocity of steam with respect to tip of blade at inlet. It is the vectorial difference between V_b and V_1

$$V_{r1} = V_1 - V_b$$

V_{f1}=Velocity of flow = Axial velocity at entrance to moving blades. It is the vertical component of V_1

α_1 = Angle of nozzle = Angle which the entering steam makes with the moving blade at entrance - with the tangent of the wheel at entrance.

β_1 = Angle which the relative velocity makes with the tangent of the wheel – direction of motion of blade. It is also known as blade angle at inlet.

The above notations stand for inlet triangle.

V_2, V_{w2}, V_{f2}, V_{r2}, α_2, β_2 are the corresponding values at the exit of the moving blades. They stand for outlet triangle.

- The steam jet with absolute velocity V_1 impinges on the blade at an angle of α_1 to the tangent of the blade. The absolute velocity V_2 can be considered as having two components. The tangential component called whirl component V_{w1}

= V_1 . cos$\square_1$ is parallel to direction of rotation of blades and axial or flow component V_{f1} = V_1 . sin $\square_1$ is perpendicular to the direction of rotation of blades.

- The tangential component of the steam jet does work on the blade because it is in the same direction as the motion of the blade. The axial component doesn't work on the blades because it is perpendicular to the direction of motion of blade. It is responsible for the flow of steam through the turbine. Change of velocity in this component causes an axial thrust on the rotor.
- As the blade moves with a tangential velocity in peripheral direction, the entering steam jet will have relative velocity to the blades. If there is no friction loss at the blade, relative velocity at inlet is equal to relative velocity at outlet i.e., $Vr_1 = Vr_2$.
- As the steam glides over the blades without shock, the surface of the blade at inlet must be parallel to relative velocity Vr_1. So, the moving blade at inlet must be inclined to the tangent of the blade at an angle $\square_1$. In other words, to avoid shock at entrance, vector Vr_1 must be tangential to the blade tip at entry i.e, $\square_1$ must be equal to angle of blade at entrance. The blade is designed on this principle. (2M)

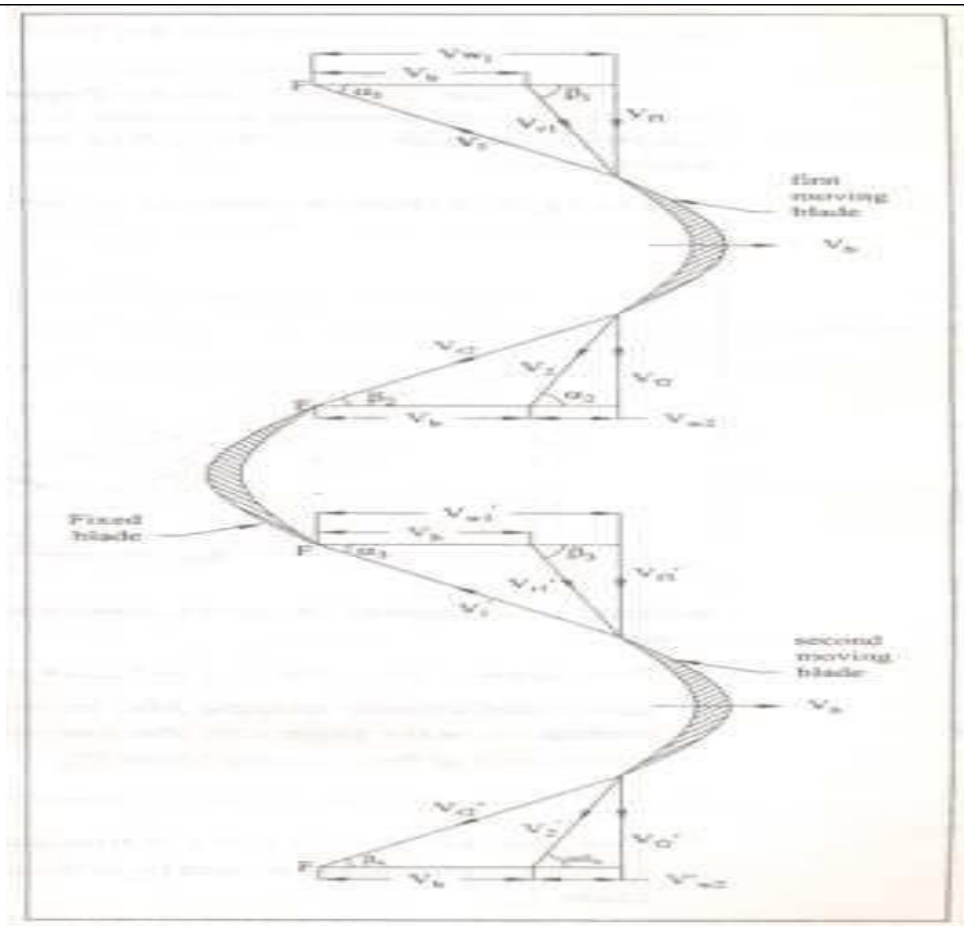
PART * C

1

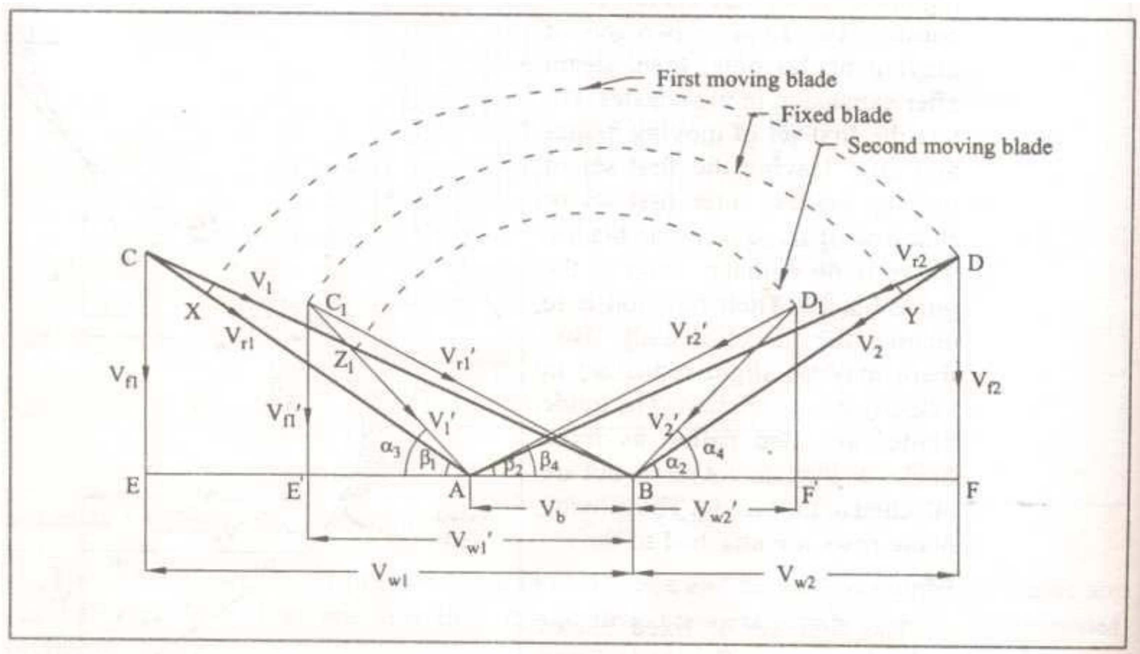
Draw and explain the combined velocity diagram for velocity compounded impulse turbine BTL2

Answer : Page – 3.12 Dr.G.K.Vijayaragavan

- In a single stage turbine, steam after leaving the nozzle impinges on one end of the blades, glides over the inner surface of the blades and leaves the blades at the other end.
- A velocity compounded impulse turbine consists of one set of nozzles, two or more sets of moving blades and guide blades. If we consider two rows or two sets of moving blades only, then, steam after expansion in the nozzles, enters the first set of moving blades and after leaving the first set of moving blades, enter first set or first row of fixed or guide blades.
- There is no enthalpy drop in the guide blades. Their function is to change the direction only. But, there may be slight reduction in velocity due to friction. The guide blades are also called as fixed blades as they do not rotate but arc attached to the casing.
- The moving blade rows are attached to the rotor.



- The first set of fixed blades make the steam to flow at designed angle and direct it to impinge on second row of moving blades After leaving the second row of moving blades, steam enters the condenser. Such a turbine in which there arc two sets of moving blades is called - two stage velocity compounded impulse turbine.
- The separate velocity diagrams for the first moving, first fixed and second moving blade rows for a two stage velocity compounded impulse turbine.
- The blade velocity is constant for both the stages as there are mounted on same shaft. The absolute velocity at exit from the first moving blade is the entry velocity to the fixed blade. Similarly, the exit velocity from the fixed blade is the entry velocity to the second moving blade.
- To draw combined velocity diagrams for the first and second row of moving blades individually with a similar procedure as given for a single stage impulse turbine. We can combine these individual velocity diagrams to obtain final combined velocity diagram for the whole turbine.



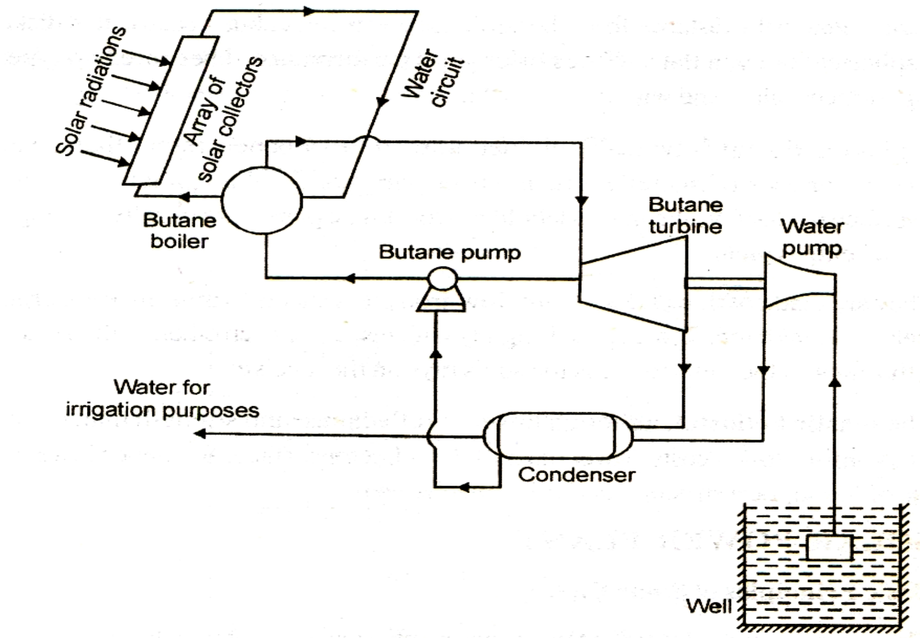
Construction :

1. First, draw a horizontal line and mark *AB* equal to blade velocity to some suitable scale.
2. Draw inlet velocity triangle *ABC* in similar lines as mentioned for a single stage impulse turbine, $\square_1$ is the angle with absolute velocity V_1 and $\square_1$ is the angle with relative velocity at entrance to first moving blade V_{r1}
3. Considering friction, cut off *CX* equal to friction in the first moving blade. *AX* gives V_{r2}.
1. Now, complete outlet velocity triangle *ABD.* $\square_2$ is the angle with absolute exit velocity of first moving blade V_2 and $\square_2$ is the angle with relative velocity at exit of first moving blade V_{r2}.
2. Cut off DY equal to effect of friction in the fixed blade. *BY* is the exit velocity of steam from fixed blade. It is equal to velocity of steam entering the second moving blade V_1'.
3. Now, draw inlet velocity diagram *ABC* for second moving blade on same base *AB.* $\square_3$ is the angle with V_1' and $\square_3$ is the angle with relative velocity at entrance of second moving blade V_{r1}'
4. Cut off *C' Z* equal to effect of friction in the second moving blade. *AZ is* the relative velocity at exit of second making blade V_{r2}'.
5. Now, complete the outlet velocity triangle *ABD'* for the second moving blade. $\square_4$ is the angle with V_2' and $\square_4$ is the angle with V_{r2}'

UNIT IV COGENERATION AND RESIDUAL HEAT RECOVERY	
Cogeneration Principles, Cycle Analysis, Applications, Source and utilisation of residual heat. Heat pipes, Heat pumps, Recuperative and Regenerative heat exchangers. Economic Aspects.	
PART * A	
Q.No.	**Questions**
1.	**Define Cogeneration.**BTL1 Cogeneration is also called combined heat power. It deals with the concept of producing two different forms of energy using single source of fuel.It is the arrangement of producing more than one useful form of energy one is heat or thermal energy and other is electrical or mechanical energy.
2	**Give the types of Cogeneration power plants.** BTL1 1) Topping cycle power plant 2) Bottoming cycle power plant.
3	**State the factors influencing Cogeneration.** BTL1 1)Base electrical load matching. 2) Base Thermal load matching 3)Electrical load matching 4)Quality of thermal energy needed.
4	**Mention the applications of Cogeneration technology.** BTL1 1) Hospitals 2) Hotels 3) Data Centres 4) Waste water treatment 5) Military applications 6) Industrial sectors
5	**Write a short note on MHD – generator.** BTL1 'Magneto Hydro Dynamic generator' is a device which converts heat energy of a fuel directly into electrical energy without a conventional electric generator.
6	**List the advantages and disadvantages of cogeneration.** BTL2 Advantages: 1) It reduces cost of production and improves productivity. 2)It saves water consumption and water costs. Disadvantages:1) The capital and maintenance cost is higher than conventional. 2)It is only suitable where hot water and electricity are needed.
7	**Define Residual heat.** BTL1 It is defined as the heat that is produced by a machine using energy as a byproduct of doing work.It is the heat generated in process by the way fuel combustion or chemical reaction is dumped to the environment.
8	**Mention the benefits of residual heat recovery.** BTL1

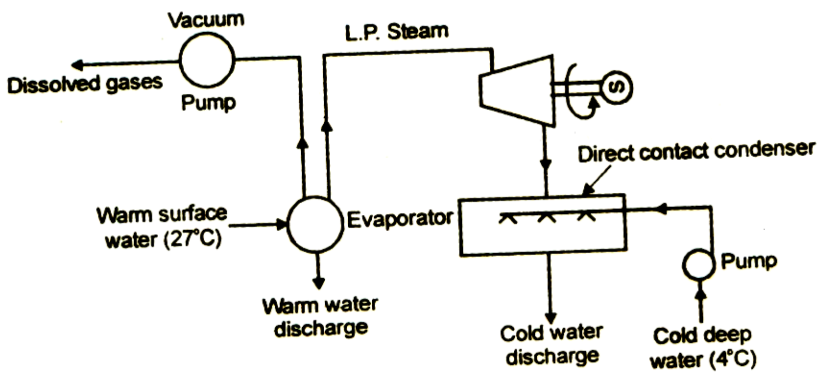
	1) Reduction in pollution. 2) Reduction in equipment size.
9	**In which system the power is Intermittently generated?** BTL1 In a single basin arrangement power can be generated only intermittently.
10	**State the applications of residual heat recovery.** BTL1 1)Load Preheating 2)Power generation 3)Steam generation 4)Space heating
11	**Write down the sources of residual heat in major industries.** BTL1 1) Steam generation 2) Fluid heating 3) Drying 4) Metal heating
12	**What are the Three R's of residual heat?** BTL1 1) Waste heat Reduction within the system. 2) Waste heat Recyclingnwithin the process. 3) Waste heat Recovery within the plant.
13	**State the methods to utilize residual heat.** BTL1 1) In-Process cycling 2) In-Plant recovery 3) Electricity generation.
14	**Define Recuperator.** BTL1 It is defined as the counter flow heat exchangers in which heat transfer takes place between flue gases and air through metallic walls.Tubes carry air to be preheated in combustion chamber and other side contains waste heat stream.
15	**Define Regenerator.**BTL1 It is the type of heat exchanger where heat from the hot fluid is stored in thermal storagemediumbefore transferred to cold fluid.Therefore hot fluid is in contact with heat storage medium and fluid is displaced with the cold fluid which absorbs the heat.
	PART * B
1	**Draw the Layout diagram of Cogeneration power plants and explain the working in brief.** **. Answer: Page – 4.3 Dr.G.K.Vijayaragahavan** The two types of cogeneration power plants are i) Topping cycle power plant ii) Bottoming cycle power plant. In a topping cycle power is generated before the delivery of thermal energy to the process and power generation is done from recovery of excess thermal energy. Power generation is derived from exothermic process reactions.In this combined cycle electricity is first generated and exhaust steam is used to heat water. (3M) The three types of topping cycles are: 1) Gas turbine topping combined heat power (CHP)plant – (2M) • A natural gas fired turbine is used to drive a generator to produce electricity. • Gas turbine producing electrical or mechanical power followed by a heat recovery

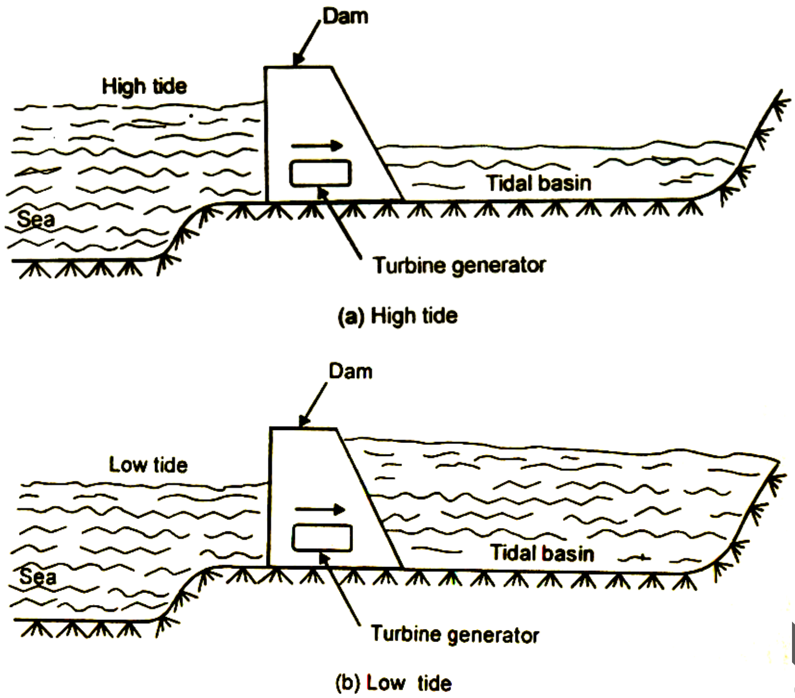
	boiler to create steam to drive a secondary steam turbine. • The exhaust gas is passed to a heat recovery boiler where water converted to steam. 2) Steam turbine topping combined heat power (CHP) plant – (2M) • Fuel is burnt to produce steam to generate power through high pressure steam. • Steam passes through the steam turbine to produce power and exhaust steam provides low pressure steam. 3) Combined topping combined heat power (CHP) plant – (2M) • Fuel is burnt in a steam boiler and the produced steam is used to drive turbine. • Generator is coupled to the turbine producing electrical energy. • Exxhaust from the turbine is used for process heating and further used for secondary steam turbine. Bottoming cycle power plant: (4M) • In this system excess heat is used to generate steamand this steam is used to generate electrical energy. • Power is produced from recovery of process thermal energy and rejected to heat sink. • The excess heat from the thermal process is used by a Heat recovery steam generator to generate steam.The steam produced to drive a steam turbine generates electricity.
3	**Explain the construction and working principle of Solar power plant** BTL2 **Answer: Page – 4.6 Dr.G.K.Vijayaragahavan** Solar electric systems use solar cells to convert the Sun's radiant energy into electricity. This is done using a principle known as the photovoltaic effect. Since a solar cell only generates about 1-2 Watts of power, it is necessary to combine them into solar power panels in order to generate more power. The electrons are captured in the form of an electric current - in other words, electricity. A solar thermal plant generates heat and electricity by concentrating the sun's energy. That in turn builds steam that helps to feed a turbine and generator to produce electricity. (7M)



(6M)

5	**Write the applications and advantages, disadvantages of solar power plant** BTL2 **Answer: Page – 4.64 Dr.G.K.Vijayaragahavan** **Advantages** 1. Sun is essentially an infinite source of energy. Therefore solar energy is a very large inexhaustible and renewable source of energy and is freely available all over the world. 2. It is environmentally very clean and is hence pollution-free. 3. It is a dependable energy source without new requirements of a highly technical and specialized nature for its wide spread utilization. 4. It is the best alternative for the rapid depletion of fossil fuels. (4M) **Disadvantages** 1. It is available in a dilute and is at low potential. The intensity of solar energy on a sunny day in India is about 1.1 kW/square meter area. Hence very large collecting areas are required. 2. Also the dilute and diffused nature of the solar energy needs large land area for the power plant for instance, about 30 square kilometers area is required for a solar power station to replace a nuclear plant on a 1 square kilometer site. Hence capital cost is more for the solar plant. 3. Solar energy is not available at night or during cloudy or rainy days. (4M) **Applications of Solar Energy:** Applications of solar energy enjoying most success today are: 1. Solar engines for pumping. 2. Solar water heaters. 3. Solar cookers. 4. Solar driers. 5. Solar furnaces.

	6. Photo-voltaic conversion (solar cells) **7.** Solar power generation. (5M)
	PART * C
1	**Draw and Explain two basic design of Ocean Thermal Energy Conversion (OTEC)** BTL2 **Answer: Page – 4.67 Dr.G.K.Vijayaragahavan** 1. In the evaporator the pressure is maintained at a value (0.0317 bar) slightly lower than the saturation pressure of warm surface water at 27°C (0.0356 bar). 2. Hence, when the surface water enters the evaporator, it gets 'superheated'. This super-heated water undergoes "volume boiling" causing the water to partially flash to steam. **(8M)**  (7M)
2	**Explain the construction and working principle of Tidal power plants.** BTL2 **Answer: Page – 4.76 Dr.G.K.Vijayaragahavan** 1. Tide or wave is periodic rise and fall of water level of the sea. 2. Tides occur due to the attraction of sea water by the moon. 3. Tides contain large amount of potential energy which is used for power generation. 4. When the water is above the mean sea level, it is called flood tide. When the water level is below the mean level it is called ebb tide. 5. Working of different tidal power plants Single basin-One-way cycle. This is the simplest form of tidal power plant. In this system, a basin is allowed to get filled during flood tide and during the ebb tide. The water flows from the basin to the sea passing through the turbine and generates power.(8M)



(a) High tide

(b) Low tide

(7M)

3

State and explain the kinds of Geothermal Sources. BTL2

Answer: Page – 4.66 Dr.G.K.Vijayaragahavan

Hydrothermal systems (3M)

1. Hydrothermal systems are those in which water is heated by contact with the hot rock, as explained above.
2. Hydrothermal systems are in turn subdivided into 1) Vapor-dominated and 2) Liquid-dominated systems.

Vapor-dominated systems (3M)

1. In these systems the water is vaporized into steam that reaches the surface in relatively dry Condition at about 205°C and rarely above 8 bar.
2. This steam is the most suitable for use in turboelectric power plants with the least cost. It does, however, suffer problems similar to those encountered by all geothermal systems, namely, the presence of corrosive gases and erosive material and environmental problems.

Liquid-dominated systems (3M)

1. In these systems the hot water circulating and trapped underground is at a temperature range of 174 to 315°C.
2. When tapped by wells drilled in the right places and to the right depths the water flows either naturally to the surface or is pumped up to it. The drop in pressure, usually to 8 bar or less, causes it to partially flash to a two-phase mixture of low quality, i.e., liquid-dominated.
3. It contains relatively large concentration of dissolved solids ranging between 3000 to 25,000 ppm and sometimes higher.

Geopressured systems (3M)

1. Geopressured systems are sources of water, or brine, that has been heated in a manner

	similar to hydrothermal water, except that geopressured water is trapped in much deeper underground acquifers, at depths between 2400 to 9100 m. 2. This water is thought to be at the relatively low temperature of about 160°C and is under very high pressure, from the overlying formations above, of more than 1000 bars. **Petrothermal systems** (3M) 1. Magma lying relatively close to the earth's surface heats overlying rock as previously explained. 2. When no underground water exists, there is simply hot, dry rock (HDR). 3. The known temperatures of HDR vary between 150 to 290°C. This energy, called petro thermal energy, represents by far the largest resource base of the United States. Other estimates put the ratio of steam: hot water: HDR at 1: 10: 1000.

UNIT V REFRIGERATION AND AIR – CONDITIONING

Vapour compression refrigeration cycle, Effect of Superheat and Sub-cooling, Performance calculations, Working principle of air cycle, vapour absorption system, and Thermoelectric refrigeration. Air conditioning systems, concept of RSHF, GSHF and ESHF, Cooling load calculations. Cooling towers – concept and types.

