

Test ID:- M15



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MECHANICAL ENGINEERING : PAPER-1

Full Length Test -15

Exam Date :- **01 March 2026**

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2 Marks

Q.1

Sol. Cam speed $N = 600$ rpm

$$\text{Time for one revolution } T = \frac{60}{600} = 0.1 \text{ s}$$

$$\text{Time for rise } t = \frac{120}{360} \times 0.1 = 0.0333 \text{ s}$$

Maximum velocity for SHM:

$$v_{\max} = \frac{\pi h}{2t}$$

$$v_{\max} = \frac{\pi \times 30}{2 \times 0.0333}$$

$$v_{\max} = 1414 \text{ mm/s} \approx 1.41 \text{ m/s}$$

Maximum follower velocity = 1.41 m/s

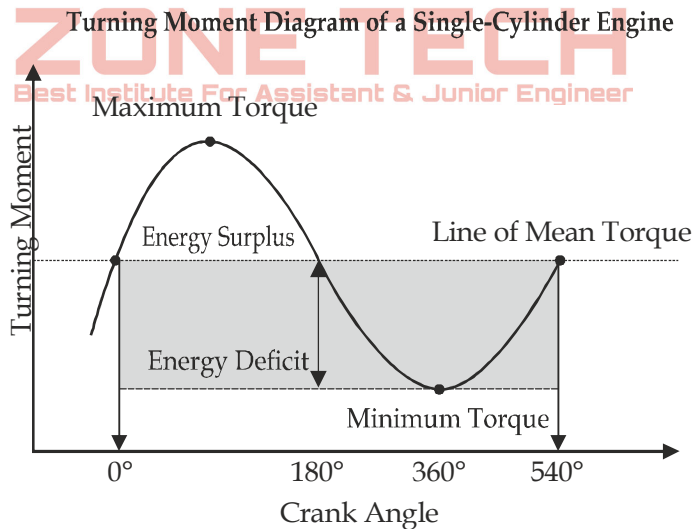
Q.2

Ans. It is a plot of turning moment versus crank angle. The area under the curve represents the work done per cycle.

KEY POINT:



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Q.3

- Sol.**
- Stabilization of ships and aircraft
 - Gyro-compass and navigation control systems

Q.4

Sol. The damped natural frequency is:

$$\omega_d = \omega_n \sqrt{1 - \zeta^2}$$

Thus, increasing damping ratio decreases the frequency of vibration.

Q.5

Sol.

$$n = 5$$

$$R_m = 0.1 \text{ m}$$

$$W = 6000 \text{ N}$$

$$\mu = 0.25$$

$$T = n \cdot \mu \cdot W \cdot R_m$$

$$T = 5 \times 0.25 \times 6000 \times 0.1$$

$$T = 750 \text{ N-m}$$

Q.6

Sol. Sharp corners are avoided because:

1. They cause stress concentration, which may lead to crack initiation and premature failure.
2. They are difficult to manufacture and increase machining cost and tool wear.

Therefore, fillets and rounded corners are always provided in design.

Q.7

Sol.

- Young's modulus depends on atomic bonding forces and crystal structure, which do not change by heat treatment.
- Yield stress depends on microstructure (grain size, dislocations, phases), which does change due to heat treatment.

Therefore, E remains almost constant, but yield stress changes.

Q.8

Sol.

- In mild steel, interstitial carbon and nitrogen atoms lock dislocations. When yielding starts, these dislocations break free suddenly, producing upper and lower yield points.
- Aluminium does not contain such interstitial atoms, so dislocations move smoothly without sudden yielding.

Hence, mild steel shows yield point, but aluminium does not.

Q.9

Sol.

- Shot peening produces compressive residual stresses on the surface.
- These stresses oppose tensile fatigue stresses and delay crack initiation and propagation.

Therefore, fatigue life and endurance limit increase.

Q.10

Sol.

- FCC crystals have more closely packed slip planes and slip directions (12 easy slip systems on {111} planes).
- Therefore, dislocations move more easily in FCC than in BCC, making FCC metals more ductile.
- In BCC, slip planes are not close-packed, so higher stress is required for slip, reducing ductility.

Q.11

Sol.

- In ionic crystals with high coordination number, ions are tightly packed and symmetrically arranged.
- In such structures, it is energetically easier for a pair of oppositely charged ions to leave their lattice sites (forming a Schottky defect) than to force an ion into an interstitial position.
- Hence, Schottky defects are more common in high coordination number ionic crystals.

Q.12

Sol. Any four additive manufacturing processes are:

1. FDM - Fused Deposition Modeling
2. SLA - Stereolithography
3. SLS- Selective Laser Sintering
4. DMLS / SLM - Direct Metal Laser Sintering / Selective Laser Melting



Q.13

- Sol.
- In spot welding, heat is generated by electrical resistance at the contact surface.
 - For thin sheets, required heat and pressure are easily achieved, and proper fusion occurs without excessive power or distortion.
 - For thick plates, very high current and force would be required, making the process uneconomical and difficult.

Q.14

Sol. Total travel:

$$L_T = 200 + 5 = 205 \text{ mm}$$

Feed rate:

$$\text{Feed per min} = fN = 0.30 \times 200 = 60 \text{ mm/min}$$

Time:

$$t = \frac{L_T}{fN} = \frac{205}{60} = 3.416 \text{ min}$$

$$t \approx 3.42 \text{ min}$$

Q.15

Sol. Abrasive Jet Machining (AJM)
KEY POINT:

Process	Full Form	Suitable Materials
AJM	Abrasive Jet Machining	Hard & brittle (glass, ceramics)
WJM/AWJM	Water Jet / Abrasive Water Jet	Soft to hard materials, composites
USM	Ultrasonic Machining	Hard & brittle, non-conductive
ECM	Electrochemical Machining	Only conductive materials
EDM	Electrical Discharge Machining	Only conductive materials
LBM	Laser Beam Machining	Almost all materials
PAM	Plasma Arc Machining	All metals

Q.16

Sol. Because ECM works on electrochemical (electrolysis) principle and requires electrical conductivity of the workpiece.