PART * A

Q.No	Questions
1.	**Define tonne of refrigeration.** BTL 2 A tonne of refrigeration is defined as the quantity of heat required to be removed from one tonne of water (1000kg) at 0 C to convert that into ice at 0 C in 24 hours. In actual practice, 1 tonne of refrigeration= 210kJ/min=3.5kW
2	**Define tonne of refrigeration. Heat is removed from a space at a rate of 42,000kJ/h. Express this heat removal rate in tons.** BTL 2 A tonne of refrigeration is defined as the quantity of heat required to be removed from one tonne of water (1000kg) to convert that into ice at 0˚ C 24 hours.
3	**How does the actual vapour compression cycle differ from that of the ideal cycle?** BTL 3 1. In actual cycles, pressure losses occur in both condenser and evaporator. 2. Friction losses occur in compressor.
4	**The door of a running refrigerator inside a room was left open. What will happen?** BTL 4 The room will be gradually warmed up.
5	**Name four important properties of a good refrigerant.** BTL 1 1. Low boiling point. 2. High critical temperature and pressure. 3. Low specific heat of liquid.
6	**State the difference between air conditioning and refrigeration.** BTL 1 Refrigeration is the process of providing and maintaining the temperature in space below atmospheric temperature.

	Air conditioning is the process of supplying sufficient volume of clean air containing a specific amount of water vapour and maintaining the predetermined atmospheric condition with in a selected enclosure.
7	**Mention the function of the throttling valve in vapour compression refrigeration system.** BTL 1 The function of throttling valve is to allow the liquid refrigerant under high pressure and temperature to pass to controlled rate after reducing its pressure and temperature.
8	**Name any four commonly used refrigerants.** BTL 1 1. Ammonia (NH3) 2. Carbon dioxide (CO2).
9	**Explain unit of Refrigeration.** BTL 2 Unit of refrigeration is expressed in terms of tonne of refrigeration. A tonne of refrigeration is defined as the quantity of heat required to be removed from one tonne of water (1000kg) to convert that into ice at 0˚ C in 24 hours.
10	**Why throttle valve is used in place of expansion cylinder for vapour compression refrigerant machine.** BTL 3 In throttling process, enthalpy remains constant and pressure is reduced so throttle valve is used.
11	**What are the effect pf superheat and sub cooling on the vapour compression cycle?** BTL 2 Superheating increases the refrigeration effect and COP may be increased or decreased. But sub cooling always increase the COP of the refrigeration and also decrease the mass flow rate of refrigerant.
12	**Enlist the properties of good refrigerant.** BTL 1 An ideal refrigerant should possess the following desirable properties. 1. The refrigerant should have low freezing point. 2. It must have high critical pressure and temperature to avoid large power requirements. 3. It should have low-specific volume to reduce the size of the compressor. 4. It should be nonflammable, non-explosive, non-toxic and non-corrosive.
13	**Name the various components used in simple vapour absorption system.** BTL 1 1. Absorber 2. Pump 3. Generator 4. Condenser. 5. Throttle valve. 6. Evaporator.
14	**Name the various components used in simple vapour absorption system.** BTL 1 1. Absorber 2. Pump

	3. Generator 4. Condenser. 5. Throttle valve. 6. Evaporator.
15	**How does humidity affect human comfort?** BTL 4 If the humidity is above a certain level, water vapour from human body moisture cannot be absorbed by the atmospheric air. It results in discomfort because of sweating.
16	**Define GSHF and ESHF.** BTL 1 Grand Sensible heat Factor=Grand Sensible Heat (TSH) / Grand Total Heat (TSH+TLH) Effective Sensible heat factor=Effective Sensible Heat (ESH) / Effective Total Heat (ESH+ELH)

PART * B

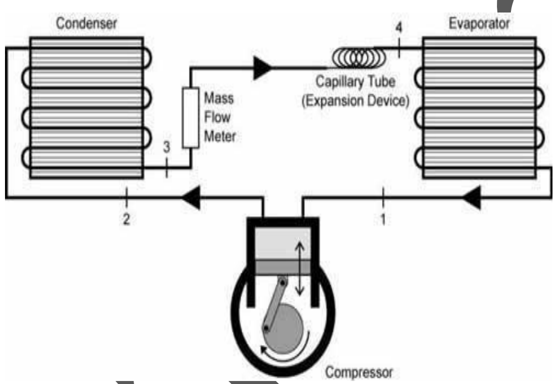
Q.No	Questions

1

With a neat layout briefly explain the construction and working principle of a vapour compression refrigeration system. BTL1

Answer:Page -5.3 Dr.G.K.Vijayaragavan

Diagram: (3M)



Construction : Vapour compression refrigeration system contains a reciprocating vapour compressor, condenser, capillary tube (expansion device) and evaporator. Reciprocating vapour compressor compresses the incoming low pressure vapour refrigerant into high pressure vapour refrigerant. The function of an expansion device (capillary tube) is to reduce the pressure of high pressure liquid refrigerant into low pressure liquid refrigerant. Condenser and evaporator are the devices in which the phase of the refrigerant occurs. (4M)

Working

(6M)

1. The low pressure refrigerant vapour coming out of the evaporator flows into the compressor.
2. The compressor is driven by a prime mover.
3. In the compressor the refrigerant vapour is compressed.
4. The high pressure refrigerant vapour from the compressor is then passed through the condenser.

5. The refrigerant gives out the heat it had taken in the evaporator.
6. The heat equivalent of work done on it on the compressor.
7. This heat is carried by condenser medium which may be air or water.
8. The high pressure liquid refrigerant then enters the expansion valve.
9. This valve allows the high pressure liquid refrigerant to flow at a controlled rate into the evaporator.
10. While passing though this valve the liquid partially evaporates.

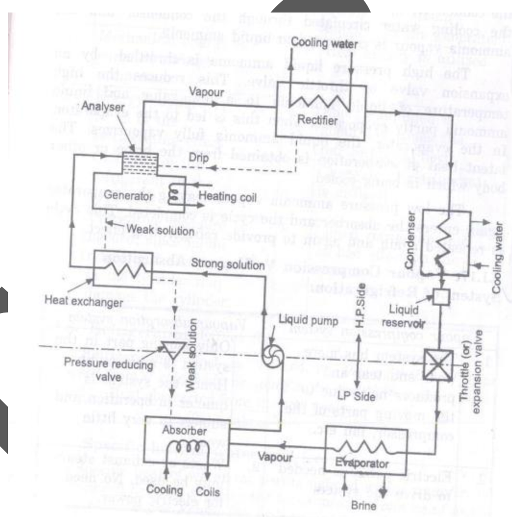
2

With a neat layout, briefly explain about the construction and working principle of a vapour absorption refrigeration system.

Answer: Page -5.67 Dr.G.K.Vijayaragavan

Construction : (2M)

- The vapour absorption system consists of a condenser, an expansion valve and an evaporator.
- They perform the same as they do in vapour compression method.
- In addition to these, this system has an absorber, a heat exchanger, an analyser and a rectifier.



Working : (8M)

- Dry ammonia vapour at low pressure passes in to the absorber from the evaporator.
- In the absorber the dry ammonia vapour is dissolved in cold water and strong solution of ammonia is formed.
- Heat evolved during the absorption of ammonia is removed by circulating cold water through the coils kept in the absorber.
- The highly concentrated ammonia (known as Aqua Ammonia) is then pumped by a pump to generator through a heat exchanger. In the heat exchanger the strong ammonia solution is heated by the hot weak solution returning from the generator to the absorber.
- In the generator the warm solution is further heated by steam coils, gas or electricity and the ammonia vapour is driven out of solution. The boiling point of ammonia is less than

that of water.

- Hence the vapours leaving the generator are mainly of ammonia. The weak ammonia solution is left in the generator is called weak aqua.
- This weak solution is returned to the absorber through the heat exchanger. Ammonia vapours leaving the generator may contain some water vapour.
- If this water vapour is allowed to the condenser and expansion valve, it may freeze resulting in chocked flow. Analyser and rectifiers are incorporated in the system before condenser.
- The ammonia vapour from the generator passes through a series of trays in the analyser and ammonia is separated from water vapour. The separated water vapour returned to generator. Then the ammonia vapour passes through a rectifier.
- The rectifier resembles a condenser and water vapour still present in ammonia vapour condenses and the condensate is returned to analyser. The virtually pure ammonia vapour then passes through the condenser.
- The latent heat of ammonia vapour is rejected to the cooling water circulated through the condenser and the ammonia vapour is condensed to liquid ammonia. The high pressure liquid ammonia is throttled by an expansion valve or throttle valve.
- This reduces the high temperature of the liquid ammonia to a low value and liquid ammonia partly evaporates.
- In the evaporator the liquid fully vaporizes. The latent heat of evaporation is obtained from the brine or other body which is being cooled.
- The low pressure ammonia vapour leaving the evaporator again enters the absorber and the cycle is completed. This cycle is repeated again to provide the refrigerating effect. the evaporator.

3 **Differentiate between vapour compression refrigeration system and vapour absorption refrigeration system.**

Answer: Page -5.8 Dr.G.K.Vijayaragavan

S.No.	Vapour compression system	Vapour absorption system
1.	This system has more wear and tear and produces more noise due to the moving parts of the compressor.	Only moving part in this system is an aqua pump. Hence the quieter in operation and less wear and tear
2.	Electric power is needed to drive the system.	Waste of exhaust steam may be used. No need of electric power.
3.	Capacity of the system drops rapidly with lowered evaporator pressure.	Capacity of the system decreases with the lowered evaporative pressure, by increasing the steam pressure in generator.
4.	At partial loads performance is poor.	At partial loads performance is not affected.

5.	Mechanical energy is supplied through compressor.	Heat energy is utilized.
6.	Energy supplied is ¼ to ½ of the refrigerating effect.	Energy supplied is about one and half times the refrigerating effect.
7.	Charging of the refrigerating to the system is easy.	Charging of refrigerant is difficult.
8.	Preventive measure is needed, since liquid refrigerant accumulated in the cylinder may damage to the cylinder.	Liquid refrigerant has no bad effect on the system.

4 **Write briefly about comfort air conditioning.**

Answer: Page -5.149 Dr.G.K.Vijayaragavan

- Due to the natural phenomenon of body heat disposal by evaporation of moisture from the human body and inflow of moisture from other sources, the humidity inside the room increases.
- The increased humidity causes difficulty in disposing of body heat.
- Also, the room temperature rises due to the heat dissipated from the human body and heat gains from light source and any other equipments.
- When the room temperature is high, it causes human discomfort. It has been found that for human comfort we need a dry bulb temperature of 20^0C and 25^0C and relative humidity of 60 percent in the room.
- Any air conditioning system should primarily be able to achieve the above conditions inside the room. (7M)

PART * C

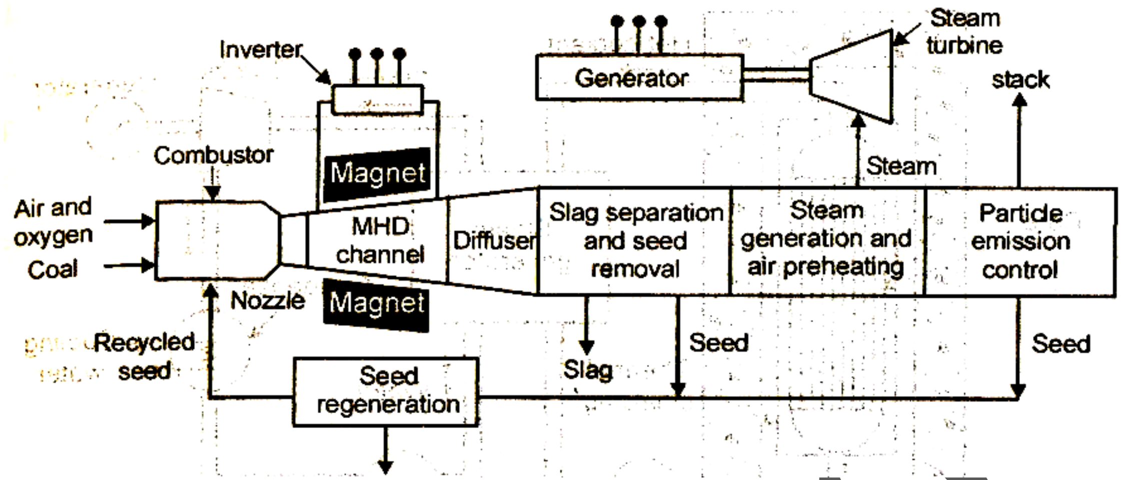
1 **Explain the construction and working principle of MHD.** BTL2

Answer: Page -5.68 Dr.G.K.Vijayaragavan

The planned application of the MHD concept for utility scale electric power generation uses MHD as a topping cycle combined with a steam bottoming cycle, as shown in figure.

The **MHD generation** also known as **magneto hydrodynamic power generation** is a direct energy conversion system which converts the heat energy directly into electrical energy, without any intermediate mechanical energy conversion, as opposed to the case in all other power generating plants.

Therefore, in this process, substantial fuel economy can be achieved due to the elimination of the link process of producing mechanical energy and then again converting it to electrical energy. (7M)



(8M)

2

Explain the Thermo electric conversion system. BTL2

Answer: Page -5.70 Dr.G.K.Vijayaragavan

A typical couple operating with hot and cold junction temperatures of 600°C and 200°C could be designed to give about 0.1 V and 2 A i.e., about 0.5 W, so that a 1 kW device could require about 5000 couples in series.

A thermoelectric generator also called a Seebeck generator is a solid state device that converts heat flux (temperature differences) directly into electrical energy through a phenomenon called the Seebeck effect.

Thermoelectric generators are solid-state heat engines made of pairs of p-type and n-type elements.

The p-type elements are made of semiconductor materials doped such that the charge carriers are positive (holes) and Seebeck coefficient is positive.

The n-type elements are made of semiconductor material doped such that the charge carriers are negative (electrons) and the Seebeck coefficient is negative. (9M)

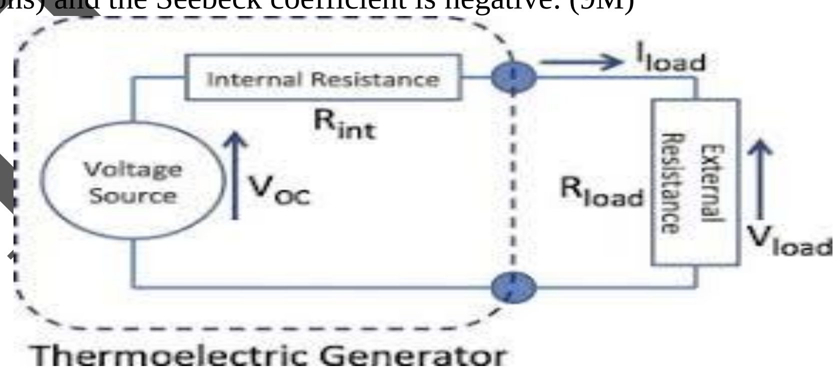


Figure: Thermoelectric generator (6M)

OAT552 INTERNAL COMBUSTION ENGINES L T P C
3 0 0 3

OBJECTIVE:

To impart the basic-fundamental knowledge on IC engines and its working along with some of the recent trends in IC engine

UNIT I INTRODUCTION IC ENGINE 9

Introduction, Types of IC engines, Constructional details IC engine, working, principles – 2 & 4 stroke engines, Cycles – Air standard cycles, Fuel air cycles and actual cycles, Actual Indicator diagram for four stroke and two stroke engines, General fuel properties, ignition properties – octane and cetane rating, Materials for engine components.

UNIT II PETROL ENGINES 9

Working and constructional details of petrol engines, Carburetor – constructional and working, types of carburetors, additional features in modern carburetor, A/F ratio calculation, Petrol Injection - introduction, Ignition – introduction and requirements, Battery and magneto coil ignition system, Electronic ignition system, Stages of combustion in petrol engines, Combustion chambers for petrol engine, formation of knock in petrol engine.

UNIT III DIESEL ENGINES 9

Working and constructional details of diesel engines, fuel injection – requirements, types of injection systems – inline, distributor pumps, unit injector, Mechanical and pneumatic governors. Fuel injector, Types of injection nozzles, Spray characteristics. Injection-timing Split and multiple injection, Stages of combustion in Diesel engines, direct and indirect combustion chambers for diesel engine, knocking in diesel engine, Introduction on supercharging and turbocharging.

UNIT IV COOLING AND LUBRICATION 9

Requirements, Types- Air cooling and liquid cooling systems, forced circulation cooling system, pressure and Evaporative cooling systems, properties of coolants for IC engine. Need of lubrication, Lubricants for IC engines - Properties of lubricants, Types of lubrication – Mist, Wet and dry sump lubrication systems.

UNIT V MODERN TECHNOLOGIES IN IC ENGINES 9

HCCI Engines – construction and working, CRDI injection system, GDI Technology, E - Turbocharger, Variable compression ratio engines, variable valve timing technology, Fuel cell, Hybrid Electric Technology

TOTAL:45 PERIODS

TEXT BOOKS:

1. Ganesan.V., Internal Combustion Engines, Tata McGraw Hill Publishing Co., New York,1994.
2. Ramalingam. K. K., Internal Combustion Engines, Scitech publications, Chennai, 2003

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1. Ellinger, H.E., Automotive Engines, Prentice Hall Publishers, 1992.
2. Heldt.P.M. High Speed Combustion Engines, Oxford IBH Publishing Co., Calcutta,1975.
3. Obert E.F., Internal Combustion Engines Analysis and Practice, International Text Books:Co., Scranton, Pennsylvania, 1988.
4. William. H. Crouse, Automotive Engines, McGraw Hill Publishers, 1985.

Subject Code :OAT552 **Year/Semester : III/ 05**
Subject Name :INTERNAL COMBUSTION ENGINES
Subject Handler : Dr. S.Boopathi & Mr.D.ArunKumar

UNIT I INTRODUCTION IC ENGINE	
Introduction, Types of IC engines, Constructional details IC engine, working, principles – 2 & 4 stroke engines, Cycles – Air standard cycles, Fuel air cycles and actual cycles, Actual Indicator diagram for four stroke and two stroke engines, General fuel properties, ignition properties – octane and cetane rating, Materials for engine components.	
PART * A	
Q.No.	**Questions**
1.	**What do you mean by IC engine? BTL1** An **internal combustion engine** (ICE) is a heat **engine** where the combustion of a fuel occurs with an oxidizer (usually air) in a combustion chamber that is an integral part of the working fluid flow circuit.
2	**How does an IC engine work? BTL1** The **engine** then partially converts the energy from the **combustion** to **work**. The **engine** consists of a fixed cylinder and a moving piston. ... After the piston compresses the fuel-air mixture, the spark ignites it, causing **combustion**. The expansion of the **combustion** gases pushes the piston during the power stroke.
3	**What is IC engine and types? BTL1** **Internal Combustion Engines**, more popularly known as **IC engines**, are the ones in which the combustion of fuel takes place inside the **engine** block itself. ... Reciprocating **engines** are classified into two **types**: spark ignition (SI) **engines** and compression ignition (CI) **engines**.
4	**What are the main components of IC engine? BTL1** Cylinder block, Cylinder head. The top end of the engine cylinder is closed by means of removable cylinder head, Piston. A piston is fitted to each cylinder as a face to receive gas pressure and transmit the thrust to the connecting rod, Piston rings, Connecting rod, Crankshaft, Engine bearing, Crankcase.
5	**What is the working principle of two stroke engine? BTL1** The fuel/air mixture is first drawn into the crankcase by the vacuum that is created during the upward **stroke** of the piston. The illustrated **engine** features a poppet intake valve; however, many **engines** use a rotary value incorporated into the crankshaft.
6	**Which is better 2 or 4 stroke engine? BTL1**

	Four-**stroke engines** are heavier; they weigh upwards of 50% more than a comparable 2stroke **engine**. Typically, a **2-stroke engine** creates more torque at a higher RPM, while a **4-stroke engine**creates a higher torque at a lower RPM. ... Two-**stroke engines** require pre-mixing of oil and fuel, while the **4-strokes** do not.
7	**How do you tell if an engine is 2 or 4 stroke? BTL1** Here are some easy ways to tell if your engine is two-cycle or four-cycle: 1. Look at the fuel cap. ... 2. Look for stickers labeling the equipment (e.g., "Four Cycle" or "No Fuel Mixing"). 3. Look for an engine oil fill cap. ... 4. The Operator's Manual will have engine fuel and oil information in it.
8	**Why 2 stroke engine is not used in cars? BTL1** A only the reason behind Crankcase-compression **two-stroke engines**, such as common small gasoline-powered **engines**, create more exhaust emissions than four-**stroke engines** because their **two-stroke** oil (petroil) lubrication mixture is also burned in the **engine**, due to the **engine's** total-loss oiling system.
9	**What is an air standard cycle? BTL1** **Air-Standard Cycle**. **Air standard cycles** are reference **cycles** which give an approximation to the performance of internal combustion engines.
10	**What are the assumptions made for air standard cycle? BTL1** The **following** assumptions are commonly known as the air- standard assumptions: 1- The working fluid is air, which continuously circulates in a closed loop (cycle). Air is considered as ideal gas. 2- All the processes in (ideal) power cycles are internally **reversible**.
11	**What are actual cycles? BTL1** The **actual cycle** experienced by internal combustion engines is an open **cycle** with changing composition, **actual cycle** efficiency is much lower than the air standard efficiency due to various losses occurring in the **actual** engine. In theoretical **cycles** the burning is assumed to be instantaneous.
12	**What is meant by fuel air cycle? BTL1** Incomplete combustion of the **fuel**. Assuming constant specific heat of the working fluid. Assuming the working fluid to be only **air**. **Fuel-Air cycle** is defined as the theoretical **cycle** that is based on the **actual** properties of the cylinder gases.
13	**What is Carnot cycle and its efficiency? BTL1** **The** most **efficient** heat engine **cycle** is **the Carnot cycle**, consisting of two isothermal processes and two adiabatic processes. To approach **the Carnot efficiency**, **the** processes involved in **the** heat

	engine **cycle** must be reversible and involve no change in entropy.
14	**What are the properties of fuel? BTL1** **An ideal fuel should have the following properties:** • High calorific value. • Moderate ignition temperature. • Low moisture content. • Low NO_xCombustible matter. • Moderate velocity of combustion. • Products of combustion not harmful. • Low cost. • Easy to transport.
15	**What should be the ignition temperature of a good fuel? BTL1** A **good fuel should** have a moderate **ignition** temperature. It **should** be neither too low nor too high; because if it has an **ignition temp**. which is lower than the room temperature, then it **can** catch fire easily when exposed to the atmosphere and so it **will** be difficult to store it or transport it.
16	**What is the self-ignition temperature of petrol and diesel? BTL1** The **Self Ignition auto ignition temperature** is lowest **temperature** at which a fuel such as **petrol** or **diesel** spontaneously ignites in normal atmosphere without an external source of **ignition**, such as a flame or spark. **Self-ignition temperature of petrol** is 247–280°C. **Self-ignition temperature** of **diesel** is around 210°C.
17	**What is octane and cetane rating? BTL1** Cetane number (cetane rating) is an indicator of the combustion speed of diesel fuel and compression needed for ignition. It is an inverse of the similar octane rating for gasoline.
18	**What is the octane rating of diesel? BTL1** **Octane rating** is the measure of a fuel's ability to resist "knocking" or "pinging" during combustion, caused by the air/fuel mixture detonating prematurely in the engine. In the U.S., unleaded gasoline typically has **octane ratings** of 87 (regular), 88–90 (midgrade), and 91–94 (premium).
19	**What is the difference between octane number and cetane number? BTL1** Fuels can release energy through burning. ... **Cetane number** is a measurement of the ignition properties of a fuel. The main **difference between octane number and cetane number** is that **octane number** gives an idea about the performance of a fuel whereas **cetane number** gives an

	idea about the ignition of a fuel.
20	**Which has highest octane number? BTL1** Octane number is also known as octane rating. Octane numbers are based on a scale on which isooctane is 100 (minimal knock) and heptane is 0 (bad knock). The higher the octane number, the more **compression** required for fuel ignition. Fuels with high octane numbers are used in high performance gasoline engines.
21	**What does cetane number of diesel fuel measure? BTL1** **Cetane rating**, also known as **cetane number is** a **measurement** of the quality or performance of **diesel fuel**. The higher the **number**, the better the **fuel** burns within the engine of a vehicle. ... In other words, it **is** how minimized the delay **is** between when the **fuel is** injected into the chamber and when the combustion begins.
22	**Why is isooctane assigned a 100 rating? BTL1** The octane number is determined by comparing the characteristics of a gasoline to **isooctane** (2,2,4-trimethylpentane) and heptane. **Isooctane** is **assigned** an octane number of **100**. ... On the other hand, heptane, a straight chain, unbranched molecule is given an octane **rating** of zero because of its bad knocking properties.
23	**What is octane number how it can improve? BTL1** For example, a petrol with an octane number of **92** has the same knock as a mixture of **92**% isooctane and **8**% heptane. Octane rating decreases with an increase in the carbon chain length. Octane ratings increase in aromatics with same number of carbons.
24	**Does higher octane fuel give more power?** **Octane does** not offer any better **fuel** mileage, **increase** engine **horsepower**, or make the engine start quicker. **Higher octane** only reduces the likelihood of engine knock or ping. ... Because **higher octane gas** burns slower, it is **more** resistant to knock when subjected to **higher** RPM and cylinder pressures.
25	**What are engine parts made of? BTL1** Materials Used. It is made of steel **alloy/cast iron** or **aluminum** by casting process.
Part B	
1	**(i) Classify the different types of IC engines. (7M)BTL4** **(ii) What are the main components of an IC Engines. Briefly explain any two components. (6M)** CLASSIFICATION OF INTERNAL COMBUSTION ENGINES1. Application1.Automotive: (i) Car(ii) Truck/Bus(iii) Off-highway2.Locomotive3.Light Aircraft4.Marine: (i) Outboard(ii) Inboard(iii) Ship5. Power Generation: (i) Portable (Domestic)(ii) Fixed (Peak Power)6. Agricultural: (i) Tractors(ii) Pump sets7. Earthmoving: (i) Dumpers(ii) Tippers(iii) Mining Equipment8.Home Use: (i) Lawnmowers(ii) Snow blowers(iii) Tools (7M) The main components of an IC engine are cylinders, pistons, **camshaft**, **crankshaft**, inlet **valves**, exhaust **valves**, **spark** plugs in the **case** of gasoline engines, **fuel** injectors, etc.(6M)

2

Explain briefly the working principle of 2S & 4S engines. (13M)**BTL2**

Four Stroke Cycle Engines. **A four-stroke cycle engine** is an internal combustion **engine** that utilizes **four** distinct piston **strokes** (intake, compression, power, and exhaust) to complete one operating **cycle**. The piston make two complete passes in the cylinder to complete one operating **cycle**.(7M)

At the top of the **stroke**, the spark plug ignites the fuel mixture. ... (At the same time, another crankcase compression **stroke** is happening beneath the piston.) Since **the two stroke engine** fires on every revolution of the crankshaft, **a two-stroke engine** is usually more powerful than a four **stroke engine** of equivalent size. (6M)

3

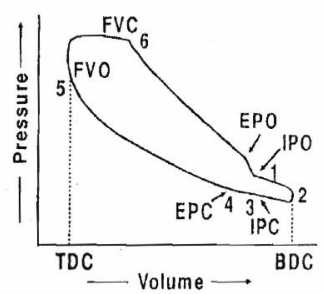
Describe the following: (i) Air standard cycle (ii) Fuel air cycles (8+5 M) BTL3

The addition and rejection of heat is considered to take place with the external reservoir and ideally all the processes are reversible. The internal combustion engines are working on the principle of **air standard cycles**. The two most commonly used **air standard cycles** are Otto **cycle** and Diesel **cycle**.