KEY POINT:

Most Important One-Liners for Exam

- ECM works on Faraday's law of electrolysis
- EDM works on spark erosion
- USM uses abrasive slurry + ultrasonic vibration
- AJM uses high velocity abrasive jet
- LBM uses laser beam heat
- PAM uses plasma jet

Q.17

Sol. (a) **Taylor's Scientific Management**

F.W. Taylor is known as the Father of Scientific Management.

He introduced scientific methods to improve efficiency and productivity of workers.

Main Principles:

1. Science, not rule of thumb
2. Scientific selection and training of workers
3. Cooperation between management and workers
4. Equal division of work and responsibility

Contributions:

- Time study
- Standardization of tools and methods
- Differential piece rate system

Aim: Maximum output with minimum waste.

(b) Mayo's Human Relations Approach

Elton Mayo emphasized the importance of human factors in management.

His ideas are based on Hawthorne Experiments.

Main Points:

- Workers are motivated by social and psychological factors, not only money
- Good working environment improves productivity
- Teamwork and communication are very important

Conclusion: Happy workers = Higher productivity.

(c) Organization Chart

An organization chart is a diagrammatic representation of the structure of an organization showing authority and responsibility relationships.

Types:

1. Line organization chart
2. Functional organization chart
3. Line and staff organization chart



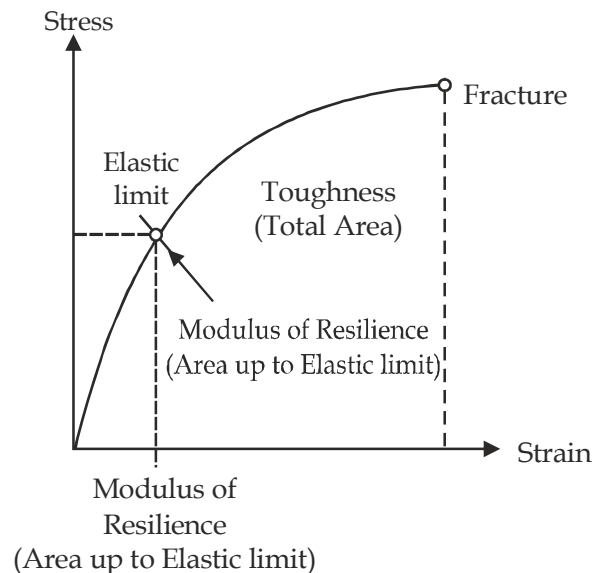
Importance:

- Shows clear authority relationships
- Avoids confusion and duplication of work
- Improves coordination and communication

Q.18

Sol.

- The area under the stress-strain curve represents the strain energy absorbed per unit volume of the material.
- Up to elastic limit, it is called modulus of resilience; for the whole curve, it represents toughness.



Q.19

- Sol.
- Therblig analysis breaks a job into basic human motions (like search, grasp, hold, transport, release, etc.).
 - It helps to identify unnecessary, ineffective and fatigue-causing motions and eliminate or simplify them, thereby improving productivity.

Q.20

Sol. Total observed time:

$$OT = 0.30 + 0.45 + 0.25 = 1.00 \text{ min}$$

Normal time:

$$NT = 1.00 \times 1.10 = 1.10 \text{ min}$$

Standard time:

$$ST = 1.10 \times 1.12 = 1.232 \text{ min}$$

$$ST = 1.232 \text{ min/cycle}$$

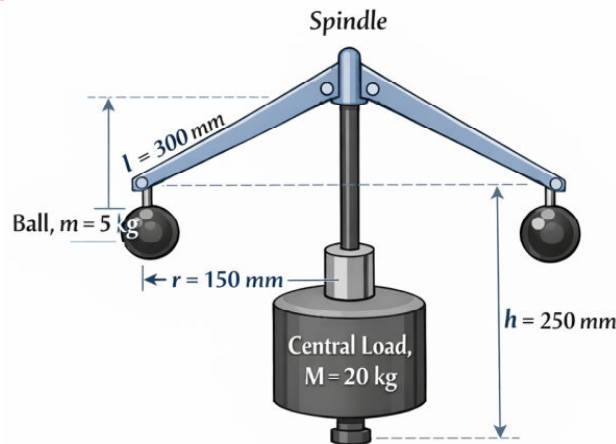
5 Marks

Q.21

Sol. Given:

- Length of arms (l) = 300 mm
- Mass of each ball (m) = 5 kg
- Central load (M) = 20 kg
- Radius of rotation (r) = 150 mm = 0.15 m
- Height (h) = 250 mm = 0.25 m
- $g = 9.81 \text{ m/s}^2$

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Formula for Porter Governor:

$$N = \frac{60}{2\pi} \sqrt{\frac{g}{h} \times \frac{w + W}{w}} = \frac{60}{2\pi} \sqrt{\frac{g}{h} \times \frac{m + M}{m}}$$

Substitute values:

$$N = \frac{60}{2\pi} \sqrt{\frac{9.81}{0.25} \times \left(\frac{5 + 20}{5}\right)}$$

$$N = 9.55 \times \sqrt{39.24 \times 5}$$

$$N = 9.55 \times \sqrt{196.2}$$

$$N = 9.55 \times 14.007$$

$$N \approx 133.7 \text{ rpm}$$

$$N \approx 134 \text{ rpm}$$

Q.22

Sol. Given:

- Reciprocating mass $m_r = 50 \text{ kg}$
- $r = 75 \text{ mm} = 0.075 \text{ m}$
- $l = 300 \text{ mm} = 0.30 \text{ m}$
- $N = 600 \text{ rpm}$
- Balancing ratio $c = 0.6$
- Balance radius $r_b = 100 \text{ mm} = 0.10 \text{ m}$

Angular speed:

$$\omega = \frac{2\pi N}{60} = \frac{2\pi(600)}{60} = 20\pi = 62.832 \text{ rad/s}$$

(1) Balance mass m_b

For partial balancing (primary):

$$m_b T_b = c m_r r$$

$$m_b = \frac{c m_r r}{r_b}$$

$$m_b = \frac{0.6 \times 50 \times 0.075}{0.10} = 22.5 \text{ kg}$$

Balance mass:

$$m_b = 22.5 \text{ kg}$$

(2) Maximum unbalanced primary force

Maximum primary inertia force:

$$F_{p,\max} = m_r r \omega^2$$

Unbalanced part after balancing:

$$F_{p,\max}^{(\text{unb})} = (1 - c) m_r r \omega^2$$

Compute

$$m_r r = 50 \times 0.075 = 3.75$$

$$\omega^2 = (62.832)^2 \approx 3947.84$$

$$F_{p,\max}^{(\text{unb})} = (1 - 0.6) \times 3.75 \times 3947.84$$

$$F_{p,\max}^{(\text{unb})} = 0.4 \times 14804.4 = 5921.8 \text{ N}$$

Max unbalanced primary force:

$$F_{p,\max}^{(\text{unb})} \approx 5.92 \text{ kN}$$



(3) Maximum unbalanced secondary force

Secondary inertia force (max):

$$F_{s,max} = m_r \left(\frac{r^2}{l} \right) \omega^2$$

Compute:

$$\frac{r^2}{l} = \frac{(0.075)^2}{0.30} = \frac{0.005625}{0.30} = 0.01875$$

$$F_{s,max} = 50 \times 0.01875 \times 3947.84$$

$$F_{s,max} = 0.9375 \times 3947.84 = 3701.1 \text{ N}$$

Max unbalanced secondary force:

$$F_{s,max} \approx 3.70 \text{ kN}$$

Q.23

Sol. (1) Construction & Working

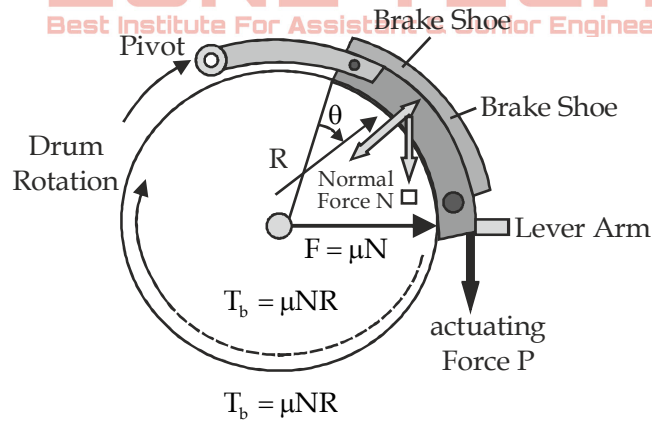
A single block (shoe) brake consists of:

- A brake drum rotating with the wheel/shaft.
- A brake shoe (block/lining) pressed against the drum by an actuating force through a lever/pivot.

When the shoe is pressed on the drum:

- A normal reaction N acts radially.
- A friction force $F = \mu N$ acts tangentially opposite to motion.

This tangential friction produces braking torque and reduces speed.



Single Block (Shoe) Brake

(2) Braking Torque (Basic Expression)

Friction force on drum:

$$F = \mu N$$

Braking torque about drum center:

$$T_b = F \cdot R = \mu NR$$

Where:

T_b = braking torque (N.m), R = drum radius (m), μ = coefficient of friction.

(3) Considering Angle of Contact 2θ (Effect on Resultant)

If shoe contacts the drum over an angle 2θ , pressure is distributed over the arc and the resultant forces are found by integrating.

Let normal reaction on a small element be dN .

Then friction on that element:

$$dF = \mu dN$$

Total braking torque:

$$T_b = \int R dF = \int R (\mu dN) = \mu R \int dN$$

$$T_b = \mu RN$$

Key Point (Exam line):

For a shoe brake, the torque expression remains $T_b = \mu RN$, but N itself depends on the geometry and the contact angle because the resultant reaction shifts along the arc.

(4) Effect of Angle of Contact

- As contact angle increases, the effective resultant reaction line shifts and the required actuating force reduces (because frictional moment contribution becomes more favorable).
- With larger contact angle, the brake becomes more self-energizing, improving braking for the same applied force.

Conclusion:

Higher contact angle \Rightarrow better braking effectiveness (less effort for same torque).

Q.24

Sol.

(1) Effect of Surface Finish on Endurance Limit

- Fatigue cracks generally start from the surface.
- A rough surface has micro-notches / scratches, which act as stress raisers and cause early crack initiation.
- Therefore, endurance limit decreases as surface finish becomes rougher.

Design factor: Surface finish factor k_a (always < 1 for real components)

Conclusion: Better polishing / grinding / shot peening \rightarrow higher endurance limit.

(2) Effect of Size on Endurance Limit

- As component size increases:
 - stressed volume increases
 - probability of internal defects/inclusions increases
 - likelihood of crack initiation increases
- Hence endurance limit reduces with increase in size.

Design factor: Size factor k_b

Large shafts have lower endurance strength than small specimens, even for same material.

(3) Effect of Type of Loading on Endurance Limit

Endurance strength depends on stress distribution:

- **Bending:** maximum stress at surface, core is less stressed \rightarrow relatively higher fatigue strength ($k_c \approx 1$)
- Axial (direct tension/compression): almost uniform stress across section \rightarrow more volume equally stressed lower endurance ($k_c < 1$)
- **Torsion:** shear stress varies from 0 at center to max at surface endurance in torsion is less than bending ($k_c < 1$)

(4) Why is Surface Finish Factor the Most Important?