Fuel-**Air cycle** is defined as the theoretical **cycle** that is based on the actual properties of the cylinder gases. The **Fuel**-**Air cycle** considers the following: 1. The actual composition of the cylinder gases (**air** + **fuel** + water vapor + residual gases).

4

Draw and explain actual indicator diagram for 4S and 2 S engines.BTL2

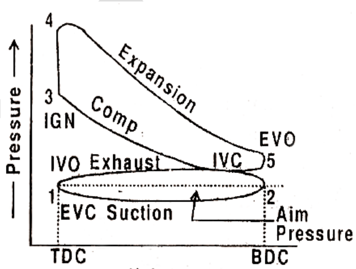


Indicator Diagram for a Two Stroke Cycle Diesel Engine.

Two Stroke engine:

Here you can observe that the inlet port opens and closes while the exhaust port is still functioning.

In a two-stroke engine, the end of the combustion stroke and the beginning of the compression stroke happen simultaneously, with the intake and exhaust (or scavenging) functions occurring at the same time.



Indicator Diagram For A Four Stroke Cycle Petrol Engine.

Four Stroke engine:

Here the Intake valve opens and closes in the first stroke itself, and exhaust valve actuates while the fourth stroke.

5

Explain the following: (i) General fuel properties and (ii) ignition properties of fuel. BTL2

An ideal fuel should have the following properties:

- High calorific value.
- Moderate ignition temperature.

- Low moisture content.
- Low NO_n combustible matter.
- Moderate velocity of combustion.
- Products of combustion not harmful.
- Low cost.
- Easy to transport.

A **good fuel should should** have a moderate **ignition**temparature . It **should** be neither too low nor too high; because if it has an **ignition temp**. which is lower than the room temparature, then it **can** catch fire easily when exposed to the atmosphere and so it **will** be difficult to store it or transport it.

6 **Describe the materials used for engine components. BTL 2**

Materials Used. It is made of steel **alloy**/**cast iron** or **aluminum** by casting process.

Brazing alloys		
Allow	**Engine part**	**Component/base material**
59.8Ni-40.2Cu (Nickel copper)	Titanium (Ti) brazing exhaust first few stages of compressor	Ti
Alloy-30	New braze	Hastelloys, Inconels
Au-6 (Gold)	New engine crack repair	Hastelloys, Inconels
Icronibsi-13	Compressor	Hastelloys, Inconels, Waspalloy
NiBSi-4	Auxiliary power unit (APU)	Hastelloys, Inconels, Waspalloy
Nioro (Gold 82/Nickel 80 Alloy)	Fuel systems/compressor	Stainless steel-grade 304 (304 ss) or Inconel 600, 625
Palnicro-36-M	High compressor and low turbine	Hastelloys, Inconels
Palniro-7	Fuel systems	304 ss or Inconel 600, 625
Presintered perform, paste, paint (PSP)	MRO engine repair hot section/high pressure turbine	Superalloys
Silcoro-75	Fuel systems	Low temp like fuel systems
TiCuNi	Low pressure compressor/Ti brazing	Ti-6-4 and Ti alloys

Part *C

1 **Present a discussion about the evolution or development pathway of SI engine. BTL4**

Historical Overview of IC Engine Development The modern reciprocating internal combustion engines have their origin in the Otto and Diesel Engines invented in the later part of 19th century. The main engine components comprising of piston, cylinder, crank-slider crankshaft, connecting road, valves and valve train, intake and exhaust system remain functionally overall similar since those in the early engines although great advancements in their design and materials have taken place during the last 100 years or so. An historical overview of IC engine development with important milestones since their first production models were built is presented.

Historical Overview and Milestones in IC Engine Development

Year Milestone 1860-1867 J. E. E. Lenoir and Nikolaus Otto developed atmospheric engine wherein combustion of fuel-air charge during first half of outward stroke of a free piston accelerating the piston which was connected to a rack assembly. The free piston would produce work during second half of the stroke creating vacuum in the cylinder and the atmospheric pressure then would push back the piston.

1876 Nikolaus Otto developed 4-stroke SI engine where in the fuel-air charge was compressed before being ignited.

1878 Dougald Clerk developed the first 2-stroke engine

1882 Atkinson develops an engine having lower expansion stroke than the compression stroke for improvement in engine thermal efficiency at cost of specific engine power. The Atkinson cycle is finding application in the modern hybrid electric vehicles (HEV)

1892 Rudolf Diesel takes patent on engine having combustion by direct injection of fuel in the cylinder air heated solely by compression , the process now known as compression ignition (CI)

1896 Henry Ford develops first automobile powered by the IC engine

1897 Rudolph Diesel developed CI engine prototype, also called as the Diesel engine

1923 Antiknock additive tetra ethyl lead discovered by the General Motors became commercially available which provided boost to development of high compression ratio SI engines.

1957 Felix Wankel developed rotary internal combustion engine

1981 Multipoint port fuel injection introduced on production gasoline cars

1988 Variable valve timing and lift control introduced on gasoline cars

1989-1990 Electronic fuel injection on heavy duty diesel introduced

1990 Carburettor was replaced by port fuel injection on all US production cars

1994 Direct injection stratified charge (DISC) engine powered cars came in production by Mitsubishi and Toyota

2

Discuss in detail about the promises and challenges exist in biodiesel production, sustainability and utilization in IC engines. BTL2

Introduction

Energy is one of the most important resources for mankind and its sustainable development. Today, the energy crisis becomes one of the global issues confronting us. Fuels are of great importance because they can be burned to produce significant amounts of energy.

Biodiesel as one promising alternative to fossil fuel for diesel engines has become increasingly important due to environmental consequences of petroleum-fuelled diesel engines and the decreasing petroleum resources. Biodiesel can be produced by chemically combining any natural oil or fat with an alcohol such as methanol or ethanol.

Biodiesel Conversion Technologies

Conventional methods of the application of vegetable oil in diesel engines are direct mixing and micro emulsion. These two physical methods can lower the viscosity of vegetable oil, but they cannot solve the problem of carbon deposits and lube pollution, and the high temperature pyrolysis cracking is hard to be controlled by its reactant at high temperature. The most relevant process parameters in these kinds of operation are reaction temperature, ratio of alcohol to vegetable oil, amount of catalyst, mixing intensity (RPM), catalyst, and the raw oils used.

Challenges of Biodiesel Industry

Development Increased demand for vegetable oil as a biodiesel feedstock is altering world agricultural landscapes and the ecosystem services they provide, which will highlight a number of negative effects associated with its use. Many countries's biodiesel industry development has been motivated by their climate change mitigation target. Because biodiesel produced from biomass have the potential to be "carbon-neutral" over their life cycles as their combustion only returns to the atmosphere the carbon dioxide absorbed from the air by feedstock crops through photosynthesis. **The Biodiesel Policy**

In recent years, incentives exist within energy-, climate- and agricultural policies in several countries to promote further progress in the use of biodiesel. Now, there are many incentives that can be offered by a government to spur the development of biodiesel industry and maintain its sustainability, they are given below 1!

1) Crop plantation in abandoned and fallowed agricultural lands;
2) Subsidizing the cultivation of non-food crops or the usage of waste oil as feedstock
3) Implementation of carbon tax;
4) Exemption from the oil tax;
5) Mandatory biodiesel blend use in gas station.

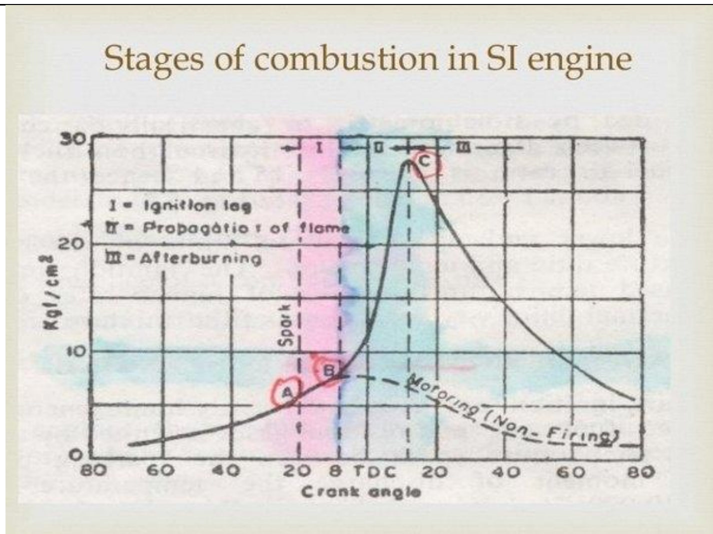
While governments are focusing on the ways to improve biodiesel production and consumption, they should give enough attention to unresolved issues like rainforest depletion, food prices increase. Without taking into account these, their policies might have detrimental effects on climate change.

Subject Code :OAT552 **Year/Semester : III/ 05**
Subject Name :INTERNAL COMBUSTION ENGINES **Subject Handler : Dr. S. Boopathi & Mr.D.ArunKumar**

UNIT II PETROL ENGINES	
Working and constructional details of petrol engines, Carburetor – constructional and working, types of carburetors, additional features in modern carburetor, A/F ratio calculation, Petrol Injection - introduction, Ignition – introduction and requirements, Battery and magneto coil ignition system, Electronic ignition system, Stages of combustion in petrol engines, Combustion chambers for petrol engine, formation of knock in petrol engine.	
PART * A	
Q.No.	**Questions**
1.	**Mention the different jets used in a carburetor.(May/June 2012)**BTL3 Main jet, Pilot jet and slow jet.
2	**List down the air fuel ratio requirements of a S.I engine. (May/June 2012)**BTL1 Chemically correct mixture, rich mixture and lean mixture.
3	**Sketch T-Head type combustion chamber used in S.I. engines. (May/June 2013)**BTL1 Diagram of T type combustion chamber.
4	**What is heterogeneous air-fuel mixture? In which engine is it used.(May/June 2013)**BTL1 In a heterogeneous gas mixture, the rate of combustion is determined by the velocity of mutual diffusion of fuel vapours in to the air, and the rate of chemical reaction is of minor importance. Heterogeneous air-fuel mixture is used in CI engines.
5	**List the various factors that influences the flame speed in SI engine combustion.(Nov/Dec 2013)**BTL **1** Turbulence, air fuel ratio, temperature and a pressure, compression ratio, engine speed, size and output.
6	**Why do we require rich mixture during idling? (Nov/Dec 2013)**BTL1 In order to minimize the effect of dilution of fresh charge by the mixing with exhaust gas.
7	**What are the factors that influence the flame speed? (April/May 2014)**BTL1 Turbulence, air fuel ratio, temperature and a pressure, compression ratio, engine speed, size and output.

8	**What are different air-fuel mixtures on which an engine can be operated?** (**April/May 2014)** BTL3 Air fuel ratio for Idling, starting, medium load, maximum load, maximum power range and acceleration.
9	**What is the principle of a carburetor? How are jet and venturi sizes decided? (April/May 2015)**BTL2 The process of formation of a combustible fuel -air mixture by mixing the proper amount of fuel with air before admission to engine cylinder is called carburetion and the device which does this job is called carburetor.
10	**Why a SI engine requires a rich mixture during idling and at full load? (April/May 2015)**BTL5 During Idling the pressure near the intake manifold is considerably below atm. Pr. Due to restriction of the air flow. The engine requires rich mixture, this is due to the existing pressure conditions between the combustion chamber and the intake manifold which causes exhaust gas dilution of the fresh charge.
11	**State any four important types (shapes) of combustion chambers common in SI engines. (Nov/Dec 2015)**BTL1 T-head combustion chamber, L-head or side valve combustion chamber, F-Head or Ricardo turbulent head side valve, Overhead valve or I-head combustion chamber.
12	**List the different Air-Fuel ratios required for different operating conditions of a gasoline engines. (Nov/Dec 2015)**BTL2 Idling- rich mixture , Crushing or normal power range-17:1 , Power range-rich mixture (14:1)
13	**List the different types of combustion chambers found in spark ignition engine. (April 2016)**BTL **3** T-head combustion chamber, L-head or side valve combustion chamber, F-Head or Ricardo turbulent head side valve, Overhead valve or I-head combustion chamber
14	**What are the various factors affecting knock in spark ignition engine? (April 2016)**BTL1 (i) Temperature factor (ii) Density factor (iii) Time factor (iv) Composition In temperature factor (a) Compression ratio (b) Supercharging (iii) Raising the inlet temperature (iv) Increasing the load (v) Raising the coolant temperature.
15	**Define normal combustion.**BTL1 In normal combustion, the flame initiated by the spark travels across the combustion chamber in a fairly uniform manner.
16	**Define abnormal combustion and its consequences.**BTL4 Under certain operating conditions the combustion deviates from its normal Course leading to loss

	of performance and possible damage to the engine are termed as abnormal combustion (or) knocking combustion. Consequences are (1). Loss of power (2). Recurring pre ignition (3). Mechanical damage to the engine.
17	**Explain the type of vibration produced when auto ignition occurs.** BTL4 Two different vibrations are produced. 1. In one case, a large amount of mixture may auto ignite giving use to a very rapid increase in pressure throughout the chamber and there will be a direct blow on free vibration of the engine parts 2. In another case, larger pressure differences may exit in the combustion chamber and the resulting gas vibration can force the walls of the chamber to vibrate at the same frequency as the gas.
18	**What is the method to detect the phenomenon of knocking?** BTL1 The scientific method to detect the phenomenon of knocking is to use a pressure transfer this transducer is connected, usually to a cathode ray oscilloscope. Thus Pressure-time traces can be obtained from the pressure transducer.
19	**Define performance number.**BTL1 Performance number is defined as the ratio. Of Knock limited Indicated mean effective pressure with the sample fuel to knock limited Indicated mean effective pressure with ISO-OCTANE .when the inlet pressure is kept constant.
20	**List the parameters in time factors that reduce the knocking.**BTL3 Parameters are turbulence, engine speed, flame travel distance, combustion chamber shape and location of spark plug.
21	**What are the factors to be considered to obtain high thermal efficiency?**BTL4 1. A high volumetric efficiency. 2. Anti-knock characteristic must be improved. 3. Compact combustion chamber reduces heat loss during combustion increases the thermal efficiency.
Part B	
1	**Explain the stages of combustion in S.I engine with a pressure crank angle diagram. (13M)** **(April/May 2017), (Nov/Dec 2016)**BTL5 **Answer: Page 2.11-Dr.S.Senthil**



(4M)

The first stage, normally called as preparation phase or ignition lag. Every chemical reactions including combustion have some delay period (that includes physical and chemical delays). In this period the charge is basically preparing for combustion. Time of this period is depends upon the temperature, pressure, composition IN the cylinder. 1st stage is marked as the region on indicator diagram from sparking point to point when pressure-crank angle diagram disconnects from motoring curve.
(3M)

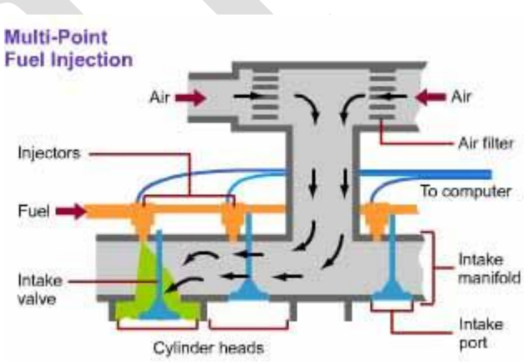
At 2nd stage, flame propagates throughout the cylinder with constant velocity and a quick rise in pressure is observed. Flame velocity is dependent on composition inside the cylinder. This period is marked as the region from the point when pressure-crank angle diagram disconnects from motoring curve to the peak pressure point.
(3M)

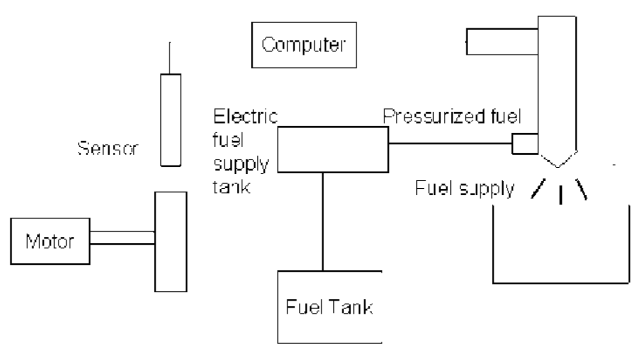
At 3rd stage the flame speed reduced. Piston already starts to move away from TDC, so no further rise in pressure. This period is marked as the peak pressure point to BDC. (3M)

2

Explain the working of multi point and gasoline direct injection systems used in S.I engines with block diagram. (13M)(April/May 2017)BTL5

Answer: Page 2.53 & 6.32-Dr.S.Senthil





(3M)

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Multi point injection systems | **Gasoline direct injection systems**

Multi point fuel injection system injects fuel into the intake ports just upstream of each cylinder's intake valve, rather than at the central point within the intake manifold. Multi point fuel injection systems are of three types, first is BATCHED in which fuel is injected to the cylinders in groups, without precisely bringing together to any particular cylinder's intake stroke, the second one is simultaneous in which fuel is injected at the same time to all the cylinders and the third one is sequential in which injection is timed to coincide with each cylinder's intake stroke. (5M)

Gasoline direct injection (GDI) (also known as petrol direct injection, direct petrol injection, spark-ignited direct injection (SIDI) and fuel-stratified injection (FSI)), is a form of fuel injection employed in modern two-stroke and four-strokegasoline engines. 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. (5M)

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Explain in detail how the fuel jet size and venturi size of the carburetor are decided for an automotive engine. (8 M)(Nov/Dec 2016)BTL5

Answer: Page SQ 25-Dr.S.Senthil

The size of a carburetor is commonly given in terms the diameter of the venturi tube in mm and the jet size is in hundreds of a millimeter. The calibrated jet have a stamped number which gives the flow in ml/min under the head of 500 mm of pure benzol**.**(4M)

For a venturi of 30 to 50 mm size (having a jet size which is one sixteenth of venturi size) the pressure difference (p_1-p_2) is about 50 mm of Hg. The velocity of throat is about 90-100 m/s and the coefficient of discharge for venturi C_{da} is usually 0.85. (4M)

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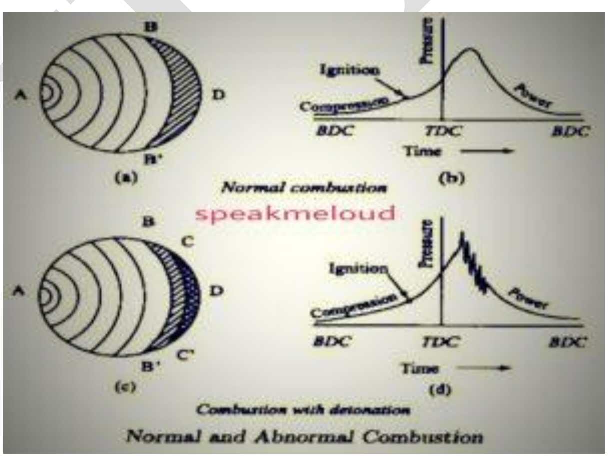
Explain in detail about normal and abnormal combustion in S.I engines. (13M)(AU April/May 2016)BTL5

Answer: Page 2.24-Dr.S.Senthil



(3M)

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Figure **normal and abnormal combustion in S.I engines**

Normal Combustion: Under ideal conditions the common internal combustion engine burns the fuel/air mixture in the cylinder in an orderly and controlled fashion. The combustion is started by the spark plug some 10 to 40 crankshaft degrees prior to top dead center (TDC), depending on many factors including engine speed and load. This ignition advance allows time for the combustion process to develop peak pressure at the ideal time for maximum recovery of work from the expanding gases. .
(5 M)

Abnormal Combustion: When unburned fuel/air mixture beyond the boundary of the flame front is subjected to a combination of heat and pressure for a certain duration (beyond the delay period of the fuel used), detonation may occur. Detonation is characterized by an almost instantaneous, explosive ignition of at least one pocket of fuel/air mixture outside of the flame front. A local shockwave is created around each pocket and the cylinder pressure will rise sharply, and possibly beyond its design limits causing damage.