Because:

1. Fatigue cracks initiate at surface, not from the core in most cases.
2. Surface roughness behaves like many tiny notches, increasing local stress.
3. Surface condition can change drastically due to machining marks, corrosion, wear, etc.

Hence k_a causes the largest reduction in endurance limit among factors.

Q.25

Sol. (1) Working principle (Hydrodynamic lubrication)

A journal bearing supports a rotating shaft (journal) inside a bush with a small radial clearance c filled with lubricant.

When the journal rotates, it drags oil into the converging wedge-shaped film due to viscosity. This develops hydrodynamic pressure in the film, which lifts the shaft and supports the load without metal-to-metal contact (in steady running).

Key terms:

- Journal diameter d , radius $r = d/2$
- Bearing length L
- Radial clearance c
- Speed N (rev/s)
- Viscosity η (Pa.s)

- Unit bearing pressure $p = \frac{W}{Ld}$

(2) Coefficient of friction (Petroff's equation: lightly loaded/full-film approximation)

For a lightly loaded journal bearing (nearly concentric, full film), viscous shear causes friction:
Surface speed:

$$v = \pi dN$$

Average shear stress in oil film (approx. Couette flow):

$$\tau = \eta \frac{v}{c}$$

Friction force on projected area $A = \pi dL$:

$$F = \tau A = \eta \frac{v}{c} (\pi dL)$$

$$F = \eta \frac{\pi dN}{c} (\pi dL) = \eta \frac{\pi^2 d^3 LN}{c}$$

Coefficient of friction: $f = \frac{F}{W}$

and $W = pLd$

So,

$$f = \frac{\eta \pi^2 d^3 LN / c}{pLd} = \boxed{f = \frac{\pi^2 \eta N}{p} \left(\frac{d}{c}\right)}$$

Final (Petroff) friction relation:

$$f = \frac{\pi^2 \eta N}{p} \left(\frac{d}{c}\right)$$

(3) Sommerfeld number and its significance

The Sommerfeld number (bearing characteristic number) is a dimensionless parameter:

$$S = \left(\frac{\eta N}{p}\right) \left(\frac{r}{c}\right)^2$$

Significance (exam points):

- S governs film thickness, eccentricity ratio, attitude angle, and friction behavior of a journal bearing.
- Higher S (higher viscosity/speed or lower load) \rightarrow thicker oil film, safer hydrodynamic lubrication.
- Used with design charts to predict minimum film thickness and friction coefficient.

Q.26

Sol. (i) **End centred unit cell**

- They contain particles at the corners and one in the centre of any two opposite faces.
- Total number of particles = 2

(ii) **Monoclinic unit cell**

$$a \neq b \neq c$$

$$\alpha = \gamma = 90^\circ$$

$$\beta \neq 90^\circ$$

Face-centred unit cell

- They contain particles at the corners and one in the centre of each face.
- Total number of particles = 4

• **Hexagonal unit cell**

$$a = b \neq c$$

$$\alpha = \beta = 90^\circ$$

$$\gamma = 120^\circ$$

Q.27

Sol. (1) **Definition of Creep**

Creep is the time-dependent permanent deformation of a material when it is subjected to a constant stress at high temperature (generally above 0.4 T_m , where T_m is melting temperature in Kelvin).

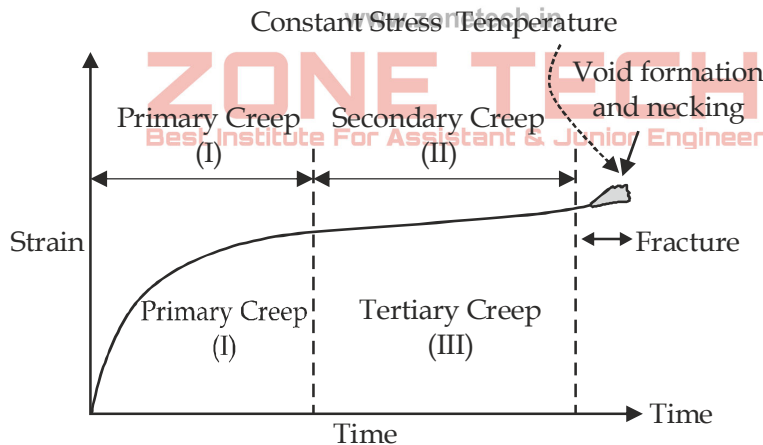
Creep is very important in boilers, turbines, IC engine parts, pressure vessels, steam pipes etc.

(2) **Creep Curve (Strain vs Time)**

The creep curve is a plot of strain versus time at constant stress and constant temperature. It has three distinct stages:

- Primary creep (I)
- Secondary creep (II)
- Tertiary creep (III)

(Examiner expects a neat labeled curve)



(3) **Stages of Creep**

(i) **Primary Creep (Transient Creep)**

- Creep rate decreases with time
- Occurs due to strain hardening of material
- Material becomes stronger and resists further deformation

Slope of curve decreases

(ii) **Secondary Creep (Steady-State Creep)**

- Creep rate is constant and minimum
- Balance between strain hardening and recovery
- This stage occupies maximum service life

This stage is most important in design

(iii) Tertiary Creep

- Creep rate increases rapidly
- Due to:
- Necking
- Grain boundary cracking
- Void formation
- Reduction in cross-section

Ends in sudden fracture

(4) Significance of Creep in Design

1. Components working at high temperature must be designed based on creep strength, not yield strength.
2. Secondary creep rate is used to predict service life.
3. Design aims to:
 - Avoid tertiary creep
 - Keep working stress in safe creep range
4. Important in:
 - Boilers
 - Turbines
 - Nuclear reactors
 - Jet engines



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Q.28

Sol. Given: $t_1 = 30$ mm, $t_2 = 24$ mm \Rightarrow draft $\Delta t = 6$ mm, $R = 300$ mm, $\mu = 0.10$

Maximum draft:

$$\Delta t_{\max} = \mu^2 R$$

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$$\Delta t_{\max} = (0.10)^2 (300) = 0.01 \times 300 = 3 \text{ mm}$$

Since required draft 6 mm > 3 mm, not possible without increasing friction / using smaller rolls / using front tension.

$\Delta t_{\max} = 3\text{mm, required } 6 \text{ mm} \Rightarrow \text{not possible}$

Q.29

Sol. Given: $D_0 = 60$ mm, $h_0 = 40$ mm, $h_1 = 30$ mm

Volume const.:

$$A_0 h_0 = A_1 h_1 \Rightarrow A_1 = A_0 \frac{h_0}{h_1}$$

$$A_0 = \frac{\pi}{4} (60)^2 = 2827.43 \text{ mm}^2 \Rightarrow A_1 = 2827.43 \left(\frac{40}{30} \right) = 3769.90 \text{ mm}^2$$

Forging load (end):

$$F = \bar{\sigma} A_1$$

Convert $\bar{\sigma} = 200$ MPa = 200 N/mm²

$$F = 200 \times 3769.90 = 753980 \text{ N} = 754 \text{ kN}$$

$F \approx 754 \text{ kN}$



Q.30

Sol. (1) Tool life at $V = 120 \text{ m/min}$

$$VT^n = C \Rightarrow T^n = \frac{C}{V} = \frac{300}{120} = 2.5$$

$$T = (2.5)^{1/n} = (2.5)^{1/0.25} = (2.5)^4$$

$$T = 39.06 \text{ min}$$

(2) Speed for doubling tool life

$$T_2 = 2T_1 \Rightarrow V_1 T_1^n = V_2 T_2^n$$

$$V_2 = V_1 \left(\frac{T_1}{T_2} \right)^n = 120 \left(\frac{1}{2} \right)^{0.25}$$

$$2^{0.25} = \sqrt{\sqrt{2}} \approx 1.1892 \Rightarrow \left(\frac{1}{2} \right)^{0.25} = \frac{1}{1.1892} = 0.8409$$

$$V_2 = 120 \times 0.8409 = 100.91 \text{ m/min}$$

$$V_2 \approx 101 \text{ m/min}$$

$$T \approx 39.06 \text{ min}, V_2 \approx 101 \text{ m/min}$$

Q.31

Sol. 1. **Meaning of Management Structure**

Management structure refers to the framework of authority, responsibility and communication in an organization. It shows:

- Who will give orders
- Who will do the work
- Who is responsible to whom

In simple words, management structure defines the hierarchy and working system of an organization.

2. **Authority**

Authority is the right or power to give orders and take decisions and to expect obedience from subordinates.

Examples:

- Manager can assign work
- Supervisor can check work and guide workers

Features of Authority:

- It flows from top to bottom
- It is attached to the position, not the person
- It must be clearly defined

3. **Responsibility**

Responsibility is the duty or obligation to perform the assigned work properly.

Features of Responsibility:

- It flows from bottom to top
- It cannot be delegated completely
- A person who accepts authority must also accept responsibility

4. **Relationship between Authority and Responsibility**

Authority and responsibility must be equal and balanced.

- If authority > responsibility → Misuse of power
- If responsibility > authority → Person cannot perform work properly

Correct Principle:

Authority = Responsibility

5. Accountability (One line)

Accountability means being answerable for the result of work done.

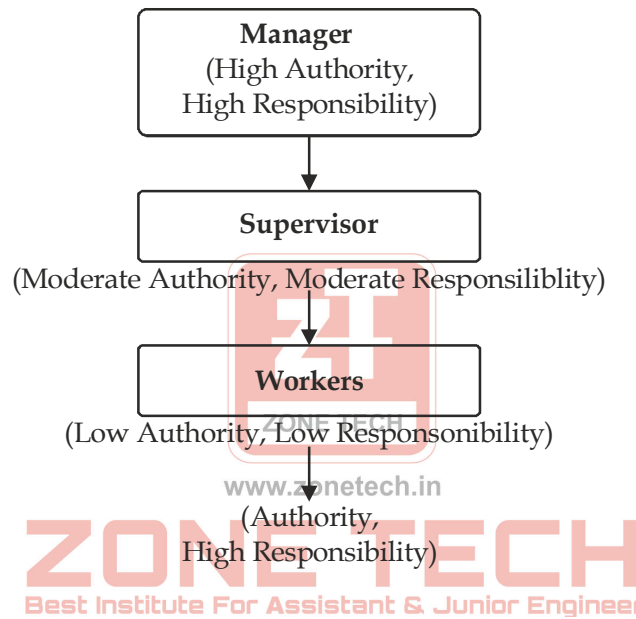
Responsibility creates accountability.

One-line exam answers:

Authority → Right to command

Responsibility → Duty to perform

Accountability → Answerability for results



Q.32

Sol. (1) Modern Concept of Material Management

Material Management is the integrated function of planning, purchasing, storing, moving and controlling materials in such a way that:

- Right material is available
- In right quantity
- At right time
- At minimum total cost

Objectives:

- Reduce inventory cost
- Avoid shortage and overstocking
- Ensure smooth production flow
- Improve customer service and profitability

(2) Role of ABC Analysis (Selective Inventory Control)

ABC analysis classifies items based on annual consumption value:

- A items: High value, tight control (≈ 70% value, 10% items)
- B items: Moderate control
- C items: Simple control (many items, low value)



Contribution:

- Focuses management attention on critical items
- Reduces capital blocked in inventory
- Improves control efficiency at low cost

(3) Role of EOQ (Economic Order Quantity)

EOQ is the optimal order quantity that minimizes:

- Ordering cost
- Carrying (holding) cost

$$EOQ = \sqrt{\frac{2DS}{H}}$$

Contribution:

- Decides how much to order
- Minimizes total inventory cost
- Avoids overstocking and frequent ordering

(4) Role of MRP-I (Material Requirement Planning)

MRP-I is a computer-based system that calculates:

- What material is needed?
- How much?
- When?