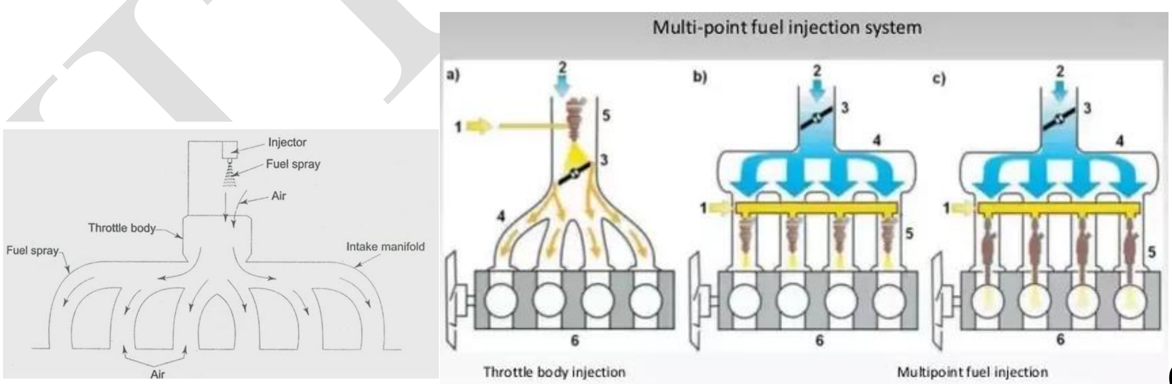
If detonation is allowed to persist under extreme conditions or over many engine cycles, engine parts can be damaged or destroyed. The simplest deleterious effects are typically particle wear caused by moderate knocking, which may further ensue through the engine's oil system and cause wear on other parts before being trapped by the oil filter.
(5M)

5

With a neat sketch in detail about different types of fuel injection system used in SI engines. (13M)(April/May 2016)BTL5

Answer: Page 2.49-Dr.S.Senthil

- **Single**-point or throttle **body injection**.
- Port or multipoint fuel injection.
- Sequential fuel injection.
- Direct injection. (2M)



(4M)

Figure. **fuel injection system**

Single point fuel injection are systems that have a single injector, or a group of injectors clustered together in one, usually centralized spot on the intake manifold. There are generally much fewer injectors than there are cylinders on the engine, and it wasn't uncommon for V-8 engines to have

	just two fuel injectors. This style of fuel injection was more common as engine makers transitioned from the use of carburetors to fuel injection. In many instances early electronic fuel injection had the injector. (3M) Multi-point, or multi-port is when there is a fuel injector for each cylinder and they are located as close as possible to the intake valve. These systems allow the engine management computer to hit a desired air fuel ratio very accurately for each cylinder. I'd venture to say that all vehicles produced in advanced nations will be multi-point of some sort, that is if they aren't direct injected, but direct injected systems can be considered multi-point as well since there is a injector for each cylinders in a throttle body that bolted in place of a carburetor. (4M)
6	**(i) Discuss the air fuel ratio requirements of a S.I engine.** **(ii) Explain the stages of combustion in S.I engine with a pressure crank angle diagram.(5+8 M) (April/May 2015)**BTL5 **Answer: Page 1.64 & 2.11-Dr.S.Senthil** (i) The best fuel economy is obtained with a 15:1 to 16:1 ratio, while maximum power output is achieved with a 12.5:1 to 13.5:1 ratio. A rich mixture in the order of 11:1 is required for idle heavy load, and high-speed conditions. A lean mixture is required for normal cruising and light load conditions. (3M) The approximate proportions of air to petrol (by weight) suitable for the different operating conditions are indicated below: Starting 9 : 1 , Idling 12 : 1 , Acceleration 12 : 1 , Economy 16 : 1 , Full power 12 : 1 (2M) (ii) Refer Question no. 1(8M)
7	**(i)Explain the various factors that affect knock in a S.I engine.** **(ii) Discuss the different types of combustion chambers employed in a S.I engine. (5+8 M)(April/May 2015)**BTL5 **Answer: Page 2.27 & 2.40-Dr.S.Senthil** (i) Temperature factor includes inlet temperature of the mixture and temperature of the combustion chamber walls. Pressure factor includes the final pressure of fresh charge that it can reach after completion of compression stroke. Density factor comprises mass of inducted charge and fuel-air ratio. (5M) (ii) **There are two types of internal combustion chambers:** 1. Piston type internal combustion engines consist of a cylinder with a piston inside and are used in cars and boats. 2. Combustors are combustion chambers used in gas turbines and jet engines. (3M) Piston engines drive motorized vehicles such as cars and boats. They typically consist of a cylinder

with a piston inside. The piston slides tightly within the cylinder driven by the force created by exploding combustion fuel. These engines have two types of combustion chambers. The combustion chamber may be located in the cylinder head, the cap at the end of the cylinder, or on top of the piston, called a 'heron head' combustion chamber.

Combustion chambers in jet engines and gas turbines are called combustors and are configured differently than piston engines. In combustors, air is pulled in and compressed through the compressor. Some of this compressed air is channeled into the combustor to drive the combustion of fuel.
(5M)

8

(i) Briefly explain the stages of combustion in S.I engine with suitable flame propagation curve.

(ii) What is delay period and what are the factors that affect the delay period? (8+5 M)(April/May 2014)BTL5

Answer: Page 2.11 & 2.16-Dr.S.Senthil

(i) Refer Question no. 1 (8M)

(ii) The ignition delay in a diesel engine is defined as the time interval between the start of injection and the start of combustion. This delay period consists of (a) physical delay, wherein atomization, vaporization and mixing of air fuel occur and (b) of chemical delay attributed to pre-combustion reactions. (2M)

Factors that influence ignition delay in *diesel engine* (Compression Ignition or ‘CI’ engine) are

1. Compression ratio
2. Inlet air temperature
3. Coolant temperature
4. Jacket water temperature
5. Fuel temperature
6. Intake pressure
7. Air-fuel ratio and
8. Engine size (3M)

9

What is meant by abnormal combustion? Explain the phenomena of knock in S.I engines. (13M)(AU April/May 2014)BTL5

Answer: Page 2.25-Dr.S.Senthil

When unburned fuel/air mixture beyond the boundary of the flame front is subjected to a combination of heat and pressure for a certain duration (beyond the delay period of the fuel used), detonation may occur. Detonation is characterized by an almost instantaneous, explosive ignition of at least one pocket of fuel/air mixture outside of the flame front. A local shockwave is created around each pocket and the cylinder pressure will rise sharply, and possibly beyond its design limits causing damage.

(8M)

Knocking is the phenomena commonly occurring in a CI engine. You may know that in a CI engine the combustion occurs due to self-ignition of fuel at high temperature generated due to compression of air. During the compression stroke the air is compressed which generates high temperatures. (5M)

10

(i) Explain the stages of combustion in S.I engines elaborating the flame front propagation. (ii) Explain briefly the various factors that influence the flame speed in S.I engines. (8+5 M)(May/June 2013)BTL5

Answer: Page 2.18-Dr.S.Senthil

(i) Refer question no. 1 (8M)

(ii)The important factors

Molecular structure of fuel, Temperature of self ignition, effect of high temperature and pressure after compression, Temperature of combustion wall chamber, Rate of burning, Spark timing, Spark intensity and duration, Air-fuel ratio**.** (2M)

Temperature of self ignition
Generally, fuels with large self-ignition temperature are less detonating, even though there exists no strict relation between the self-ignition temperature and detonation. (1M)

Effect of high temperature and pressure after compression. The velocity of the flame decreases the tendency to detonate, though the pressure and temperature increase at the end of compression. In other words, increase in these two factors leads to decrease the delay period of the initial reactions there by increasing the tendency to detonate. This will also result in predomination and the tendency increases due to rise in both temperature and pressure. (1M)

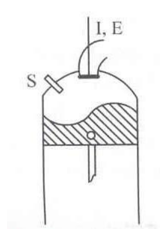
Temperature of combustion wall chamber. Wall temperature gives a profound influence indicating the liability of an air cooled engine for detonating more readily than water cooled engine for the same combustion chamber. The exhaust valves and effective cooling lead to reduce the detonation.

Rate of burning: The huge rate of burning will give less time for flow of heat to the wall of chamber and hence results in high temperature that normally increases the tendency to detonate. (1M)

11

Describe the requirements of an S.I engine combustion chamber and explain the various types of combustion chambers. (13M)(May/June 2013)BTL5

Answer: Page 2.37-Dr.S.Senthil

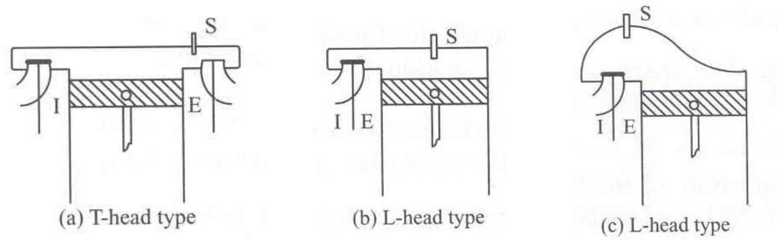


(d) I-head type

High power output, High thermal efficiency and low specific fuel, smooth engine operation. (4M)

Different type's combustionchambers have been developedoveraperiodoftimeSomeofthemareshowninFig.T- HeadType, L-

HeadType, I-HeadTypeorOverheadValve, F-HeadType. (5M)



(4M)

Figure Various types of Combustion chambers

TheT-headcombustionchamberswereusedintheearlystageofenginedevelopment. Knockingtendencyishighinthistypeofengines.Thisconfigurationprovidestwovalvesoneithersideofthecylinder.

Part *C

1

A simple jet carburetor is required to supply 5.5 kg of air per minute and 0.6 kg of fuel per minute. The density of fuel is 750 kg/m3. The air is initially at 1 bar and 30C. Calculate the throat diameter of the choke for a flow velocity of 95 m/s. The velocity is taken as 0.78. If the pressure drop across the fuel metering orifice is 0.76 of that at the choke. Calculate orifice diameter assuming C_{df}=0.62. (15 M)BTL5

Answer: Page 1.52-Dr.S.Senthil2018

Velocity at throat $V_2 = \sqrt{2C_P T_1\left[1-\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right]}$ ➔ P_2=0.9176 x 10^5 N/m^2(3M)

For adiabatic flow of air $v_2 = v_1\left(\frac{P_1}{P_2}\right)^{\frac{1}{\gamma}}$ = 0.925 m^3/kg (3M)

Throat area, $A_2 = \frac{m_a v_2}{v_2} =$ ➔ $d = 3.22\ cm$ (3M)

Orifice diameter, from $\dot{m}_f = A_f C_{df}\sqrt{2\rho_f(P_1-P_2)}$ ➔ $A_f = 5.255\ x10^{-6} m^2$ (3M)

d_f = 2.5867 mm (3M)

2

The throat diameter of a carburetor is 80 mm and diameter is 6 mm. The Cda=0.85 and Cdf=0.7. The nozzle lip is 6 mm. The pressure difference causing the flow is 0.6 bar. Find (i) Air-fuel ratio supplied by the carburetor by neglecting nozzle lip. (ii) Air-fuel ratio considering nozzle lip (iii) The minimum velocity of air required to start the fuel flow. Neglect air compressibility. Take $\rho_a = 1.2\ kg/m^3$ and $\rho_f = 750\ kg/m^3$. (15 M)BTL5

Answer: Page 1.60-Dr.S.Senthil

(i) When the nozzle lip is neglected

Mass flow of air, $\dot{m}_a = C_{da} A_a\sqrt{2\rho_a(P_1-P_2)}$

Mass flow of fuel, $\dot{m}_f = C_{df} A_f \sqrt{2\rho_f (P_1 - P_2)}$

Air-fuel ratio = $\frac{\dot{m}_a}{\dot{m}_f} = 8.635$ (5M)

(ii) When the nozzle lip is taken for consideration

$\dot{m}_f = C_{df} A_f \sqrt{2\rho_f (P_1 - P_2 - gh\rho_f)}$

Air-fuel ratio = $\frac{\dot{m}_a}{\dot{m}_f} = 8.645$(5M)

(iii) Minimum velocity of air $V_{min} = \sqrt{2gh\frac{\rho_f}{\rho_a}} = 8.58\ m/s$(5M)

3

Air-fuel ratio of a mixture supplied to an engine by a carburetor is 13. The fuel consumption of the engine is 7.5 kg/hr. The diameter of the venturi is 20 mm. Find the diameter of fuel nozzle if the lip of the nozzle is 4 mm. Take the following data $\rho_f = 750\frac{kg}{m3}, Cda = 0.8, Cdf = 0.7$ and atmospheric pressure =1.013 bar and temperature =27ºC. (15 M)BTL5

Answer: Page 1.62-Dr.S.Senthil

Density of air, $\rho_a = \frac{P_1}{RT_1} = 1.1765\frac{kg}{m3}$ (3M)

The air flow through the engine per second = 0.0271 kg/s (2M)

The mass flow of air, $\dot{\boldsymbol{m}}_{\boldsymbol{a}} = C_{da} A_a \sqrt{2\rho_a (P_1 - P_2)}$

$(P_1 - P_2)$=4935.17 N/m2
(5M)

The fuel flow through the nozzle is $\dot{\boldsymbol{m}}_{\boldsymbol{f}} = \boldsymbol{C}_{\boldsymbol{df}} A_f \sqrt{2\rho_f (P_1 - P_2 - gh\rho_f)}$

$A_f = 1.097\ x\ 10^{-3} m^2$

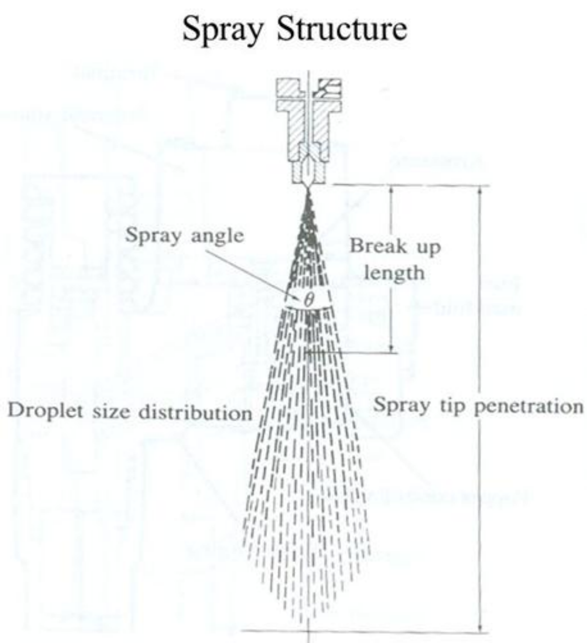
d_f =1.1819 mm (5M)

UNIT III DIESEL ENGINES	
Working and constructional details of diesel engines, fuel injection – requirements, types of injection systems – inline, distributor pumps, unit injector, Mechanical and pneumatic governors. Fuel injector, Types of injection nozzles, Spray characteristics. Injection-timing Split and multiple injection, Stages of combustion in Diesel engines, direct and indirect combustion chambers for diesel engine, knocking in diesel engine, Introduction on supercharging and turbocharging.	
PART * A	
Q.No.	**Questions**
1.	**List down the major constituents of natural gas and LPG.(May/June 2012)**BTL1 Natural gas is a mixture of components consisting mainly of methane (60-95%) with small amount of other hydrocarbons. LPG consists of mainly methane 90%, ethane 4%, propane 1.7% and other.
2	**Compare the octane number and the calorific value of alcohol with petrol. (May/June 2012)**BTL4 Octane number- 80 to 90 (Petrol) and 111 for ethanol, CV- 44100 kJ/kg for Petrol and 26880 kJ/kg for ethanol.
3	**Comment on the water tolerance of alcohol blends. (May/June 2013)**BTL3 i) Gasoline and water free alcohol are miscible in all proportions over a wide range of temperatures. ii) However, even addition of small addition of water to this blended fuel causes separation of the alcohol and gasoline. iii) The difficulties due to water separation have commonly led to the use of either 20-25 % of blends of alcohol alone or 10-15% alcohol and Benzol to reduce preparation troubles.
4	**State the methods by which ethanol is produced. (May/June 2013)**BTL1 Manufacture from saccharine materials, Starchy materials, cellulose material and hydrocarbon gases.
5	**What are the advantages of hydrogen as a fuel? (Nov/Dec 2013)**BTL3 Its CV is about 19% higher in combustion energy density on a mass basis, Its wide flammability allows its utilization over extremely wide range of air fuel ratio without misfire, Its gaseous form eliminates the problem of atomization, vaporization, mixing and reconditioning leads to low emission, and H2 is easily ignites and has very high flame velocity.
6	**What are the commonly used alternative fuels? (Nov/Dec 2013)**BTL3 Alcohol can be used in CI engines. The techniques of using alcohol in CI engines are Alcohol diesel emulsions, dual fuel injection, Alcohol fumigation and surface ignition of alcohols.
7	**Can alcohol be used for CI engines? Explain. (April/May 2014)**BTL4 Turbulence, air fuel ratio, temperature and a pressure, compression ratio, engine speed, size and

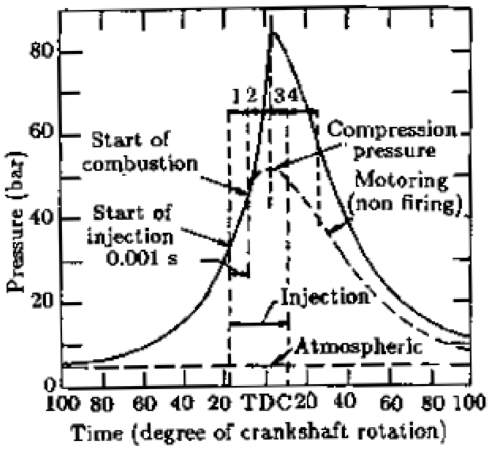
	output.
8	**Can one use solid fuels for IC engines? If so how. (April/May 2014)** BTL4 Yes, Solid fuels can be used for IC engines, a valve outlet for exhaust of combustion products, after combustion a fuel valve for retaining a quantity of solid fuel out of the cylinder and opening on pressure reduction in the cylinder by piston movement beyond top dead center to introduce the quantity of fuel into the cylinder.
9	**List down four properties that are important in the selection of a fuel for an engine. (April/May 2015)**BTL2 i)Air fuel ratio ii) Calorific value iii) latent heat of vaporization v) vapour pressure vi) Octane quality
10	**What are the problems of using methanol in an engine? (April/May 2015)**BTL2 i) low calorific value ii) produces more aldehydes iii) more corrosive iv) poor ignition characteristics v) danger of storage tank flammability -due to low vapour pressure.
11	**Indicate any two limitations of vegetable oil as a CI engine fuel. (Nov/Dec 2015)**BTL1 NOx emissions will form smoke and it does not suits all types of engines. In some engines the reduction in power occurred at 10%.
12	**State any two reasons for using ethyl alcohol as a SI engine fuel. (Nov/Dec 2015)**BTL1 Low lubricating qualities, much corrosive, increase the cetane number
13	**Which are the different types of onboard hydrogen storage methods that can be used? (April 2016)**BTL4 Hydrogen can be stored using six different methods and phenomena: (1) high-pressure gas cylinders (up to 800 bar), (2) liquid hydrogen in cryogenic tanks (at 21 K), (3) adsorbed hydrogen on materials with a large specific surface area (at T<100 K), (4) absorbed on interstitial sites in a host metal (at ambient pressure and temperature), (5) chemically bonded in covalent and ionic compounds (at ambient pressure), or (6) through oxidation of reactive metals, e.g. Li, Na, Mg, Al, Zn with water.
14	**WAlternative Fuel Types of alternative fuels available. (April 2016)**BTL2 Liquefied Petroleum Gas (LPG, commonly known as propane), Compressed Natural Gas (CNG), Liquefied Natural Gas (LNG), Methanol (M85), Ethanol (E85), Biodiesel (B20), Electricity, Hydrogen.
15	**What are the stages of combustion in C.I engine?** BTL1 The stages of combustion in C.I engine are four stages: Stage I: ignition delay period (preparatory phase), Stage 2: Period of rapid combustion. Stage 3: Period of controlled combustion. Stage 4: Period of after burning.
16	**What is ignition delay period?** BTL1 The fuel does not ignite immediately upon injection into the combustion chamber. There is a

	definite period of inactivity between the time when the first droplet of fuel hits the hot air in the combustion chamber and the time it starts through the actual burning phase. This period is known as ignition delay period.
17	**What are two delays occur in ignition delay period?** BTL1 The two delays occur in ignition delay period are the physically delay and chemically delay. Physical delay is the time between the beginning of injection and the attainment of chemical reaction conditions. Chemical delay is the reaction starts slowly and then accelerates until the inflammation or ignition takes place.
18	**Explain the effect of quality of fuel factor on the delay period.** BTL3 Self-ignition temperature is the most important property of the fuel which affects the delay period. A lower self-ignition temperature and fuel with higher cetane number give lower delay period and smooth engine operation. Other properties of the fuel which affects the delay period are latent heat, viscosity and surface tension.
19	**List the factors affecting the delay period.** BTL2 The factors affecting the delay period are: 1. Compression ratio. 2. Atomization of the fuel. 3. Quality of the fuel. 4. Intake temperature and pressure.
20	**What are the types of open combustion chamber?** BTL1 In open combustion chamber there are many designs some are a. Shallow depth chamber b. Hemispherical chamber c. Cylindrical chamber d. Toroidal chamber
21	**What are the advantages and disadvantages of open combustion chamber type?**BTL4 **Advantages:** 1. Minimum heat loss during compression because of lower surface area to volume ratio 2. No cold starting problems 3. Fine atomization because of multi hole nozzle **Disadvantages:** 1. High fuel injection pressure required and hence complex design of fuel injection pump 2. Necessity of accurate metering of fuel by the injection system, particularly for small engines.
22	**Why specific fuel consumption is high in indirect injection type combustion chamber?** BTL5 Specific fuel consumption is high because there is a loss of pressure due to air motion through the duct and heat loss due to large heat transfer area.
23	**Why there is a large pressure differences across the injector nozzle are required ?** BTL5 The fuel is introduced in to the cylinder of a diesel engine through a nozzle with a large pressure differences across the nozzle jet will enter the chamber at high velocity to 1. Atomize in to small sized droplets to enables rapid evaporation and 2. Traverse the combustion chamber in the time available and fully utilize the air charge.
24	**Define rapid burning angle.** BTL1 The crank angle interval required to burn the bulk of the charge is defined as the interval between the end of the flame development stage and the end of the flame propagation process.

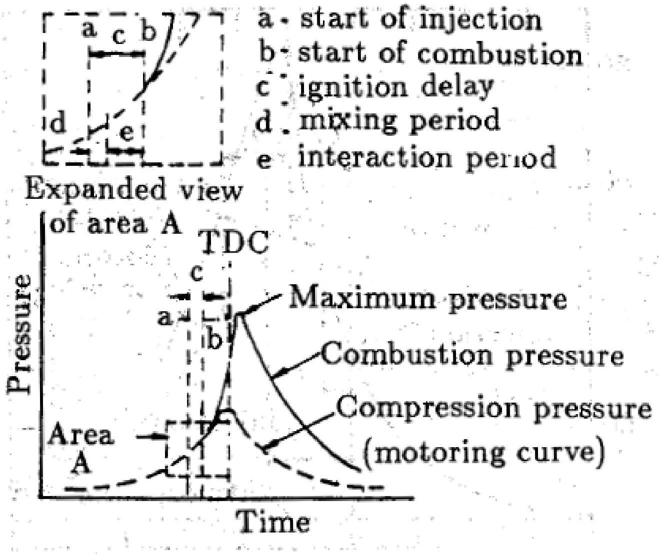
Part B	
1	**Give the detailed comparison of knock in C.I and factors affecting knock. (13 M)(April/May 2017)** BTL5 **Answer: Page 3.1-Dr.S.Senthil** **Knocking – Factors affecting knock** The diesel combustion process which includes ignition delay, premixed burning due to delay period and diffusion burning and injector needle lift and pressure variation with respect to crank angle can be seen in fig. The premixed burning is responsible for diesel knock. The following are the factors which influence ignition delay and thereby contribute to knock: Higher inlet air pressure, air temperature and compression ratio reduce knock. Supercharging reduces knock. Increased humidity increases knock. Combustion chamber design and associated air motion influence heat losses from the compressed air. Tendency to knock will be lesser, with less heat losses. A combustion chamber with a minimum surface to volume ratio and with lesser intensity of air motion is desirable.**(6M)** Knocking tendency is lesser in engines where compressed air injects the fuel into the combustion space. In the case of mechanical injection of fuel, finer the atomization of fuel, lesser is the tendency to knock. A fuel with long pre flame reactions (i.e. self-ignition possible only at a higher temperature) will result in the injection of a considerable amount of fuel before the initial part ignites. This in turn results in a large amount or number of parts of the mixture to ignite at the same time and produce knock. Thus, a good CI engine fuel should have a short ignition delay and low self-ignition temperature, if knock is to be avoided. Ignition delay of fuels is generally measured in terms of cetane number. Fuels of higher cetane number have shorter ignition delay and thus will have a lesser tendency to knock. The ignition delay of CI engine fuels may be decreased by the addition of small amounts of certain compounds (called ignition accelerators or improves). These compounds are ethyl nitrate and amylthionitrate. These compounds affect the combustion process by speeding the molecular interactions.**(7M)**
2	**Describe diesel fuel spray behavior and spray structure with neat sketch. (13 M)(April/May 2017)**BTL5 **Answer: Page 3.70, 3.67-Dr.S.Senthil** Fuel Spray behaviour • Spray formation is explained as Breakup Mechanism, described as: Stretching of fuel ligament into sheets or streams, Appearance of ripples and protuberances, Formation of small ligaments or holes in sheets, Collapse of ligaments or holes in sheets, Further

	breakup due to vibration of droplets, Agglomeration or shedding from large drops, The flow parameters of a jet:Jet Reynolds number, Jet weber number, Ohnesorge number. (5M) **Spray structure**  During spraying it is essential to maintain a constant top surface temperature and hence maintain steady-state conditions if a billet with consistent microstructure is to be produced. At the billet surface, during spraying an enthalpy balance must be maintained where the rate of enthalpy lost (H_{out}) from the billet by conduction to the atomizing gas and through the substrate, convection and radiation must be balanced with the rate of enthalpy input (H_{in}) from the droplets in the spray. There are a variety of factors that can be adjusted in order to maintain these conditions: spray height, atomizer gas pressure, melt flow rate, melt superheat and atomizer configuration, being those parameters most readily adjusted. **Figure- Spray structure**(3M) Typically equipment such as closed circuit cameras and optical pyrometry can be used to monitor billet size/position and top surface temperature. If H_{out} is much greater H_{in} then a steady temperature is maintained at the billet top surface. The top surface should be in a mushy condition in order to promote sticking of incoming droplets and partial re-melting of solid particles. The necessary partial re-melting of solid droplets explains the absence of dendritic remnants from pre-solidified droplets in the final microstructure. If Hin is insufficient to cause significant re-melting, a 'splat' microstructure of layered droplets will form, typical of thermal spray processes such as vacuum plasma spraying (VPS), arc spraying and high velocity oxy-fuel. Processing maps have been produced for plasma spraying and spray forming using a steady-state heat balance in terms of the interlayer time (time between deposition events) against average deposition rate per unit area. These maps show the boundaries between banded un-fused microstructure and an equated homogeneous structure. (5M)
3	**With the aid of a schematic diagram, explain the combustion process in a C.I engine. (13 M)(Nov/Dec 2016)** BTL5

Answer: Page 3.1-Dr.S.Senthil



Stages of combustion



Pressure Time diagram illustrating Ignition delay

(4M)

Delay period

In an actual engine, fuel injection beings at the point B during the compression stroke. The injected fuel does not ignite immediately. It takes some time to ignite. Ignition sets in at the point C. During the crank travel B to C pressure in the combustion chamber does not rise above the compression curve. The period corresponding to the crank angle B to C is called delay period or ignition delay (about 0.001 seconds).