Based on:

- Master production schedule
- Bill of materials
- Inventory records



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Contribution:

- Ensures timely availability of materials
- Reduces work-in-progress and shortages
- Improves production planning and scheduling

(5) Role of MRP-II (Manufacturing Resource Planning)

MRP-II is an extension of MRP-I which also includes:

- Machine capacity planning
- Manpower planning
- Financial planning

Contribution:

- Integrates material + capacity + finance
- Improves overall manufacturing control

(6) Role of ERP (Enterprise Resource Planning)

ERP is a fully integrated company-wide information system covering:

- Purchase
- Stores
- Production
- Finance
- HR
- Sales



20 Marks

Q.33

Sol. Given

- $Z_A = 20, Z_B = 60, Z_C = 25, Z_D = 75$
- Input speed $N_A = 1200$ rpm
- Power $P = 15$ kW = 15000 W
- Module $m = 4$ mm 0.004 m

(1) Overall velocity ratio & output speed

Stage-1 (A drives B)

$$\frac{N_A}{N_B} = \frac{Z_B}{Z_A} = \frac{60}{20} = 3 \Rightarrow N_B = \frac{N_A}{3} = \frac{1200}{3} = 400 \text{ rpm}$$

Stage-2 (C drives D)

Since B and C are on same shaft:

$$N_C = N_B = 400 \text{ rpm}$$

$$\frac{N_C}{N_D} = \frac{Z_D}{Z_C} = \frac{75}{25} = 3 \Rightarrow N_D = \frac{N_C}{3} = \frac{400}{3} = 133.33 \text{ rpm}$$

Overall velocity ratio

$$\text{V.R.} = \frac{N_A}{N_D} = \frac{1200}{133.33} = 9$$

$$\boxed{\text{Overall V.R.} = 9}$$

$$\boxed{N_{\text{out}} = N_D \approx 133.33 \text{ rpm}}$$

(2) Output torque

Power relation:

$$P = \frac{2\pi NT}{60} \Rightarrow T = \frac{P \times 60}{2\pi N}$$

At output:

$$T_{\text{out}} = \frac{15000 \times 60}{2\pi \times 133.33}$$

$$T_{\text{out}} \approx \frac{900000}{837.76} \approx 1074. \text{N} - \text{m}$$

$$\boxed{T_{\text{out}} \approx 1075 \text{ N} - \text{m}}$$

(3) Verify reverted condition

For a reverted gear train (coaxial input & output shafts):

$$D_A + D_B = D_C + D_D$$

Since $D = mZ$, module is same:

$$m(Z_A + Z_B) = m(Z_C + Z_D) \Rightarrow Z_A + Z_B = Z_C + Z_D$$

Check:

$$Z_A + Z_B = 20 + 60 = 80$$

$$Z_C + Z_D = 25 + 75 = 100$$

Since $80 \neq 100$, condition is NOT satisfied.

Conclusion:

Given gear train is NOT reverted with these teeth numbers.

(Examiner's note: question said "reverted", but verification shows it's not possible unless teeth numbers are modified)

(4) Pitch circle diameters (module $m = 4$ mm)

$$D = mZ$$

- $D_A = 4 \times 20 = 80$ mm
- $D_B = 4 \times 60 = 240$ mm
- $D_C = 4 \times 25 = 100$ mm
- $D_D = 4 \times 75 = 300$ mm

$$D_A = 80 \text{ mm}, D_B = 240 \text{ mm}, D_C = 100 \text{ mm}, D_D = 300 \text{ mm}$$

(5) Tangential tooth load on gear A

First find input torque:

$$T_{in} = \frac{P \times 60}{2\pi N_A} = \frac{15000 \times 60}{2\pi \times 1200}$$

$$T_{in} \approx \frac{900000}{7539.84} \approx 119.37 \text{ N-m}$$

Pitch radius of gear A:

$$r_A = \frac{D_A}{2} = \frac{80}{2} = 40 \text{ mm} = 0.04 \text{ m}$$

Tangential load:

$$F_t = \frac{T_{in}}{r_A} = \frac{119.37}{0.04} = 2984.25 \text{ N}$$

$$F_t \approx 2.98 \text{ kN}$$

Q.34

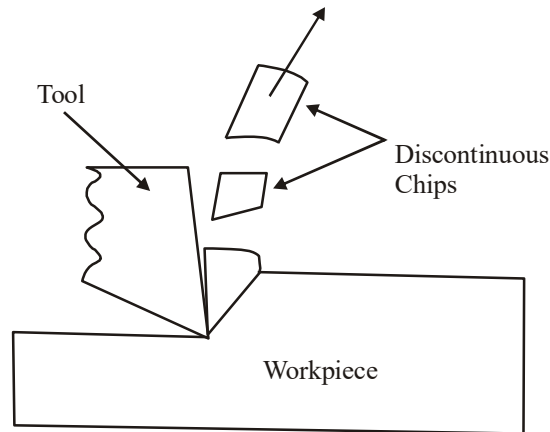
Sol. Mainly chips are of three types :-

- (i) Discontinuous chips.
- (ii) Continuous chips.
- (iii) Continuous Chips with built up edges (**or BUE chips**)

These three types are elaborated below:

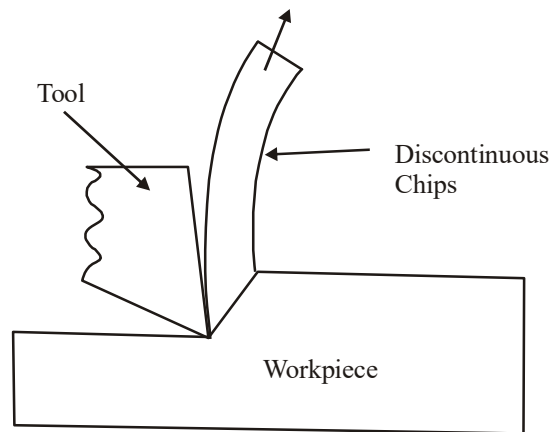
(i) Discontinuous Chips:

- If the chips during machining process is not continuous i.e. formed with breakage are called **discontinuous chips**.
- **Discontinuous chips** are formed when brittle or hard metals like brass, bronze and cast iron are used as workpiece in the machining process.
- **Discontinuous chips** are also formed in ductile material when the friction between tool and workpiece is high. Discontinuous chips is not a good sign for machining of ductile material as it gives poor surface finish and machining process becomes slow.



Discontinuous Chips

- **Factors responsible for formation of Discontinuous chips :**
 - (1) **Material of workpiece:** When the workpiece is made of brittle material such as cast iron and bronze.
 - (2) **Bevels:** Small bevels of cut tools.
 - (3) **Cutting Speed:** Cutting speed is low.
 - (4) **Feed:** When the feed is large and chip is thick.
 - (5) **Rake Angle:** Small rake angle.
 - (6) **Friction:** High friction forces at the chip-tool interface.
 - (7) **Depth of cut:** Large value of depth of cut.
- (ii) **Continuous Chips:**
 - **Continuous chips** are the chips formed during machining without breakage or without segments.
 - These chips are formed by the continuous plastic deformation of metal without fracture in front of the cutting edge.
 - **Continuous Chips** are mainly formed during cutting of ductile material like mild steel, aluminum and copper.



Continuous Chip

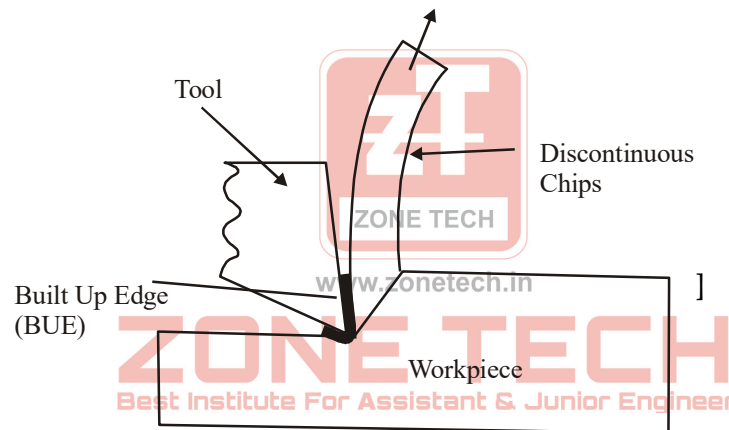
- **Factors responsible for formation of continuous chips :**
 - (1) **Material of Workpiece:** When ductile material is used as the workpiece.
 - (2) **Cutting Speed:** Cutting speed is high.



- (3) **Chip thickness:** Thickness of chip is less.
- (4) **Rake Angle:** Rake angle is large.
- (5) **Depth of cut:** Depth of cut should be small.
- (6) **Lubricants and Coolants:** Lubricants and coolants should be used efficiently.
- (7) **Coefficient of friction:** Coefficient of material of tool should be low.
- (8) **Friction:** Friction of chip on tool face should be minimum. This condition can be achieved by:
 - (a) Polishing tool face.
 - (b) Use of efficient cutting lubricants.
 - (c) Using tool made of low coefficient of friction.

(iii) **Continuous Chip With Built Up Edge :**

- This type of chip is similar to continuous chip and it has a built up edge adjacent to the tool face and also is not as smooth as continuous edge.
- Actually, Built Up Edge (BUE) is an accumulation of material against the rake face, that siezes to the tool tip, separating it from the chip.
- BUE is form during machining of ductile metal when excessive friction exists between tool and workpiece.



Continuous Chip with Built Up Edge (BUE)

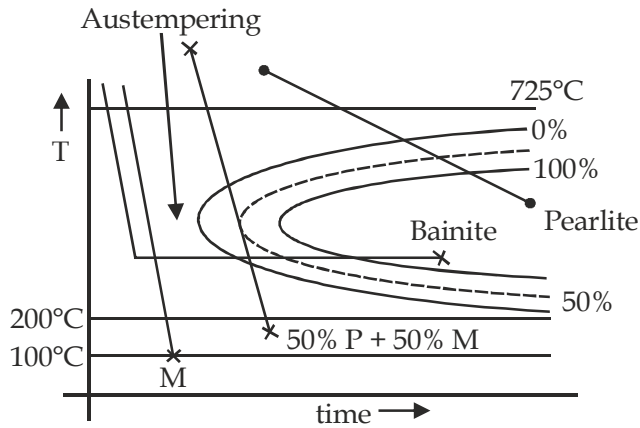
Formation of Built Up Edge:

- Built Up Edges are formed mainly due to friction between the tool and interface of chip. Because of friction between the tool and the chip, very intense heat is generated near the nose of the tool. The compressed metal near the nose of the tool get welded due to high temperature near the nose. This compressed metal near welded to the nose is called built up edge.
- The chip flows through this built up edge and gets broken and get carried away by the chip and are called as built up edge chip.
- Rest of the built up edge stick to the surface of the workpiece and make it rough.
- As built up edge is formed near nose of tool, rake angle of the tool changes and so the cutting force also changes.
- **Factors responsible for formation of Built up Edge :**
 - (1) **Workpiece Material:** Metal used as workpiece is ductile.
 - (2) **Friction:** High friction exists near the face of the tool.
 - (3) **Coolant:** Insufficient coolant and lubricant.
 - (4) **Temperature:** High temperature near the tool face while cutting.
 - (5) **Feed Rate:** High value of feed rate.
 - (6) **Cutting Speed:** Low cutting speed.
 - (7) **Rake Angle:** Very small rake angle.