Uncontrolled combustion takes place will depend upon the following:

- The quantity of fuel in the combustion chamber at the point C. This quantity depends upon the rate at which fuel is injected during delay period and the duration of ignition delay.
- The condition of fuel that has got accumulated in the combustion chamber at the point C.

The rate of combustion during the crank travel C to D and the resulting rate of pressure rise determine the quietness and smoothness of operation of the engine. (3M)

Controlled combustion

During controlled combustion, following thing happen. The flame spreads rapidly (but less than 135 m/min), as a turbulent, heterogeneous or diffusion flame with a gradually decreasing rate of energy release. Even in this stage, small auto ignition regions may be present. The diffusion flame is characterized by its high luminosity. Bright, white carbon flame with a peak temperature of 2500^o C is noticed. In this stage, radiation plays a significant part in engine heat transfer.

During the period D to E, combustion is gradual. Further by controlling the rate of fuel

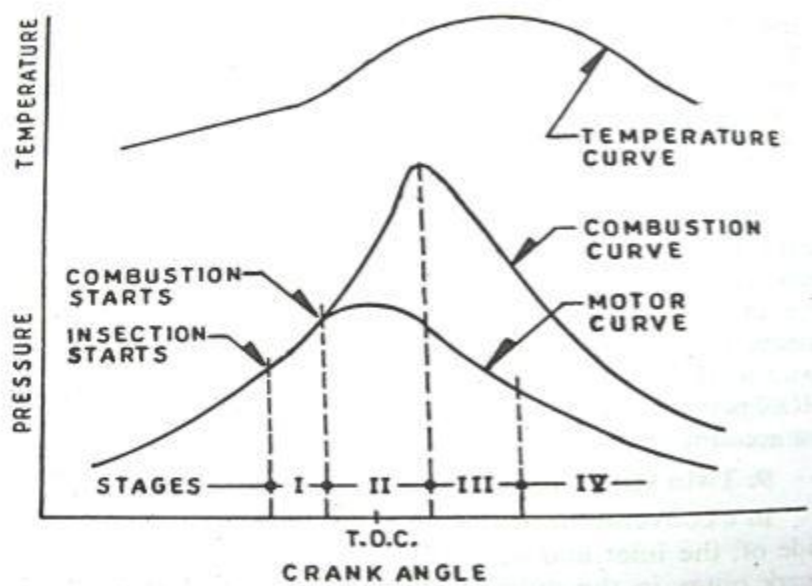
	injection, complete control is possible over the rate of burning. Therefore, the rate of pressure rise is controllable. Hence, this stage of combustion is called Gradual combustion or Controlled combustion. (3M) **After burning** At the last stage, i.e. between E and F the fuel that is left in the combustion space when the fuel injection stops is burnt. This stage of combustion is called after burning (burning on the expansion stroke). In the indicator diagram after burning will not be visible. This is because the downward movement of the piston causes the pressure to drop inspired of the heat that is released by the burning of the last portion of the charge. Increasing excess air, or air motion will shorten after burning i.e. reduce the quantity of fuel that may undergo after burning). (3M)
4	**Explain the factors affecting the delay period in C.I engines and summarize them. (13 M)(Nov/Dec 2016)** BTL5 **Answer: Page 3.11-Dr.S.Senthil** Compression ratio , Engine speed, output, Injection timing, Quality of the fuel, Intake temperature, Intake pressure. 1. Compression ratio: With the increase in compression ratio reduces ignition lag, a higher pressure increases density resulting in closer contact of the molecules which reduce the time of action when fuel is injected. 2. Inlet air temperature: With the increase in inlet temperature increases the air temperature after compression and hence decreases the ignition delay. 3. Coolant temperature: Increase in engine speed increases cylinder air temperature and thus reduces ignition lag. The increase in engine speed increases turbulence and this reduces the ignition lag. 4. Jacket water temperature: With the increase in jacket water temperature also increases compressed air temperature and hence delay period is reduced. 5. Fuel temperature: Increase in fuel temperature would reduce both physical and chemical delay period. 6. Intake pressure (supercharging): Increase in intake pressure or supercharging reduces the auto-ignition temperature and hence reduces delay period. Since the compression pressure will increase with intake pressure, the peak pressure will be higher. Also, the power output will be more air and hence more fuel can be injected per stroke. 7. Air-fuel ratio (load): With the increase in air-fuel ratio (leaner mixture) the combustion temperatures are lowered and cylinder wall temperatures are reduced and hence the delay period increases, with an increase in load, the air-fuel ratio decreases, operating temperature increases and hence, delay period decreases.

8. Engine size: The engine size has little effect on the delay period in milliseconds. As large engines operate at low revolutions per minute (rpm) because of inertia stress limitations, the delay period in terms of crank angle is smaller and hence less fuel enters the cylinder during the period. Thus combustion in large slow speed Compression Ignition engines is smooth. **(13M)**

5

Discuss in detail about the various stages of combustion in C.I engines. (13 M)(April/May 2016) BTL5

Answer: Page 3.6-Dr.S.Senthil



(2M)

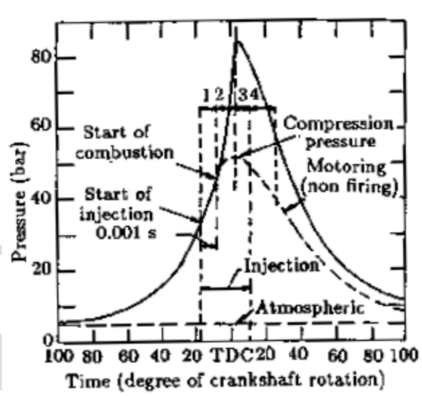
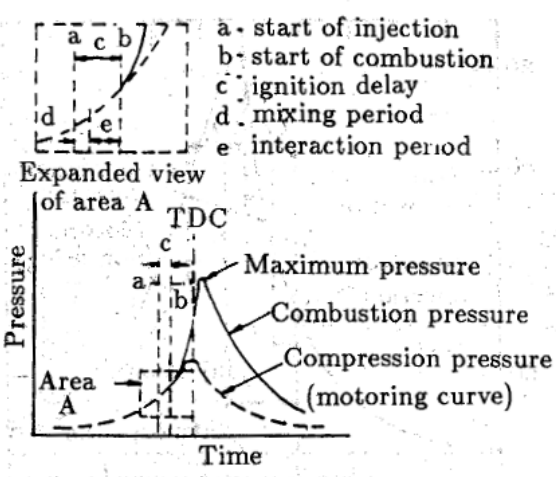
Figure- Pressure-Crank angle diagram

1. Ignition delay- During this stage there is a physical delay period which is the time from beginning of injection to the attainment of chemical reaction conditions. The fuel is atomized and mixed with air and its temperature is raised. This period is followed by a chemical delay period in which pre-flame reactions start and accelerate until local ignition takes place. (2M)

2. Rapid or uncontrolled combustion- This is second stage in which pressure rise is rapid since during delay period the fuel droplets have had time to spread themselves over a wide area and have fresh air around them. This phase extends from end of delay period to point of maximum pressure. (3M)

3. Controlled combustion- The very high temperature and pressure at end of second stage cause the fuel droplets injected during last stage to burn instantly and any further pressure rise can be controlled by purely mechanical means that is injection rate. This period ends at maximum cycle temperature. The heat evolved by end of this phase is 70 to 80 percent of total heat of fuel supplied. (3M)

4. After burning- This fourth stage may not be present in all cases but due to poor distribution of fuel particles combustion may continue in the expansion stroke. Its duration may be 70 to 80 degrees of crank travel from TDC.

	(3M)
6	**What are the various factors that influence spray penetration in C.I engines? Explain in detail. (13 M) (April/May 2016)** BTL5 **Answer: Page 3.6-Dr.S.Senthil** The graphs of the penetration of plume tips 1 and 6 are shown in Figure 6-4 to Figure 6-7 for gas pressures of 0.5 and 1.0 and injector bogy temperatures of 20, 90 and 120 °C. These graphs show the penetrations measured from the sprays produced by Ethanol and Butanol in comparison to those produced by the Standard Gasoline and the main high and low volatility components n-Pentane and iso-Octane. (6M) The overarching observation from the plume penetration graphs above is the striking similarity of penetration rate reaction to the conditions of Ethanol and Standard Gasoline and of Butanol and iso-Octane. This is especially evident from the graphs showing the spray plume penetrations at the elevated injector body temperature of 120,229°C which is also the condition where the most difference between high and low volatility fuels is observed. (7M)
7	**Using pressure-crank angle diagram explain the different stages of combustion observed a typical CI engine. Why is it undesirable to have the fourth phase of combustion (combustion during the late expansion stroke)?(13 M) (Nov/Dec 2015)** BTL5 **Answer: Page 3.55Dr.S.Senthil**  *Stages of combustion*  *Pressure Time diagram illustrating Ignition delay* (6M) **After burning** At the last stage, i.e. between E and F the fuel that is left in the combustion space when the fuel injection stops is burnt. This stage of combustion is called after burning (burning on the expansion stroke). In the indicator diagram after burning will not be visible. This is because the downward movement of the piston causes the pressure to drop inspired of the heat that is released by the burning of the last portion of the charge. Increasing excess air, or air motion will shorten after burning i.e. reduce the quantity of fuel that may undergo after burning).

(7M)

8

Discuss the characteristics of DI and IDI diesel engines. (13 M)(April/May 2015) BTL5

Answer: Page 3.70, 3.67-Dr.S.Senthil

Direct injection systems

Direct injection diesel engines inject fuel directly into the cylinder. Usually there is a combustion cup in the top of the piston where the fuel is sprayed. Many different methods of injection can be used. Electronic control of the fuel injection transformed the direct injection engine by allowing much greater control over the combustion. (3M)

Unit direct injection

Unit direct injection also injects fuel directly into the cylinder of the engine. In this system the injector and the pump are combined into one unit positioned over each cylinder controlled by the camshaft. Each cylinder has its own unit eliminating the high-pressure fuel lines, achieving a more consistent injection. This type of injection system, also developed by Bosch, is used by Volkswagen AG in cars (where it is called a *Pumpe-Düse-System*—literally *pump-nozzle system*) and by Mercedes-Benz ("PLD") and most major diesel engine manufacturers in large commercial engines (MAN SE, CAT, Cummins, Detroit Diesel, Electro-Motive Diesel, Volvo). With recent advancements, the pump pressure has been raised to 2,400 bars (240 MPa; 35,000 psi), allowing injection parameters similar to common rail systems. (3M)

Common rail direct injection

"Common Rail" injection was first used in production by Atlas Imperial Diesel in the 1920s. The rail pressure was kept at a steady 2,000 - 4,000 psi. In the injectors a needle was mechanically lifted off of the seat to create the injection event.[79] Modern common rail systems use very high-pressures. In these systems an engine driven pump pressurizes fuel at up to 2,500 bar (250 MPa; 36,000 psi), in a "common rail". The common rail is a tube that supplies each computer-controlled injector containing a precision-machined nozzle and a plunger driven by a solenoid or piezoelectric actuator. (3M)

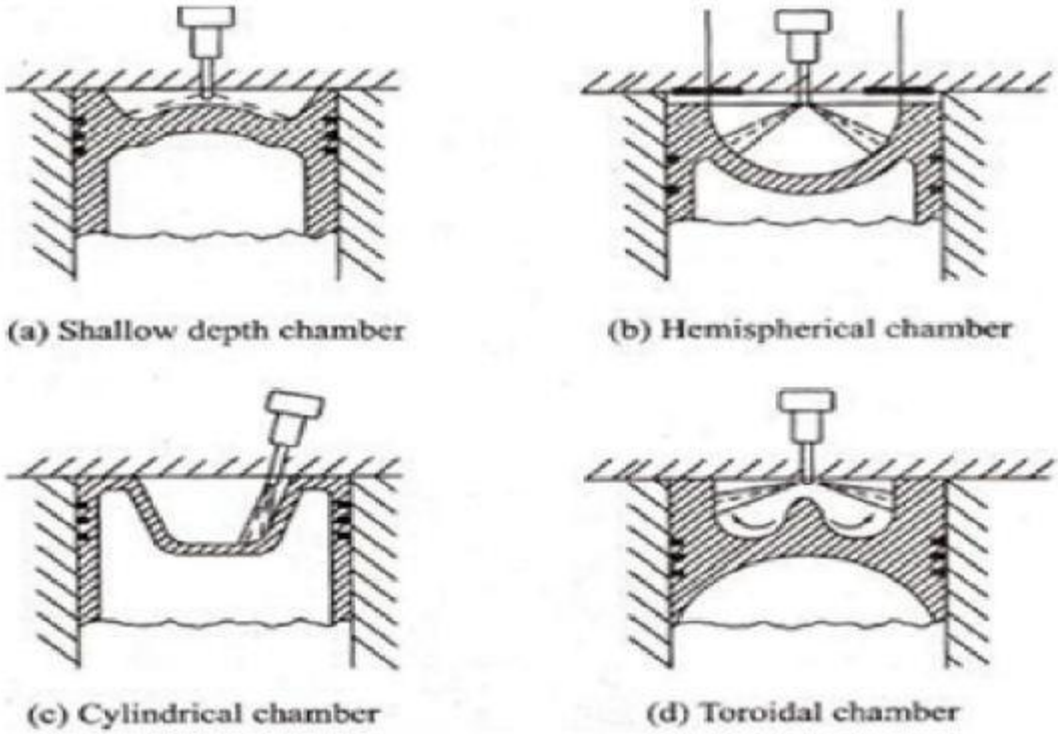
Indirect injection systems

An indirect Diesel injection system (IDI) engine delivers fuel into a small chamber called a swirl chamber, pre combustion chamber, pre chamber or ante-chamber, which is connected to the cylinder by a narrow air passage. Generally the goal of the pre camber is to create increased turbulence for better air / fuel mixing. This system also allows for a smoother, quieter running engine, and because fuel mixing is assisted by turbulence, injector pressures can be lower. Most IDI systems tend to use a single orifice injector. The pre-chamber has the disadvantage of lowering efficiency due to increased heat loss to the engine's cooling system, restricting the combustion burn, thus reducing the efficiency by 5–10%.. IDI engines are also more difficult to start and usually require the use of glow plugs. IDI engines may be cheaper to build but generally require a higher compression ratio than the DI counterpart. IDI also makes it easier to produce smooth, quieter running engines with a simple mechanical injection system since exact injection

	timing is not as critical. Most modern automotive engines are DI which have the benefits of greater efficiency, easier starting, however IDI engines can still be found in the many ATV and small Diesel applications. (4M)
9	**What are the Effects of turbo charging? (13 M)**BTL5 **Answer: Page 3.70, 3.67-Dr.S.Senthil** The following are the effects of supercharging engines. Some of the points refer to CI engines: Higher power output, Mass of charge inducted is greater, Better atomization of fuel, Better mixing of fuel and air, Combustion is more complete and smoother, Can use inferior (poor ignition quality) fuels, Scavenging of products is better, Improved torque over the whole speed range, Quicker acceleration (of vehicle) is possible, Reduction in diesel knock tendency and smoother operation, Increased detonation tendency in SI engines, Improved cold starting, Eliminates exhaust smoke, Lowers specific fuel consumption, in turbocharging, Increased mechanical efficiency, Extent of supercharging is limited by durability, reliability and fuel economy ,Increased thermal stresses, Increased turbulence may increase heat losses, Increased gas loading, Valve overlap period has to be increased to about 60 to 160 degrees of crank angle, Necessitates better cooling of pistons and valves. . **(13M)**
10	**Discuss the significance of air-motion in a CI engine. Also define and mention the significance of swirl, tumble and squish. (13 M)**BTL5 **Answer: Page 3.70, 3.67-Dr.S.Senthil** The air motion inside the cylinder greatly influences the performance of diesel engines. It is one of the major factors that controls the fuel-air mixing in diesel engines. Air-fuel mixing influences combustion, performance and emission level in the engine. The air motion inside the cylinder mainly depends on manifold design, inlet and exhaust valve profile and combustion chamber configuration. The initial in-cylinder intake flow pattern is set up by the intake process, and then it is modified during the compression process. The shape of the bowl in the piston and the intake system, control the turbulence level and air-fuel mixing of the DI diesel engine. The variation of shape of intake system, shape of piston cavity, etc. lead to a change in the flow field inside the engine. (3M) **EFFECTS OF AIR MOTION** The air motion inside the cylinder 1.Atomizes the injected fuel into droplets of different sizes. 2. Distributes the fuel droplets uniformly in the air charge. 3. Mixes injected fuel droplets with the air mass. 4. Assists combustion of fuel droplets. 5. Peels off the combustion products from the surface of the burning drops as they are being consumed. 6. Supplies fresh air to the interior portion of the fuel drops and thereby ensures complete combustion. 7. Reduces delay period. 8. Reduces after burning of the fuel. 9. Better utilization of air contained in the cylinder. Swirl is defined as the organized rotation of the charge about the cylinder axis. It is created by bringing the intake flow into the cylinder with an initial angular momentum. Swirl is generated during the intake process in DI diesel engines by the intake port and subsequently by combustion chamber geometry during the compression stroke. The swirl intensity increases the tangential

	component of the velocity of air inside the cylinder, which aids in the mixing of fuel and air, and significantly affects the combustion and emission characteristics of diesel engines. The squish motion of air is brought about by a recess in the piston crown. At the end of the compression stroke, the piston is brought to within a very small distance from the cylinder head. This fact causes a flow of air from the periphery of the cylinder to its center and into the recess in the piston crown. This radial inward movement of air is called squish by Ricardo. Turbulence contributes to the dispersion of fuel and the micro mixing of fuel and air respectively. As such, they greatly influence the diesel engine performance. The flow processes in the engine cylinder are turbulent. In turbulent flows, the rates of transfer and mixing are several times greater than the rates due to molecular diffusion. This turbulent diffusion results from the local fluctuations in the flow field. It leads to increased rates of momentum and heat and mass transfer, and is essential to the satisfactory operation of Spark Ignition and Diesel engines.(10M)
Part *C	
1	**Discuss about the functions, requirements and types combustion chambers used in CI engine with neat sketch. (15 M)**(**April 2018)** BTL5 **Answer: Page 3.70, 3.67-Dr.S.Senthil** The shape of the combustion chamber and the fluid dynamics inside the chamber are of great importance in diesel combustion. Diesel engines are divided into two basic categories according to their combustion chamber design. (2M) 1)Direct-Injection (DI) engines: This type of combustion chamber is also called an open combustion chamber. In this type, the entire volume of the combustion chamber is located in the main cylinder and the fuel is injected into this volume. (3M) 2)Indirect-Injection (IDI) engines: This type of combustionchambers, the combustion space is divided into two parts, one part in the main cylinder and the other part in the cylinder head. The fuel injection is effected usually into that part of the chamber located in the cylinder head. (3M) These chambers are classified further into: (a) Swirl chamber in which compression swirl is generated. (b) Pre combustion chamber in which combustion swirl is induced.

(c) Air cell chamber in which both compression and combustion swirl are induced. (2M)



(2M)

Shallow depth chamber

In the shallow depth chamber the depth of the cavity provided in the piston is quite small. This chamber is usually adopted for large engines running at low speeds. Since the cavity diameter is very large, the squish is negligible.

Hemispherical chamber

This chamber also gives small squish. However, the depth to diameter ratio can be varied to give any desired squish to give better performance.

Cylindrical chamber

This design was attempted in recent diesel engines. This is a modification of the cylindrical chamber in the form of a truncated cone with a base angle of 30^o. The swirl was produced by masking the valve for nearly 180^o of circumference. Squish can also be varied by varying the depth.

Toroidal chamber

The idea behind this shape is to provide a powerful squish along with the air movement, similar to that of the familiar smoke ring, within the toroidal chamber. Due to powerful squish the mask needed on inlet valve is small and there is better utilization of oxygen. The cone angle of spray for this type of chamber is $150^o$to 160^o. (3M)

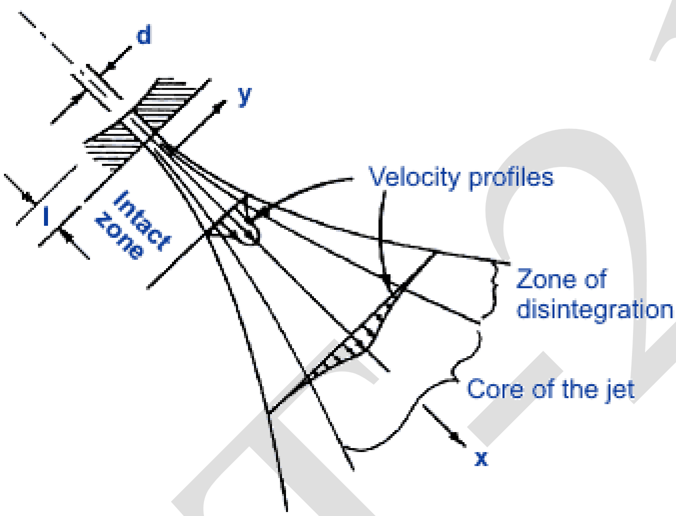
2

Explain the spray formation, spray behavior, spray structure and spray penetration in diesel engine. (15 M)BTL5

Answer: Page 3.67-Dr.S.Senthil 2018

Fuel Atomization

The first step in the mixture formation process in the conventional, mixing controlled diesel engine combustion is spray formation. Figure 1 shows a spray formed by injecting fuel from a single hole in stagnant air. Upon leaving the nozzle hole, the jet becomes completely turbulent a very short distance from the point of discharge and mixes with the surrounding air. This entrained air is carried away by the jet and increases the mass-flow in the x-direction and causes the jet to spread out in the y-direction. Two factors lead to a decrease in the jet velocity: the conservation of momentum when air is entrained into the jet and frictional drag of the liquid droplets. Figure 1 gives the velocity distribution at two cross sections. The fuel velocity is highest at the centerline and decreases to zero at the interface between the zone of disintegration (or the conical envelope of the spray) and ambient air. (5M)



(3M)

Figure Schematic of a spray from a single hole nozzle

Primary Atomization. Near the injector nozzle, the continuous liquid jet disintegrates into filaments and drops through interaction with the gas in the cylinder. This initial break-up of the continuous liquid jet is referred to as *primary atomization*.

In general, the atomization of a jet can be divided into different regimes depending on the jet velocity:

- *Rayleigh Regime.* In this low jet velocity regime, breakup is due to the unstable growth of surface waves caused by surface tension and results in drops larger than the jet diameter.
- *First Wind Induced Breakup Regime.* In this medium jet velocity regime, forces due to the relative motion of the jet and the surrounding air augment the surface tension force, and lead to drop sizes of the order of the jet diameter.
- *Second Wind-Induced Breakup Regime.* In this high jet velocity regime breakup is

	characterized by divergence of the jet spray after an intact or undisturbed length downstream of the nozzle. The unstable growth of short-wavelength waves induced by the relative motion between the liquid and surrounding air produces droplets whose average size is much less than the jet diameter. • *Atomization Regime.* At very high jet velocity, breakup of the outer surface of the jet occurs at, or before, the nozzle exit plane. The average droplet diameter is much smaller than the nozzle diameter. Aerodynamic interactions at the liquid/gas interface appear to be one major component of the atomization mechanism in this regime. (5M) Initial break-up in diesel fuel jets generally occurs in the atomization regime. The dominant mechanisms driving this process are not entirely clear. Interdependent phenomena such as turbulence and collapse of cavitating bubbles may initiate velocity fluctuations in the flow within the nozzle of the injector that destabilize the exiting liquid jet. The unsteadiness of the injection velocity and drop shedding also play an important role. (2M)
3	**Explain the principle of operation of turbocharger with a neat sketch. Indicate the objectives of turbocharging. (15 M)**BTL5 **Answer: Page 3.43-Dr.S.Senthil 2018** **Principle of operation:**Have you ever watched cars buzzing past you with sooty fumes streaming from their tailpipe. It's obvious exhaust fumes cause air pollution, but it's much less apparent that they're wasting energy at the same time. The exhaust is a mixture of hot gases pumping out at speed and all the energy it contains—the heat and the motion (kinetic energy)—is disappearing uselessly into the atmosphere. Wouldn't it be neat if the engine could harness that waste power somehow to make the car go faster? That's exactly what a turbocharger does. Car engines make power by burning fuel in sturdy metal cans called cylinders. Air enters each cylinder, mixes with fuel, and burns to make a small explosion that drives a piston out, turning the shafts and gears that spin the car's wheels. When the piston pushes back in, it pumps the waste air and fuel mixture out of the cylinder as exhaust. The amount of power a car can produce is directly related to how fast it burns fuel. The more cylinders you have and the bigger they are, the more fuel the car can burn each second and (theoretically at least) the faster it can go. (5M)

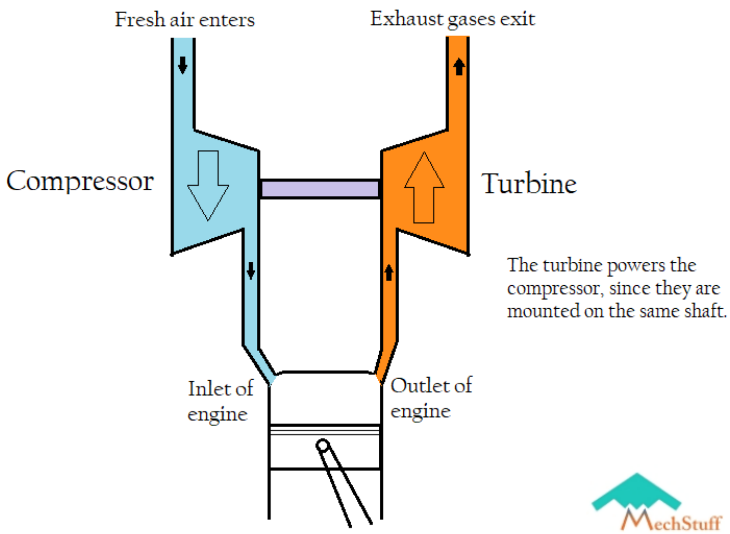


Figure- Principle of operation of turbocharger (5M)

Objectives of Turbocharger: (i) The objective of a turbocharger is to improve an engine's volumetric efficiency by increasing the intake density, (ii) The compressor draws in ambient air and compresses it before it enters into the intake manifold at increased pressure, that results in a greater mass of air entering the cylinders on each intake stroke, (iii) The power needed to spin the centrifugal compressor's is derived from the high pressure and temperature of the engine's exhaust gases, (iv) The turbine converts the engine exhaust's potential pressure energy and kinetic velocity energy into rotational power, which is in turn used to drive the compressor. (5M)

REGULATION : 2017 **ACADEMIC YEAR : 2019-20**

Subject Code :OAT552 **Year/Semester : III/ 05**
Subject Name :INTERNAL COMBUSTION ENGINES
Subject Handler:Dr. S. Boopathi & Mr.D.Arun Kumar

UNIT IV COOLING AND LUBRICATION

Requirements, Types- Air cooling and liquid cooling systems, forced circulation cooling system, pressure and Evaporative cooling systems, properties of coolants for IC engine. Need of lubrication, Lubricants for IC engines - Properties of lubricants, Types of lubrication – Mist, Wet and dry sump lubrication systems

PART * A

Q.No.	Questions
1.	**Why do you need an engine cooling system?BTL1** Internal combustion **engines** remove waste heat through cool intake air, hot exhaust gases, and explicit **engine cooling**. Thus, all heat **engines** need **cooling** to operate. **Cooling** is also **needed** because high temperatures damage **engine** materials and lubricants and becomes even more important in hot climates.
2	**Why lubrication is required?BTL1** **Lubricant** is a substance that reduces friction, heat, and wear when introduced as a film between solid surfaces. Using the correct **lubricant** helps maximize the life of your bearings and machinery, therefore saving money, time, and manpower, thus making operations more efficient and more reliable.
3	**What is the most important property of a lubricant?BTL1** Properties of Good Lubricants. Suitable **Viscosity**: The **viscosity** of oil should not change with rise in temperature. **Oilness**: It ensures the adherence to the bearings and spread over the surface. This property makes oil **smooth** and very important in boundary lubrication.
4	**What is the main purpose of the cooling system?BTL1** The thermostat flow restriction helps to increase the pressure in the cooling system, which makes it harder for the coolant to boil in the **water** pump. However, it does little to help the radiator keep the engine cool.
5	**What are the types of engine cooling systems?BTL1** There are two **types** of **cooling systems**: (i) Air **cooling system** and (ii) Water-**cooling system**. In this **type** of **cooling system**, the heat, which is conducted to the outer parts of the **engine**, is radiated and conducted away by the stream of air, which is obtained from the atmosphere. ... A blower is used to provide air.
6	**What type of pump is used in engine cooling system?BTL1** A **centrifugal** pump like the one used in your car. The water pump is a simple **centrifugal** pump driven by a belt connected to the crankshaft of the engine. The pump circulates fluid whenever the

	engine is running.
7	**Do air cooled engines use coolant?BTL4** If you have a modern car, you probably have a water-**cooled engine** that **uses** a water and **coolant** mixture to, well, **cool** the **engine**. But some **engines** don't need **coolant**. They don't have radiators and they don't regulate the internal temperature of the **engine**. It sounds a little like magic, but it's not.
8	**Why do we prefer water as coolant?BTL1** **Water is** the most common **coolant**. Its high heat capacity and low cost makes it a suitable heat-transfer medium. It **is** usually used with additives, **like** corrosion inhibitors and **antifreeze**. ... Heavy **water is** a neutron moderator used in some nuclear reactors; it also has a secondary function as their **coolant**.
9	**What is perfect pH level for engine coolant?BTL1** Here's **the** pitch: water has a **pH** of 7.0 and **antifreeze** has a **pH** of 10.5, so a 50-50 mix has a **pH** of 8.75, and that's too acidic to protect **the cooling** system, so **the pH** must be modified to something around 10 to protect **the** dissimilar metals in **the** modern **cooling** system.
10	**Is coolant acidic or basic?BTL4** In basic terms, pH is an indication of the acidity or alkalinity of a fluid. Water has a pH of 7, which is **neutral**. An acidic fluid will range from 0-7 pH, and an alkaline fluid will have a range of 7-14 pH. pH levels in your coolant drop due to bacterial emissions.
11	**What are the 3 main properties of coolant?BTL1** Coolant within an engine does three main things: Prevents Freezing and Boiling. Lubricates the **Water** Pump Seal. Inhibits Corrosion.
12	**Why is it important to provide lubrication in an engine?BTL1** It creates a slippery gap between moving metal parts in the **engine** and reduces friction, heat and wear. It coats all of the surfaces within the **engine**, so even when the **motor** is not running, it is protected from corrosion. It disperses the heat that is naturally created by the combustion process within an auto **engine.**
13	**What are the different types of lubrication systems?BTL1** **There are several different types of automatic lubrication systems including:** • Single Line Parallel systems. • Dual Line Parallel systems. • Single Point Automatics. • Single Line Progressive systems (or Series Progressive)

	• Single Line Resistance. • Oil Mist and Air-Oil systems. • Oil re-circulating. • Chain lube systems.
14	**What are the properties of lubricants?BTL1** A good lubricant generally possesses the following characteristics: A high **boiling point** and low freezing point (in order to stay liquid within a wide **range** of **temperature**) A high **viscosity** index. Thermal **stability**.
15	**What is the most important property of a lubricant?BTL1** Properties of Good Lubricants. Suitable **Viscosity**: The **viscosity** of oil should not change with rise in temperature. **Oilness**: It ensures the adherence to the bearings and spread over the surface. This property makes oil **smooth** and very important in boundary lubrication.
16	**What are the types of lubricants?BTL1** Dry Lubricants. Dry lubricants are made up of lubricating particles such as **graphite**, **molybdenum disulfide**, **silicone**, or PTFE.
17	**What are the types of lubrication?BTL1** There are three **different types of lubrication**: boundary, mixed and full film. Each **type** is **different**, but they all rely on a **lubricant** and the additives within the oils to protect against wear. Full-film **lubrication** can be broken down into two **forms**: hydrodynamic and elastohydrodynamic.
18	**What's the difference between a wet and dry sump?BTL1** **Wet sump** systems store the oil **in the**pan but a **dry sump** system stores it **in a** separate tank and pumps the pan clean leaving it essentially "**dry**". The usual set up for a **dry** sup system uses all but one of the stages to scavenge oil from the pan and the last stage is used to pump oil from the motor.
19	**What is a dry sump oil system?BTL1** A **dry-sump system** is a method to manage the lubricating motor **oil** in four-stroke and large two-stroke piston driven internal combustion engines. ... In the wet-**sump system** of most production automobile engines, a **pump** collects this **oil** from the **sump** and directly circulates it back through the engine.
20	**What is meant by a wet sump lubrication system?BTL1** A **wet sump** is a **lubricating oil** management design for piston engines which uses the crankcase as a built-in reservoir for **oil**, as opposed to an external or secondary reservoir used in a **dry sump** design.A **wet sump** offers the advantage of a simple design, using a single pump and no external reservoir.

21	**Why is a dry sump system used in some high-performance vehicles?BTL1** **Dry sump systems** have **several** important advantages over wet **sumps**: Because a **dry sump** does not need to have an oil pan big enough to hold the oil under the engine, the main mass of the engine can be placed lower in the **vehicle**. This helps lower the center of gravity and can also help aerodynamics.
22	**How do I change the oil in my dry sump?BTL1** Draining the oil in a Dry Sump System. To change oil in a Dry Sump System, the oil should first be still warm from running. Dry sumps differ from standard wet sump systems in that the majority of the engines oil is stored in the Dry Sump tank. However, there will still be oil in the pan, lines and filter.
23	**What is mist lubrication system?BTL1** Oil mist lubrication oils are applied to rolling element (antifriction) bearings as an oil mist. Neither oil rings nor constant level lubricators are used in pumps and drivers connected to plant-wide oil mist systems. Oil mist is an atomized amount of oil carried or suspended in a volume of pressurized dry air.
24	**What are the lubrication systems used in IC engines?BTL1** • Mist lubrication system is a very simple type of lubrication. ... • In the wet-sump lubrication system, the bottom of the crank case contains an oil pan or sump that serves as oil supply, oil storage tank and oil cooler. ... • Splash lubrication system is used on small, stationary four-stroke engines.
	Part B
1	**Give the detailed comparison of knock in C.I and factors affecting knock. (13 M)(April/May 2017)** BTL5 **Answer: Page 3.1-Dr.S.Senthil** **Knocking – Factors affecting knock** The diesel combustion process which includes ignition delay, premixed burning due to delay period and diffusion burning and injector needle lift and pressure variation with respect to crank angle can be seen in fig. The premixed burning is responsible for diesel knock. The following are the factors which influence ignition delay and thereby contribute to knock: Higher inlet air pressure, air temperature and compression ratio reduce knock. Supercharging reduces knock. Increased humidity increases knock. Combustion chamber design and associated air motion influence heat losses from the compressed air. Tendency to knock will be lesser, with less heat losses. A combustion chamber with a minimum surface to volume ratio and with lesser intensity of air motion is desirable.**(6M)**

Knocking tendency is lesser in engines where compressed air injects the fuel into the combustion space. In the case of mechanical injection of fuel, finer the atomization of fuel, lesser is the tendency to knock.

A fuel with long pre flame reactions (i.e. self-ignition possible only at a higher temperature) will result in the injection of a considerable amount of fuel before the initial part ignites. This in turn results in a large amount or number of parts of the mixture to ignite at the same time and produce knock. Thus, a good CI engine fuel should have a short ignition delay and low self-ignition temperature, if knock is to be avoided.

Ignition delay of fuels is generally measured in terms of cetane number. Fuels of higher cetane number have shorter ignition delay and thus will have a lesser tendency to knock.

The ignition delay of CI engine fuels may be decreased by the addition of small amounts of certain compounds (called ignition accelerators or improves). These compounds are ethyl nitrate and amylthionitrate. These compounds affect the combustion process by speeding the molecular interactions.**(7M)**

2

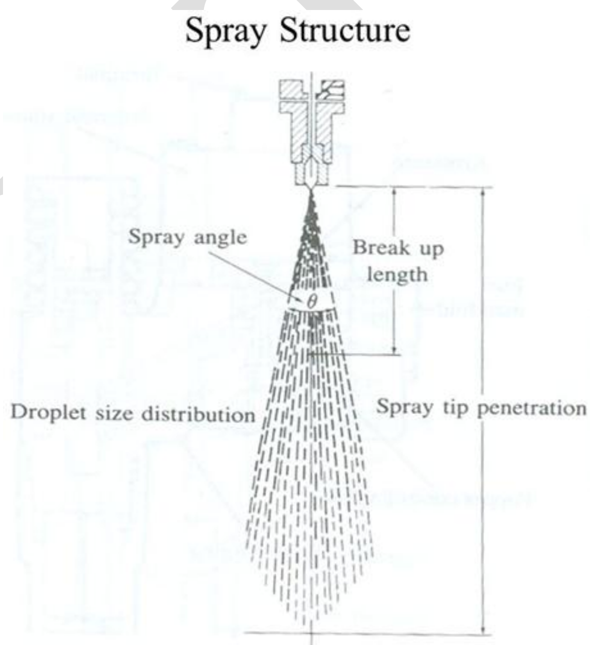
Describe diesel fuel spray behavior and spray structure with neat sketch. (13 M)(April/May 2017)BTL5

Answer: Page 3.70, 3.67-Dr.S.Senthil

Fuel Spray behaviour

- Spray formation is explained as Breakup Mechanism, described as:

Stretching of fuel ligament into sheets or streams, Appearance of ripples and protuberances, Formation of small ligaments or holes in sheets, Collapse of ligaments or holes in sheets, Further breakup due to vibration of droplets, Agglomeration or shedding from large drops, The flow parameters of a jet:Jet Reynolds number, Jet weber number, Ohnesorge number. (5M)



Spray structure

During spraying it is essential to maintain a constant top surface temperature and hence maintain steady-state conditions if a billet with consistent microstructure is to be produced. At the billet surface, during spraying an enthalpy balance must be maintained where the rate of enthalpy lost (H_{out}) from the billet by conduction to the atomizing gas and through the substrate, convection and radiation must be balanced with the rate of enthalpy input (H_{in}) from the droplets in the spray. There are a variety of factors that can be adjusted in order to maintain these conditions: spray height, atomizer gas pressure, melt flow rate, melt superheat and atomizer configuration, being those parameters most readily adjusted.

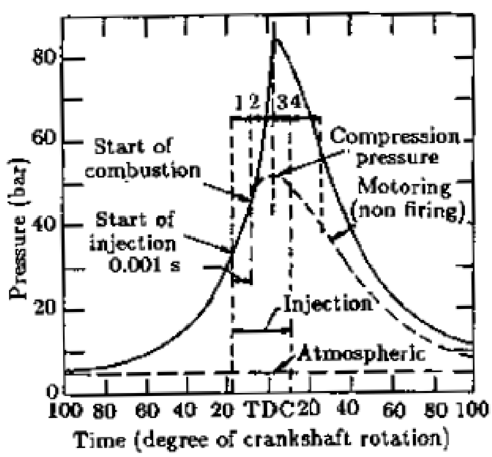
Figure- Spray structure(3M)

Typically equipment such as closed circuit cameras and optical pyrometry can be used to monitor billet size/position and top surface temperature. If H_{out} is much greater H_{in} then a steady temperature is maintained at the billet top surface. The top surface should be in a mushy condition in order to promote sticking of incoming droplets and partial re-melting of solid particles. The necessary partial re-melting of solid droplets explains the absence of dendritic remnants from pre-solidified droplets in the final microstructure. If Hin is insufficient to cause significant re-melting, a 'splat' microstructure of layered droplets will form, typical of thermal spray processes such as vacuum plasma spraying (VPS), arc spraying and high velocity oxy-fuel. Processing maps have been produced for plasma spraying and spray forming using a steady-state heat balance in terms of the interlayer time (time between deposition events) against average deposition rate per unit area. These maps show the boundaries between banded un-fused microstructure and an equated homogeneous structure. (5M)

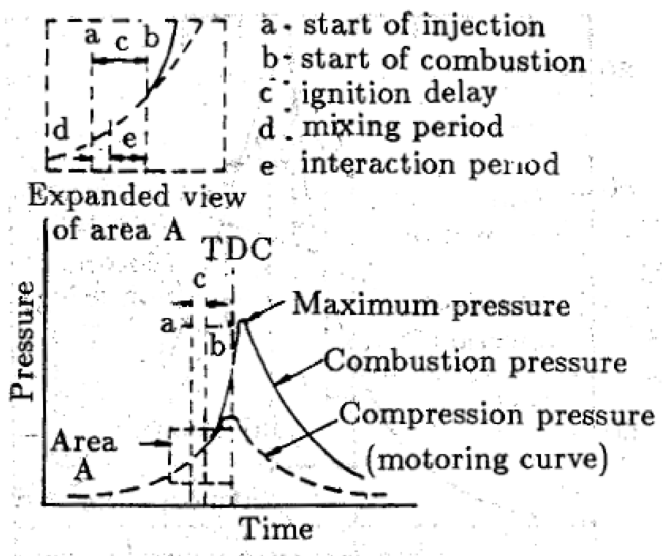
3

With the aid of a schematic diagram, explain the combustion process in a C.I engine. (13 M)(Nov/Dec 2016) BTL5

Answer: Page 3.1-Dr.S.Senthil



Stages of combustion



Pressure Time diagram illustrating Ignition delay

(4M)

Delay period

In an actual engine, fuel injection beings at the point B during the compression stroke. The injected fuel does not ignite immediately. It takes some time to ignite. Ignition sets in at the point C. During the crank travel B to C pressure in the combustion chamber does not rise above the compression curve. The period corresponding to the crank angle B to C is called delay period or ignition delay (about 0.001 seconds).

Uncontrolled combustion takes place will depend upon the following:

	• The quantity of fuel in the combustion chamber at the point C. This quantity depends upon the rate at which fuel is injected during delay period and the duration of ignition delay. • The condition of fuel that has got accumulated in the combustion chamber at the point C. The rate of combustion during the crank travel C to D and the resulting rate of pressure rise determine the quietness and smoothness of operation of the engine. (3M) **Controlled combustion** During controlled combustion, following thing happen. The flame spreads rapidly (but less than 135 m/min), as a turbulent, heterogeneous or diffusion flame with a gradually decreasing rate of energy release. Even in this stage, small auto ignition regions may be present. The diffusion flame is characterized by its high luminosity. Bright, white carbon flame with a peak temperature of 2500^{o} C is noticed. In this stage, radiation plays a significant part in engine heat transfer. During the period D to E, combustion is gradual. Further by controlling the rate of fuel injection, complete control is possible over the rate of burning. Therefore, the rate of pressure rise is controllable. Hence, this stage of combustion is called Gradual combustion or Controlled combustion. (3M) **After burning** At the last stage, i.e. between E and F the fuel that is left in the combustion space when the fuel injection stops is burnt. This stage of combustion is called after burning (burning on the expansion stroke). In the indicator diagram after burning will not be visible. This is because the downward movement of the piston causes the pressure to drop inspired of the heat that is released by the burning of the last portion of the charge. Increasing excess air, or air motion will shorten after burning i.e. reduce the quantity of fuel that may undergo after burning). (3M)
4	**Explain the factors affecting the delay period in C.I engines and summarize them. (13 M)(Nov/Dec 2016)** BTL5 **Answer: Page 3.11-Dr.S.Senthil** Compression ratio , Engine speed, output, Injection timing, Quality of the fuel, Intake temperature, Intake pressure. 1. Compression ratio: With the increase in compression ratio reduces ignition lag, a higher pressure increases density resulting in closer contact of the molecules which reduce the time of action when fuel is injected. 2. Inlet air temperature: With the increase in inlet temperature increases the air temperature after compression and hence decreases the ignition delay.

3. Coolant temperature: Increase in engine speed increases cylinder air temperature and thus reduces ignition lag. The increase in engine speed increases turbulence and this reduces the ignition lag.

4. Jacket water temperature: With the increase in jacket water temperature also increases compressed air temperature and hence delay period is reduced.

5. Fuel temperature: Increase in fuel temperature would reduce both physical and chemical delay period.

6. Intake pressure (supercharging): Increase in intake pressure or supercharging reduces the auto-ignition temperature and hence reduces delay period. Since the compression pressure will increase with intake pressure, the peak pressure will be higher. Also, the power output will be more air and hence more fuel can be injected per stroke.

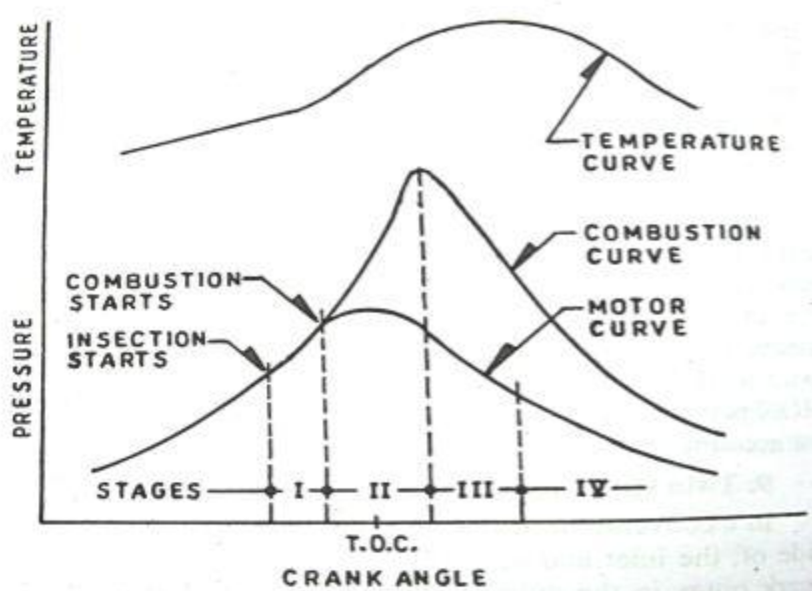
7. Air-fuel ratio (load): With the increase in air-fuel ratio (leaner mixture) the combustion temperatures are lowered and cylinder wall temperatures are reduced and hence the delay period increases, with an increase in load, the air-fuel ratio decreases, operating temperature increases and hence, delay period decreases.

8. Engine size: The engine size has little effect on the delay period in milliseconds. As large engines operate at low revolutions per minute (rpm) because of inertia stress limitations, the delay period in terms of crank angle is smaller and hence less fuel enters the cylinder during the period. Thus combustion in large slow speed Compression Ignition engines is smooth. **(13M)**

5

Discuss in detail about the various stages of combustion in C.I engines. (13 M)(April/May 2016) BTL5

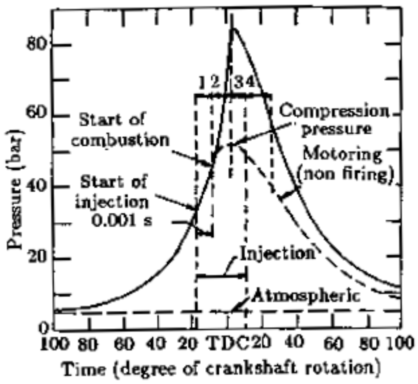
Answer: Page 3.6-Dr.S.Senthil



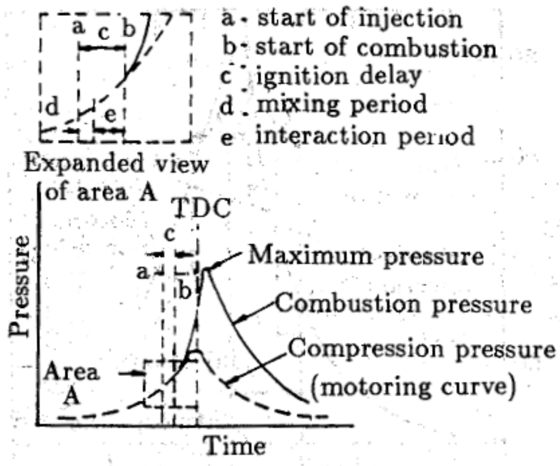
(2M)

Figure- Pressure-Crank angle diagram

	1. Ignition delay- During this stage there is a physical delay period which is the time from beginning of injection to the attainment of chemical reaction conditions. The fuel is atomized and mixed with air and its temperature is raised. This period is followed by a chemical delay period in which pre-flame reactions start and accelerate until local ignition takes place. (2M) 2. Rapid or uncontrolled combustion- This is second stage in which pressure rise is rapid since during delay period the fuel droplets have had time to spread themselves over a wide area and have fresh air around them. This phase extends from end of delay period to point of maximum pressure. (3M) 3. Controlled combustion- The very high temperature and pressure at end of second stage cause the fuel droplets injected during last stage to burn instantly and any further pressure rise can be controlled by purely mechanical means that is injection rate. This period ends at maximum cycle temperature. The heat evolved by end of this phase is 70 to 80 percent of total heat of fuel supplied. (3M) 4. After burning- This fourth stage may not be present in all cases but due to poor distribution of fuel particles combustion may continue in the expansion stroke. Its duration may be 70 to 80 degrees of crank travel from TDC. (3M)
6	**What are the various factors that influence spray penetration in C.I engines? Explain in detail. (13 M) (April/May 2016)** BTL5 **Answer: Page 3.6-Dr.S.Senthil** The graphs of the penetration of plume tips 1 and 6 are shown in Figure 6-4 to Figure 6-7 for gas pressures of 0.5 and 1.0 and injector bogy temperatures of 20, 90 and 120 °C. These graphs show the penetrations measured from the sprays produced by Ethanol and Butanol in comparison to those produced by the Standard Gasoline and the main high and low volatility components n-Pentane and iso-Octane. (6M) The overarching observation from the plume penetration graphs above is the striking similarity of penetration rate reaction to the conditions of Ethanol and Standard Gasoline and of Butanol and iso-Octane. This is especially evident from the graphs showing the spray plume penetrations at the elevated injector body temperature of 120,229°C which is also the condition where the most difference between high and low volatility fuels is observed. (7M)
7	**Using pressure-crank angle diagram explain the different stages of combustion observed a typical CI engine. Why is it undesirable to have the fourth phase of combustion (combustion during the late expansion stroke)?(13 M) (Nov/Dec 2015)** BTL5 **Answer: Page 3.55Dr.S.Senthil**



Stages of combustion



Pressure Time diagram illustrating Ignition delay

(6M)

After burning

At the last stage, i.e. between E and F the fuel that is left in the combustion space when the fuel injection stops is burnt. This stage of combustion is called after burning (burning on the expansion stroke). In the indicator diagram after burning will not be visible.

This is because the downward movement of the piston causes the pressure to drop inspired of the heat that is released by the burning of the last portion of the charge.

Increasing excess air, or air motion will shorten after burning i.e. reduce the quantity of fuel that may undergo after burning). (7M)

8

Discuss the characteristics of DI and IDI diesel engines. (13 M)(April/May 2015) BTL5

Answer: Page 3.70, 3.67-Dr.S.Senthil

Direct injection systems

Direct injection diesel engines inject fuel directly into the cylinder. Usually there is a combustion cup in the top of the piston where the fuel is sprayed. Many different methods of injection can be used. Electronic control of the fuel injection transformed the direct injection engine by allowing much greater control over the combustion. (3M)

Unit direct injection

Unit direct injection also injects fuel directly into the cylinder of the engine. In this system the injector and the pump are combined into one unit positioned over each cylinder controlled by the camshaft. Each cylinder has its own unit eliminating the high-pressure fuel lines, achieving a more consistent injection. This type of injection system, also developed by Bosch, is used by Volkswagen AG in cars (where it is called a *Pumpe-Düse-System*—literally *pump-nozzle system*) and by Mercedes-Benz ("PLD") and most major diesel engine manufacturers in large commercial engines (MAN SE, CAT, Cummins, Detroit Diesel, Electro-Motive Diesel, Volvo). With recent advancements, the pump pressure has been raised to 2,400 bars (240 MPa; 35,000 psi), allowing injection parameters similar to common rail systems.

	(3M) **Common rail direct injection** "Common Rail" injection was first used in production by Atlas Imperial Diesel in the 1920s. The rail pressure was kept at a steady 2,000 - 4,000 psi. In the injectors a needle was mechanically lifted off of the seat to create the injection event.[79] Modern common rail systems use very high-pressures. In these systems an engine driven pump pressurizes fuel at up to 2,500 bar (250 MPa; 36,000 psi), in a "common rail". The common rail is a tube that supplies each computer-controlled injector containing a precision-machined nozzle and a plunger driven by a solenoid or piezoelectric actuator. (3M) **Indirect injection systems** An indirect Diesel injection system (IDI) engine delivers fuel into a small chamber called a swirl chamber, pre combustion chamber, pre chamber or ante-chamber, which is connected to the cylinder by a narrow air passage. Generally the goal of the pre camber is to create increased turbulence for better air / fuel mixing. This system also allows for a smoother, quieter running engine, and because fuel mixing is assisted by turbulence, injector pressures can be lower. Most IDI systems tend to use a single orifice injector. The pre-chamber has the disadvantage of lowering efficiency due to increased heat loss to the engine's cooling system, restricting the combustion burn, thus reducing the efficiency by 5–10%.. IDI engines are also more difficult to start and usually require the use of glow plugs. IDI engines may be cheaper to build but generally require a higher compression ratio than the DI counterpart. IDI also makes it easier to produce smooth, quieter running engines with a simple mechanical injection system since exact injection timing is not as critical. Most modern automotive engines are DI which have the benefits of greater efficiency, easier starting, however IDI engines can still be found in the many ATV and small Diesel applications. (4M)
9	**What are the Effects of turbo charging? (13 M)**BTL5 **Answer: Page 3.70, 3.67-Dr.S.Senthil** The following are the effects of supercharging engines. Some of the points refer to CI engines: Higher power output, Mass of charge inducted is greater, Better atomization of fuel, Better mixing of fuel and air, Combustion is more complete and smoother, Can use inferior (poor ignition quality) fuels, Scavenging of products is better, Improved torque over the whole speed range, Quicker acceleration (of vehicle) is possible, Reduction in diesel knock tendency and smoother operation, Increased detonation tendency in SI engines, Improved cold starting, Eliminates exhaust smoke, Lowers specific fuel consumption, in turbocharging, Increased mechanical efficiency, Extent of supercharging is limited by durability, reliability and fuel economy ,Increased thermal stresses, Increased turbulence may increase heat losses, Increased gas loading, Valve overlap period has to be increased to about 60 to 160 degrees of crank angle, Necessitates better cooling of pistons and valves. . **(13M)**
10	**Discuss the significance of air-motion in a CI engine. Also define and mention the significance of swirl, tumble and squish. (13 M)**BTL5

	Answer: Page 3.70, 3.67-Dr.S.Senthil The air motion inside the cylinder greatly influences the performance of diesel engines. It is one of the major factors that controls the fuel-air mixing in diesel engines. Air-fuel mixing influences combustion, performance and emission level in the engine. The air motion inside the cylinder mainly depends on manifold design, inlet and exhaust valve profile and combustion chamber configuration. The initial in-cylinder intake flow pattern is set up by the intake process, and then it is modified during the compression process. The shape of the bowl in the piston and the intake system, control the turbulence level and air-fuel mixing of the DI diesel engine. The variation of shape of intake system, shape of piston cavity, etc. lead to a change in the flow field inside the engine. (3M) **EFFECTS OF AIR MOTION** The air motion inside the cylinder 1.Atomizes the injected fuel into droplets of different sizes. 2. Distributes the fuel droplets uniformly in the air charge. 3. Mixes injected fuel droplets with the air mass. 4. Assists combustion of fuel droplets. 5. Peels off the combustion products from the surface of the burning drops as they are being consumed. 6. Supplies fresh air to the interior portion of the fuel drops and thereby ensures complete combustion. 7. Reduces delay period. 8. Reduces after burning of the fuel. 9. Better utilization of air contained in the cylinder. Swirl is defined as the organized rotation of the charge about the cylinder axis. It is created by bringing the intake flow into the cylinder with an initial angular momentum. Swirl is generated during the intake process in DI diesel engines by the intake port and subsequently by combustion chamber geometry during the compression stroke. The swirl intensity increases the tangential component of the velocity of air inside the cylinder, which aids in the mixing of fuel and air, and significantly affects the combustion and emission characteristics of diesel engines. The squish motion of air is brought about by a recess in the piston crown. At the end of the compression stroke, the piston is brought to within a very small distance from the cylinder head. This fact causes a flow of air from the periphery of the cylinder to its center and into the recess in the piston crown. This radial inward movement of air is called squish by Ricardo. Turbulence contributes to the dispersion of fuel and the micro mixing of fuel and air respectively. As such, they greatly influence the diesel engine performance. The flow processes in the engine cylinder are turbulent. In turbulent flows, the rates of transfer and mixing are several times greater than the rates due to molecular diffusion. This turbulent diffusion results from the local fluctuations in the flow field. It leads to increased rates of momentum and heat and mass transfer, and is essential to the satisfactory operation of Spark Ignition and Diesel engines.(10M)
Part *C	
1	**Discuss about the functions, requirements and types combustion chambers used in CI engine with neat sketch. (15 M)(April 2018)** BTL5 **Answer: Page 3.70, 3.67-Dr.S.Senthil** The shape of the combustion chamber and the fluid dynamics inside the chamber are of great importance in diesel combustion. Diesel engines are divided into two basic categories according to their combustion chamber design.

(2M)

1)Direct-Injection (DI) engines: This type of combustion chamber is also called an open combustion chamber. In this type, the entire volume of the combustion chamber is located in the main cylinder and the fuel is injected into this volume. (3M)

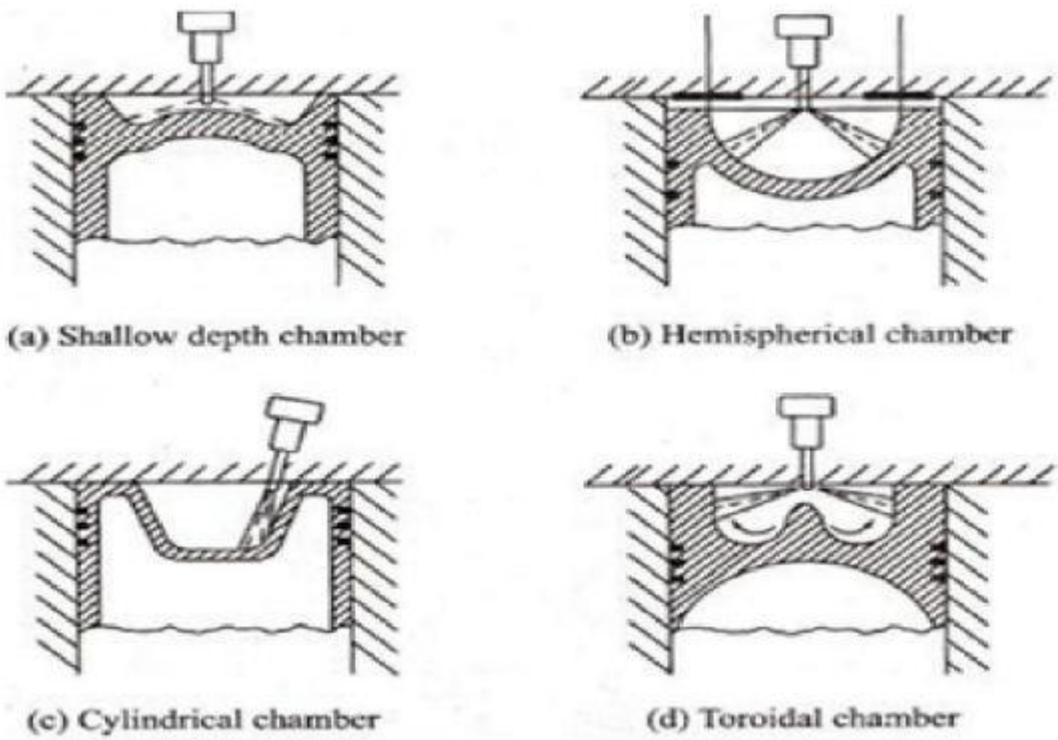
2)Indirect-Injection (IDI) engines: This type of combustionchambers, the combustion space is divided into two parts, one part in the main cylinder and the other part in the cylinder head. The fuel injection is effected usually into that part of the chamber located in the cylinder head. (3M)

These chambers are classified further into:

(b) Swirl chamber in which compression swirl is generated.

(b) Pre combustion chamber in which combustion swirl is induced.

(c) Air cell chamber in which both compression and combustion swirl are induced. (2M)



(2M)

Shallow depth chamber

In the shallow depth chamber the depth of the cavity provided in the piston is quite small. This chamber is usually adopted for large engines running at low speeds. Since the cavity diameter is very large, the squish is negligible.

Hemispherical chamber

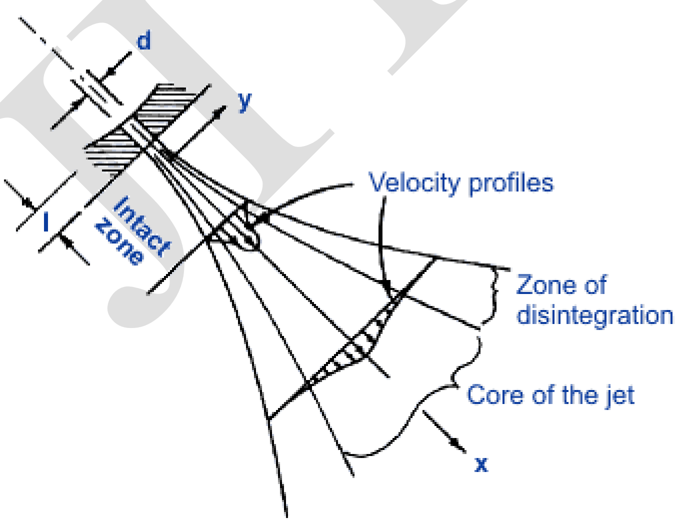
	This chamber also gives small squish. However, the depth to diameter ratio can be varied to give any desired squish to give better performance. **Cylindrical chamber** This design was attempted in recent diesel engines. This is a modification of the cylindrical chamber in the form of a truncated cone with a base angle of 30^o. The swirl was produced by masking the valve for nearly 180^o of circumference. Squish can also be varied by varying the depth. **Toroidal chamber** The idea behind this shape is to provide a powerful squish along with the air movement, similar to that of the familiar smoke ring, within the toroidal chamber. Due to powerful squish the mask needed on inlet valve is small and there is better utilization of oxygen. The cone angle of spray for this type of chamber is $150^o$to 160^o. (3M)
2	**Explain the spray formation, spray behavior, spray structure and spray penetration in diesel engine. (15 M)**BTL5 **Answer: Page 3.67-Dr.S.Senthil 2018** **Fuel Atomization** The first step in the mixture formation process in the conventional, mixing controlled diesel engine combustion is spray formation. Figure 1 shows a spray formed by injecting fuel from a single hole in stagnant air. Upon leaving the nozzle hole, the jet becomes completely turbulent a very short distance from the point of discharge and mixes with the surrounding air. This entrained air is carried away by the jet and increases the mass-flow in the x-direction and causes the jet to spread out in the y-direction. Two factors lead to a decrease in the jet velocity: the conservation of momentum when air is entrained into the jet and frictional drag of the liquid droplets. Figure 1 gives the velocity distribution at two cross sections. The fuel velocity is highest at the centerline and decreases to zero at the interface between the zone of disintegration (or the conical envelope of the spray) and ambient air. (5M)  **(3M)**

Figure Schematic of a spray from a single hole nozzle

Primary Atomization. Near the injector nozzle, the continuous liquid jet disintegrates into filaments and drops through interaction with the gas in the cylinder. This initial break-up of the continuous liquid jet is referred to as *primary atomization*.

In general, the atomization of a jet can be divided into different regimes depending on the jet velocity:

- *Rayleigh Regime.* In this low jet velocity regime, breakup is due to the unstable growth of surface waves caused by surface tension and results in drops larger than the jet diameter.
- *First Wind Induced Breakup Regime.* In this medium jet velocity regime, forces due to the relative motion of the jet and the surrounding air augment the surface tension force, and lead to drop sizes of the order of the jet diameter.
- *Second Wind-Induced Breakup Regime.* In this high jet velocity regime breakup is characterized by divergence of the jet spray after an intact or undisturbed length downstream of the nozzle. The unstable growth of short-wavelength waves induced by the relative motion between the liquid and surrounding air produces droplets whose average size is much less than the jet diameter.
- *Atomization Regime.* At very high jet velocity, breakup of the outer surface of the jet occurs at, or before, the nozzle exit plane. The average droplet diameter is much smaller than the nozzle diameter. Aerodynamic interactions at the liquid/gas interface appear to be one major component of the atomization mechanism in this regime. (5M)

Initial break-up in diesel fuel jets generally occurs in the atomization regime. The dominant mechanisms driving this process are not entirely clear. Interdependent phenomena such as turbulence and collapse of cavitating bubbles may initiate velocity fluctuations in the flow within the nozzle of the injector that destabilize the exiting liquid jet. The unsteadiness of the injection velocity and drop shedding also play an important role.
(2M)

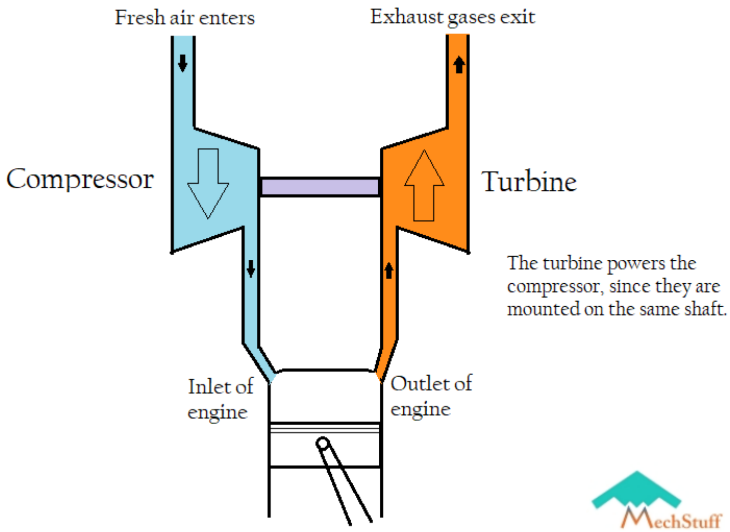
3

Explain the principle of operation of turbocharger with a neat sketch. Indicate the objectives of turbocharging. (15 M)BTL5

Answer: Page 3.43-Dr.S.Senthil 2018

Principle of operation: Have you ever watched cars buzzing past you with sooty fumes streaming from their tailpipe. It's obvious exhaust fumes cause air pollution, but it's much less apparent that they're wasting energy at the same time. The exhaust is a mixture of hot gases pumping out at speed and all the energy it contains—the heat and the motion (kinetic energy)—is disappearing uselessly into the atmosphere. Wouldn't it be neat if the engine could harness that waste power somehow to make the car go faster? That's exactly what a turbocharger does.

Car engines make power by burning fuel in sturdy metal cans called cylinders. Air enters each cylinder, mixes with fuel, and burns to make a small explosion that drives a piston out, turning the shafts and gears that spin the car's wheels. When the piston pushes back in, it pumps the waste air and fuel mixture out of the cylinder as exhaust. The amount of power a car can produce is directly

	related to how fast it burns fuel. The more cylinders you have and the bigger they are, the more fuel the car can burn each second and (theoretically at least) the faster it can go. (5M)
	 Figure- Principle of operation of turbocharger (5M) Objectives of Turbocharger: (i) The objective of a turbocharger is to improve an engine's volumetric efficiency by increasing the intake density, (ii) The compressor draws in ambient air and compresses it before it enters into the intake manifold at increased pressure, that results in a greater mass of air entering the cylinders on each intake stroke, (iii) The power needed to spin the centrifugal compressor's is derived from the high pressure and temperature of the engine's exhaust gases, (iv) The turbine converts the engine exhaust's potential pressure energy and kinetic velocity energy into rotational power, which is in turn used to drive the compressor. (5M)

<table>
<tr><td colspan="2">UNIT V MODERN TECHNOLOGIES IN IC ENGINES</td></tr>
<tr><td colspan="2">HCCI Engines – construction and working, CRDI injection system, GDI Technology, E - Turbocharger, Variable compression ratio engines, variable valve timing technology, Fuel cell, Hybrid Electric Technology.</td></tr>
<tr><td colspan="2">PART * A</td></tr>
<tr><td>Q.No.</td><td>Questions</td></tr>
<tr><td>1.</td><td>What is the potential benefit of an HCCI engine?BTL1

Homogeneous Charge Compression Ignition (HCCI) engines can have efficiencies as high as compression-ignition, direct-injection (CIDI) engines (an advanced version of the commonly known diesel engine), while producing ultra-low emissions of oxides of nitrogen (NO_x) and particulate matter (PM).</td></tr>
<tr><td>2</td><td>Which fuel is used in HCCI engine?BTL1

HCCI is more difficult to control than other combustion engines, such as SI and diesel. In a typical gasoline engine, a spark is used to ignite the pre-mixed fuel and air. In Diesel engines, combustion begins when the fuel is injected into pre-compressed air. In both cases, combustion timing is explicitly controlled.</td></tr>
<tr><td>3</td><td>What is the advantage of CRDI engine?BTL1

It also offers superior pick up, lower levels of noise and vibration, higher mileage, lower emissions, lower fuel consumption, and improved performance. In India, diesel is cheaper than petrol and this fact adds to the credibility of the common rail direct injection system.</td></tr>
<tr><td>4</td><td>What Crdi means?BTL1

Common rail direct injection :CRDi stands for Common rail direct injection which means direct injection of fuel into the cylinder of a diesel engine through a single common line called common rail which is connected to fuel injectors.</td></tr>
<tr><td>5</td><td>Which is better Crdi vs VTVT?BTL1

VVT and VTVT have the same features which helps to increase the car's optimum mileage.VVT is variable valve timing and VTVT(variable timing valve train) is the same but it is manufactured by hyundai. The engine performance will be optimum and in control when compared to other engines.Almost all vehicles use CRDI.</td></tr>
<tr><td>6</td><td>Which is better Crdi or TDI?BTL1

“CRDI” is for “Common Rail Direct Injection” while TDI is for “Turbocharged Direct Injection.” both are developed for diesel engines. ... Though CRDI is just a bit more expensive than other diesel engine technologies, you can save a lot in the fuel costs since LESS FUEL IS WASTED.</td></tr>
<tr><td>7</td><td>What is CRDI engine technology?BTL1

CRDi stands for Common Rail Direct Injection meaning, direct injection of the fuel into the</td></tr>
</table>

	cylinders of a diesel **engine** via a single, common line, called the common rail which is connected to all the fuel injectors.
8	**What is GDI technology?**BTL1 Gasoline direct injection (**GDI**) (also known as petrol direct injection, direct petrol injection, spark-ignited direct injection (SIDI) and fuel-stratified injection (FSI)), is a form of fuel injection employed in modern two-stroke and four-stroke gasoline engines.
9	**Which cars have GDI engines?**BTL1 **GDI Dominates Ward's 10 Best Engines List** • 3.0L TFSI Supercharged DOHC V-6 (Audi A6) • 2.0L N20 Turbocharged DOHC I-4 (BMW Z4/528i) • 3.0L N55 Turbocharged DOHC I-6 (BMW 335i coupe) • 3.6L Pentastar DOHC V-6 (Chrysler 300S/Jeep Wrangler) • 2.0L EcoBoost DOHC I-4 (Ford Edge) • 5.0L DOHC V-8 (Ford Mustang Boss 302) • 2.0L Turbocharged DOHC I-4 (Buick Regal GS)
10	**Why is direct injection more efficient?**BTL1 One, they use a "leaner" fuel-air mixture ratio. Second, the way the fuel disperses inside the chamber allows it to burn more efficiently. ... A leaner mixture allows fuel to be burned much more conservatively. A second efficiency plus for direct injection engines is that they can burn their fuel more completely.
11	**Is a GDI engine good?**BTL4 With GDI engines, a common fuel line injects gasoline at high pressure directly into the combustion chamber of each cylinder. ... In addition, your car gets improved fuel efficiency and reduced emissions. While great, the power of the GDI engine is a double-edged sword.
12	**Do direct injection have spark plugs?**BTL3 Direct injection came first to diesels, no spark plugs there. Some of the latest generation of gasoline engines now include direct injection, and these do have spark plugs. ... Spark plug ignites the air fuel mixture in the combustion cylinder. injectors are used to allow only the fuel.
13	**What is the difference between a turbo and a hybrid turbo?**BTL1 A hybrid turbocharger is an electric turbocharger consisting of a high speed turbine-generator and a high speed electric air compressor. ... In other words, hybrid turbocharger refers to a series hybrid setup, in which compressor speed and power are independent from turbine speed and power.

14	**What is the difference between a turbocharger and a supercharger on a car's engine?**BTL1 A turbo/supercharged engine produces more power overall than the same engine without the charging. ... The key difference between a turbocharger and a supercharger is its power supply. Something has to supply the power to run the air compressor. In a supercharger, there is a belt that connects directly to the engine.
15	**Are hybrid turbos good?**BTL4 For many road-going cars, a standard specification, good quality Service Exchange turbocharger will be capable of giving a small increase in power with minor modification to the engine and ECU. A hybrid turbo on a standard engine may offer a small benefit, but will be more effective on a modified engine.
16	**Are superchargers more reliable than turbos?**BTL4 The **turbocharger** is not connected to the engine and can spin much faster. Both will produce large amounts of power. ... **Superchargers** can deliver their boost at lower RPMs then a **turbocharger**, whereas the **turbocharger** works best at high engine speeds.**Turbochargers** are quieter and **superchargers** are **more reliable**.
17	**What is variable compression ratio engine?**BTL1 Variable compression ratio is a technology to adjust the compression ratio of an internal combustion engine while the engine is in operation. This is done to increase fuel efficiency while under varying loads.
18	**What are the benefits of variable valve timing?**BTL1 Engine valves control the intake of fresh air and fuel, and the exhaust of combustion gases. VVT and lift systems adjust the timing of the valves to match the operating conditions of the engine. This improves efficiency over a wide range of engine operating speeds.
19	**What is Variable Valve Timing with intelligence?**BTL1 VVT-i, or Variable Valve Timing with intelligence, is an automobile variable valve timing technology developed by Toyota. ... Adjustments in the overlap time between the exhaust valve closing and intake valve opening result in improved engine efficiency.
20	**Who invented variable valve timing?**BTL1 Corliss Orville Burandt
21	**What is a fuel cell and how does it work?**BTL1 But in general terms, hydrogen atoms enter a fuel cell at the anode where a chemical reaction strips them of their electrons. The hydrogen atoms are now "ionized," and carry a positive electrical charge. The negatively charged electrons provide the current through wires to do work.
22	**What are the types of fuel cells?**BTL1 Polymer electrolyte membrane fuel cells,Direct methanol fuel cells, Alkaline fuel cells, Phosphoric

	acid fuel cells, Molten carbonate fuel cells, Solid oxide fuel cells, Reversible fuel cells.
23	**What are fuel cells used for?BTL1** A fuel cell is a device that uses a source of fuel, such as hydrogen, and an oxidant to create electricity from an electrochemical process. Much like the batteries that are found under the hoods of automobiles or in flashlights, a fuel cell converts chemical energy to electrical energy.
24	**What is fuel cell and its advantages?BTL1** Benefits include: Fuel cells have a higher efficiency than diesel or gas engines. Most fuel cells operate silently, compared to internal combustion engines. ... Fuel cells can eliminate pollution caused by burning fossil fuels; for hydrogen fuelledfuel cells, the only by-product at point of use is water.
25	**What does hybrid electric mean?BTL1** A hybrid car is one that uses more than one means of propulsion - that means combining a petrol or diesel engine with an electric motor. The main advantages of a hybrid are that it should consume less fuel and emit less CO2 than a comparable conventional petrol or diesel-engined vehicle.
26	**Define hybrid technology.**BTL1 A hybrid vehicle uses two or more distinct types of power, such as internal combustion engine to drive an electric generator that powers an electric motor, e.g. in diesel-electric trains using diesel engines to drive an electric generator that powers an electric motor, and submarines.
27	**List the disadvantages of hybrid cars?**BTL1 Environmentally Friendly: One of the biggest advantage of hybrid car over gasoline powered car is that it runs cleaner and has better gas mileage which makes it environmentally friendly. A hybrid vehicle runs on twin powered engine (gasoline engine and electric motor) that cuts fuel consumption and conserves energy.
28	**How long does a hybrid battery last?**BTL1 The length of time your hybrid battery will last is clearly dependent on several factors. While Toyota states an 8 year lifespan we typically see lifespans of 5 – 10 years depending on these factors.
Part B	
1	**Explain the construction and working of common rail direct injection (CRDI) system with neat block diagram. (13 M)(April/May 2017)** BTL5 **Answer: Page 6.30-Dr.S.Senthil**

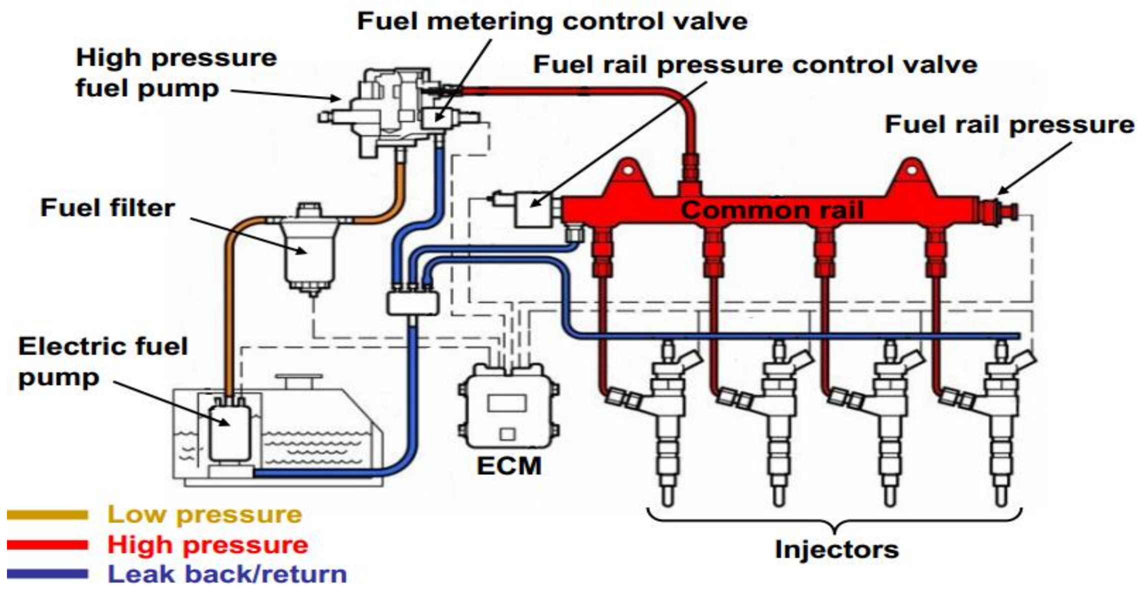


Figure- Common Rail Injection System **(5M)**

Common Rail Injection System has benefits of High Injection Pressure and finer atomizing of fuels and reduction in overall exhaust emissions.

Fuel Metering Control Valve:

It is located at the backside of high pressure pump and controls the fuel intake volume to the pump. It receives battery voltage from engine Electronic Control module.

Fuel Intake Volume Regulation:

Only the required volume of fuel is supplied to the common rail from the high pressure pump. Reduced fuel flow around the system result in lower fuel return flow temperature.

High Pressure Regulator Valve:

It is fitted to back of high pressure pump and it controls the high pressure fuel delivery to the common rail. Excess fuel will return to the fuel tank.

Common Rail (or) High Pressure Accumulator:

Fuel is supplied to the common rail at high pressure from high pressure pump which stores it and distributes to the individual injectors. It also damps the vibration caused due to injection and pressure vibrations.

Typical Volume of fuel held in Common rail is 16 to 20 cm^3

Fuel Rail Pressure Sensor:

It monitors the pressure of fuel in the common rail and signals to the ECM

Rail Pressure Limiter Valve:

This valve fitted at common Rail will release the pressure if abnormal pressure is build up in the system. **(8M)**

2

Discuss the following (i) Hybrid electric vehicle (HEV) and (ii) On-Board diagnostics (OBD). (13 M)(April/May 2017) BTL5

Answer: Page 6.13 & 6.1-Dr.S.Senthil

Hybrid electric vehicle (HEV) The addition of a battery-powered electric motor increases the fuel efficiency of hybrids in a number of ways.

Like the switch that turns off your refrigerator's light bulb when the door is closed, "**idle-off**" is a feature that turns off your car's conventional engine when the vehicle is stopped, saving fuel. The battery provides energy for the air conditioner and accessories while the vehicle idles at stoplights or in traffic, and the electric motor can start the vehicle moving again. If needed, the conventional engine will reengage to provide more power for acceleration.

"**Regenerative braking**" is another fuel-saving feature. Conventional cars rely entirely on friction brakes to slow down, dissipating the vehicle's kinetic energy as heat. Regenerative braking allows some of that energy to be captured, turned into electricity, and stored in the batteries. This stored electricity can later be used to run the motor and accelerate the vehicle.

Plug-in hybrid vehicles combine a gas engine with an electric motor and battery.

Having an electric motor also allows for more efficient engine design. This "**power assist**" feature helps reduce demands on a hybrid's gasoline engine, which in turn can be downsized and more efficiently operated. The gasoline engine produces less power, but when combined with electric motors, the system's total power can equal or exceed that of a conventional vehicle.

The most efficient hybrids utilize "**electric-only drive**," allowing the vehicle to drive entirely on electricity and use less fuel. In hybrids that can't be plugged-in, electric-only drive is typically only utilized at low speeds and startup, enabling the gas or diesel-powered engine to operate at higher speeds, where it's most efficient.. Most plug-in hybrids—which tend to have larger batteries and motors—can drive entirely on electricity at relatively high speeds for extended distances (typically 10 to 30 miles).

Different hybrids also use different types of "drivetrains," the mechanical components that deliver power to the driving wheels. **(8M)**

On-board diagnostics (**OBD**) is an automotive term referring to a vehicle's self-diagnostic and reporting capability. OBD systems give the vehicle owner or repair technician access to the status of the various vehicle subsystems. The amount of diagnostic information available via OBD has varied widely since its introduction in the early 1980s versions of on-board vehicle computers. Early versions of OBD would simply illuminate a malfunction indicator light or "idiot light" if a problem was detected but would not provide any information as to the nature of the problem. Modern OBD implementations use a standardized digital communications port to provide real-time data in addition to a standardized series of diagnostic trouble codes, or DTCs, which allow one to rapidly identify and remedy malfunctions within the vehicle.
(5M)

3

(i) Explain the characteristics of a common rail direct injection diesel engine. (ii) Discuss the

	method of obtaining pressure crank angle diagram. List down the parameters that can studied from the pressure crank angle diagram. (13 M) (Nov/Dec 2016) BTL5 **Answer: Page 2.11 -Dr.S.Senthil** (i) (a) ***Fuel pressure independent of engine speed and load conditions.*** This allows for flexibility in controlling both the fuel injection quantity and injection timing and enables better spray penetration and mixing even at low engine speeds and loads. This feature differentiates the common rail system from other injection systems, where injection pressure increases with engine speed, as illustrated in. This characteristic also allows engines to produce higher torque at low engine speed—especially if a variable geometry turbocharger (VGT) is used. It should be noted that while common rail systems could operate with maximum rail pressure held constant over a wide range of engine speeds and loads, this is rarely done. Fuel pressure in common rail systems can be controlled as a function of engine speed and load to optimize emissions and performance while ensuring engine durability is not com*(b) Lower fuel pump peak torque requirements.* As high speed direct injection (HSDI) engines developed, more of the energy to mix the air with fuel came from the fuel spray momentum as opposed to the swirl mechanisms employed in older, IDI combustion systems. Only high pressure fuel injection systems were able to provide the mixing energy and good spray preparation needed for low PM and HC emissions. Promised. (c) *Improved noise quality*. DI engines are characterized by higher peak combustion pressures and, thus, by higher noise than IDI engines. It was found that improved noise and low NOx emissions were best achieved by introducing pilot injection(s). This was most easily realized in the common rail system, which was capable of stable deliveries of small pilot fuel quantities over the entire load/speed range of the engine. **(8M)** **Method of obtaining pressure crank angle diagram:** There is several ways to obtain pressure versus crank angle traces. The first one is through experimental procedure. You will need an in-cylinder pressure sensor and an encoder. Using a Daq board you can acquire these data and, after some simple conversions that can be find in John B. Heywood (Internal combustion engines fundamentals), you will find P-V diagram. Be careful in integration of P-V diagram. A more-easier way to obtain Indicated Power is using engine modelling software's as for example Gt-Power, Avl-Boost, Ricardo Wave. These software's will require some geometric and flow data as inputs, but they can reach good agreement. Also, you can use friction work and brake work to find indicated power. Please, let me know more about what you are doing. I did not understand if you want to calculate Indicated Power of a real engine or you just want a method for generic engines. **(5M)**
4	**With a neat sketch explain in detail about gasoline direct engine. (13 M)(April/May 2016)**BTL5 **Answer: Page 6.32-Dr.S.Senthil** Gasoline direct injection (GDI) (also known as petrol direct injection, direct petrol injection, spark-ignited direct injection (SIDI) and fuel-stratified injection (FSI), is a form of fuel injection employed in modern two-stroke and four-strokegasoline engines. 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.
(5M)

In some applications, gasoline direct injection enables a stratified fuel charge (ultra-lean burn) combustion for improved fuel efficiency, and reduced emission levels at low load. **(2M)**

GDI has seen rapid adoption by the automotive industry over the past years, from 2.3% of production for model year 2008 vehicles to just over 45% expected production for model year 2015.**(2M)**

The major advantages of a GDI engine are increased fuel efficiency and high power output. Emissions levels can also be more accurately controlled with the GDI system. GDI engine operates into two modes 1) overall lean equivalence ratio composition during low load and low speed operation. 2) Homogeneous stoichiometric mode at higher loads and at all loads and higher speed. At medium load region charge is lean or stoichiometric. The combustion system are classified into air guided, wall guided and spray guided system.
(4M)

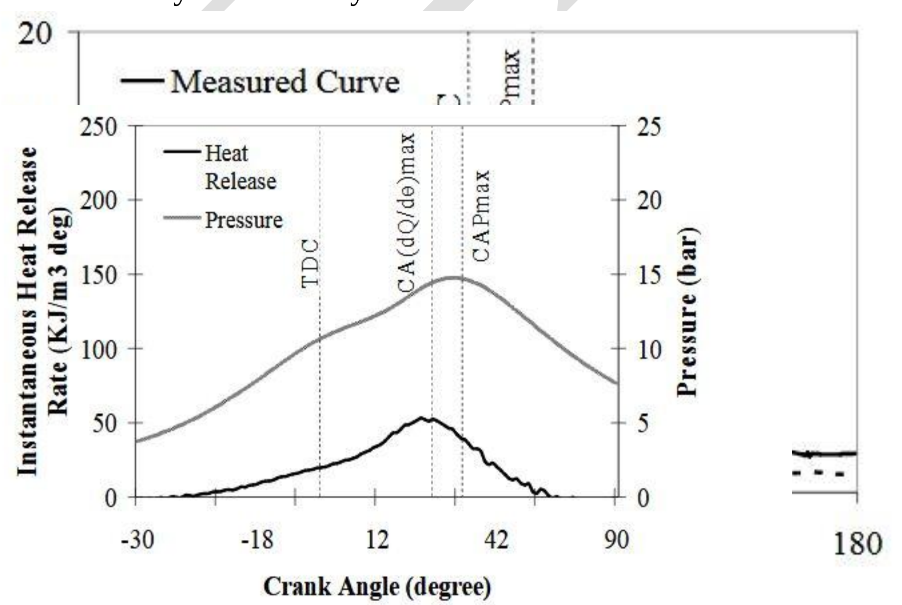
5

Discuss in detail about the heat release analysis in engines.(13 M)(April/May 2016) BTL5

Answer: Page 6.44-Dr.S.Senthil

There is substantial variation in the shape of the curve and the above relation fails to predict the total heat release values. The relation is used to predict the total heat release value and the results. The predicted values are compared with the calculated value obtained from the instantaneous heat release rate curve. The error between the values obtained and the actual heat release values are also indicated in the table. It can be observed from the table that the errors are higher for both very rich and very lean mixtures.

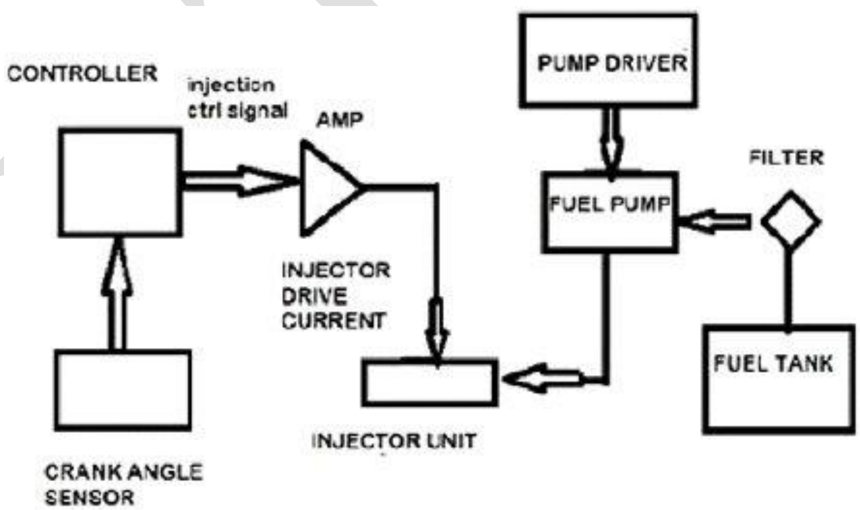
(5M)



(4M)

Figure 6.3 Plot of instantaneous heat release rates calculated from measured cylinder pressure

ık angle

	(4M)
6	**With aneat sketch explain the operation of an electronic fuel injection system used in a S.I engine. (7 M)(April/May 2015)** BTL-5 **Answer: Page 6.44-Dr.S.Senthil** **Electronic injection** Because mechanical injection systems have limited adjustments to develop the optimal amount of fuel into an engine that needs to operate under a variety of different conditions (such as when starting, the engine's speed and load, atmospheric and engine temperatures, altitude, ignition timing, etc.) electronic fuel injection (EFI) systems were developed that relied on numerous sensors and controls. When working together, these electronic components can sense variations and the main system computes the appropriate amount of fuel needed to achieve better engine performance based on a stored "map" of optimal settings for given requirements.in 1953, the Bendix Corporation began exploring the idea of an electronic fuel injection system as a way eliminate the well-known problems of traditional carburetors. **(4M)**  **Figure . Electronic fuel injection** system **(3M)**

7	**Discuss the method of obtaining the rate of heat transfer from engines. (6 M)** BTL-5 **Answer: Refer class notes** In diesel engines, fuel is often injected into the engine cylinder near the end of the compression stroke, just a few crank angle degrees before top dead center. The liquid fuel is usually injected at high velocity as one or more jets through small orifices or nozzles in the injector tip. It atomizes into small droplets and penetrates into the combustion chamber. The atomized fuel absorbs heat from the surrounding heated compressed air, vaporizes, and mixes with the surrounding high-temperature high-pressure air. As the piston continues to move closer to top dead center (TDC), the mixture (mostly air) temperature reaches the fuel's ignition temperature. Rapid ignition of some premixed fuel and air occurs after the ignition delay period. This rapid ignition is considered the start of combustion (also the end of the ignition delay period) and is marked by a sharp cylinder pressure increase as combustion of the fuel-air mixture takes place. Increased pressure resulting from the premixed combustion compresses and heats the unburned portion of the charge and shortens the delay before its ignition. It also increases the evaporation rate of the remaining fuel. Atomization, vaporization, fuel vapor-air mixing, and combustion continue until all the injected fuel has combusted. **(6M)**
8	**Discuss about the HCCI engines. (13 M)(April 2014)** BTL-5 **Answer: Page 6.44-Dr.S.Senthil** **Homogeneous charge compression ignition** (**HCCI**) is a form of internal combustion in which well-mixed fuel and oxidizer (typically air) are compressed to the point of auto-ignition. As in other forms of combustion, this exothermic reaction releases energy that can be transformed in an engine into work and heat. HCCI combines characteristics of conventional gasoline engine and diesel engines. Gasoline engines combine *homogeneous charge* (HC) with *spark ignition* (SI), abbreviated as HCSI. Diesel engines combine *stratified charge* (SC) with *compression ignition* (CI), abbreviated as SCCI. As in HCSI, HCCI injects fuel during the intake stroke. However, rather than using an electric discharge (spark) to ignite a portion of the mixture, HCCI raises density and temperature by compression until the entire mixture reacts spontaneously. Stratified charge compression ignition also relies on temperature and density increase resulting from compression. However, it injects fuel later, during the compression stroke. Combustion occurs at the boundary of the fuel and air, producing higher emissions, but allowing a leaner and higher compression burn, producing greater efficiency. **(6M)** Controlling HCCI requires microprocessor control and physical understanding of the ignition process. HCCI designs achieve gasoline engine-like emissions with diesel engine-like efficiency. HCCI engines achieve extremely low levels of oxides of nitrogen emissions (NO_x) without a catalytic converter. Hydrocarbons (unburnt fuels and oils) and carbon monoxide emissions still require treatment to meet automobile emissions control regulations. **(4M)** Recent research has shown that the hybrid fuels combining different reactivities (such as gasoline

and diesel) can help in controlling HCCI ignition and burn rates. RCCI, or reactivity controlled compression ignition, has been demonstrated to provide highly efficient, low emissions operation over wide load and speed ranges. **(3M)**

Part*C

1 **Write a short note on data acquisition system. (15 M)(April 2014)** BTL5

Answer: Page 6.30-Dr.S.Senthil

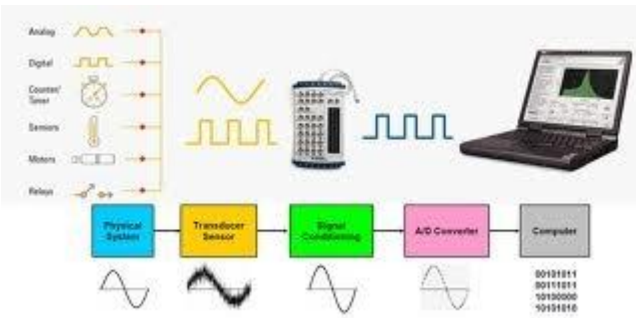


Figure- data acquisition system **(5M)**

A data acquisition system is a device designed to measure various parameters. The purpose of the data acquisition system is generally the analysis of the data and the improvement in accuracy of measurements. The data acquisition system is normally electronics based, and it is made of hardware and software. The hardware part is made of sensors, signal conditioners & data acquisition card and computer. The data acquisition system increases efficiency of measurement and lowers the cost for test, through easy to integrate software like Visual Basic. With this system, Engineers cause graphical representation to meet their specific needs – very different from the conventional and traditional measurements. Additionally, data acquisition system capitalized on the ever-increasing performance of personal computers. In test, measurement, and control, the system experiences up to a 10 times increase in efficiency at a fraction of the cost, in a fraction of time, of traditional measurement system. .

(10M)

2 **Explain the electronic engine management system used in modern engines. (15 M)(Dec 2013)** BTL5

Answer: Page 6.30-Dr.S.Senthil

An engine control unit (ECU), also commonly called an engine control module (ECM), is a type of electronic control unit that controls a series of actuators on an internal combustion engine to ensure optimal engine performance. It does this by reading values from a multitude of sensors within the engine bay, interpreting the data using multidimensional performance maps (called lookup tables), and adjusting the engine actuators. Before ECUs, air-fuel mixture, ignition timing, and idle speed were mechanically set and dynamically controlled by mechanical and pneumatic means. **(5M)**

If the ECU has control over the fuel lines, then it is referred to as an Electronic Engine Management System (EEMS). The fuel injection system has the major role to control the engine's fuel supply.

The whole mechanism of the EEMS is controlled by a stack of sensors and actuators.

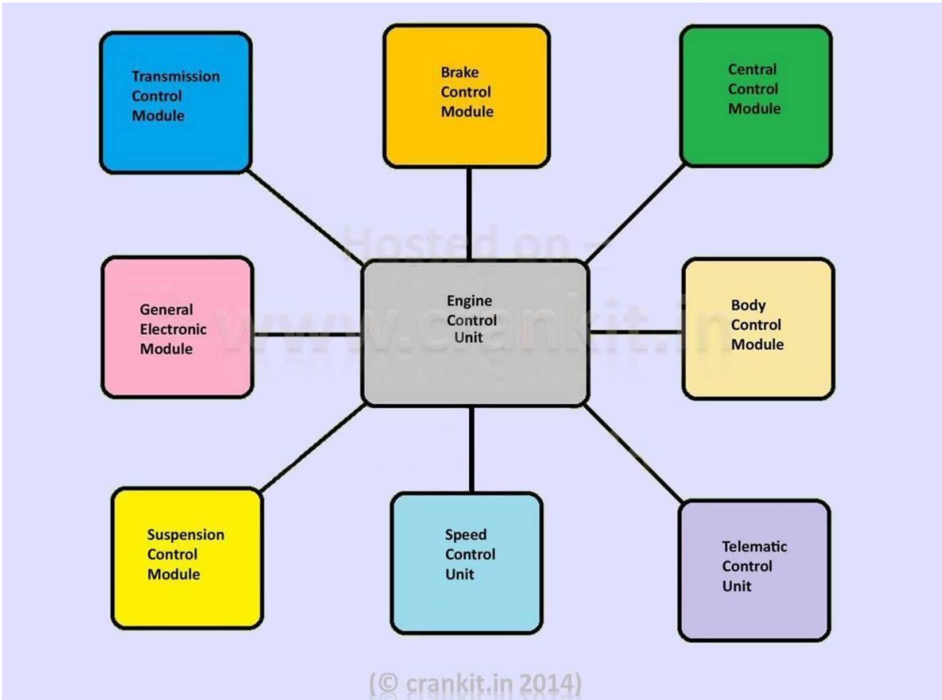


Figure- Engine management system **(5M)**

Engine management system

- Technology Outline the Engine Management System (EMS) is responsible for controlling the amount of fuel being injected and for adjusting the ignition timing.
- Electronic Fuel Injection System.
- Air Induction System/Control.
- Fuel Delivery System/Control.
- Electronic Control System.
- The Air Induction System. **(5M)**

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