Q.35

Sol. Tempering:- It is heat treatment process by which hardness is reduced and toughness is improved in it. The specimen is heated upto specified temperature and then quenched in air or any other suitable medium.



Austempering: The change of structure of steel from austenite to bainite is known as austempering. In this process, the steel sample is heated and then cooled at a rate more than critical cooling rate but above martensite start line, the sample is then maintained at that temperature for some time and all the austenite is then converted into bainite.

The advantages are:

1. Brittle martensite does not form.
2. Quenching cracks between core and surface do not develop.
3. Ductility is increased.
4. Impact strength and toughness are increased.

Martempering: This is also called step quenching. It is done in phases

1. The austenite sample is initially quenched into a hot bath maintained below the nose of TTT diagram but above martensite start line. Then core also gets cooled up to the temperature of the outer surface and no residual stresses are there.
2. The sample is cooled in another medium like oil or air, and held there until they are completely cooled. The purpose of transfer to another medium is to reduce internal stresses associated with austenite to martensite transformation.

Advantages of martempering over normal quenching:-

1. Less volume change occurs due to large amount of retained austenite.
2. Less distortion, since transformation occurs almost simultaneously in entire volume.
3. Less danger of quenching cracks.

Q.36

Sol. Step 1: Section Properties

Area:

$$A = 120 \times 80 = 9600 \text{ mm}^2$$

Moment of inertia about weaker axis:

$$I_{\min} = \frac{120 \times 80^3}{12} = 5.12 \times 10^6 \text{ mm}^4$$

Radius of gyration:

$$k = \sqrt{\frac{I}{A}} = \sqrt{\frac{5.12 \times 10^6}{9600}} = 23.1 \text{ mm}$$

Effective length (hinged-hinged):

$$L_e = L = 3000 \text{ mm}$$

Slenderness ratio:

$$\lambda = \frac{L_e}{k} = \frac{3000}{23.1} \approx 130$$

Step 2: Rankine Load

$$P_R = \frac{\sigma_c A}{1 + \alpha \left(\frac{L}{k}\right)^2}$$

$$P_R = \frac{320 \times 9600}{1 + \frac{1}{7500} \times (130)^2}$$

$$P_R = 3.072 \times 10^6 \quad 3.072 \times 10^6 = 1 + 2.25 \quad 3.25$$

$$P_R = \frac{3.072 \times 10^6}{1 + 2.25} = \frac{3.072 \times 10^6}{3.25}$$

$$P_R \approx 945 \text{ kN}$$



Step 3: Euler Load

$$P_E = \frac{\pi^2 EI}{L^2}$$

$$P_E = \frac{\pi^2 \times 2 \times 10^5 \times 5.12 \times 10^6}{3000^2}$$

$$P_E \approx 1120 \text{ kN}$$



Step 4: Stress Due to Eccentric Loading

$$\sigma = \frac{P}{A} \pm \frac{My}{I} = \sigma_d + \sigma_b$$

Where:

$$M = P \times e = 180000 \times 20 = 3.6 \times 10^6 \text{ Nmm}$$

$$y = \frac{80}{2} = 40 \text{ mm}$$

Direct stress:

$$\sigma_d = \frac{180000}{9600} = 18.75 \text{ MPa}$$

Bending stress:

$$\sigma_b = \frac{3.6 \times 10^6 \times 40}{5.12 \times 10^6} = 28.1 \text{ MPa}$$

Maximum stress:

$$\sigma_{\max} = 18.75 + 28.1 = 46.85 \text{ MPa}$$

Minimum stress:

$$\sigma_{\min} = 18.75 - 28.1 = -9.35 \text{ MPa (tensile)}$$

Step 5: Safety Check

Given permissible stress = 80 MPa:

$$\sigma_{\max} = 46.85 < 80 \Rightarrow \text{SAFE}$$

Also:

$$P = 180 \text{ kN} \ll P_R = 945 \text{ kN} \Rightarrow \text{SAFE}$$

Step 6: Conclusion (Very Important for Examiner)

- Euler load > Rankine load → Rankine formula governs
- Stress is within permissible limit → Design is SAFE
- Tensile stress appears due to eccentric loading → important observation

Q.37

Sol. Maintaining an inventory is necessary because of the following reasons:

- It helps in smooth and efficient running of an enterprise. It decouples the production from customers and vendors and simplifies the otherwise complex organisation for manufacture and reduces the co-ordination effort.
- It provides services to the customer at a short notice. Timely deliveries can fetch more goodwill and orders.
- In the absence of inventory, the enterprise may have to pay high prices because of piecemeal purchasing. Maintaining of inventory may earn price discount because of bulk purchasing. It also takes advantage of favourable market.
- It reduces product costs since there is an added advantage of batching and long, uninterrupted production runs.
- It acts as a buffer stock when raw materials are received late and shop rejections are too many.
- Process and movement inventories (also called pipeline stocks) are quite necessary in big enterprises where significant amount of time is required to transship items from one location to another.
- Bulk purchases will entail less orders and, therefore, less clerical costs. This applies to goods produced with in the organisation as well. Less orders, as a result of larger lots, will entail lesser machine setups and other associated costs.
- An organisation may have to deal with several customers and vendors who are not necessarily near it. Inventories, therefore, have to be built to meet the demand at least during the transit time.
- It helps in maintaining economy by absorbing some of the fluctuations when the demand for an item fluctuates or is seasonal.

Each order has associated with it the ordering cost or acquisition cost. To keep it low, the number of orders should be as few as possible. i.e., the order size should be large. But large order size would imply high inventory carrying cost. Hence the need of optimisation of order quantity is arised.

Given, Demand, $D = 10,000$ pieces/year. Order cost, $C_0 = \text{Rs. } 240/\text{order}$

Inventory carrying cost or holding cost = 1% of Rs. 50/month

$$C_h = \frac{1}{100} \times 50 \times 12 / \text{year} = \text{Rs. } 6 / \text{year} / \text{item}$$

$$EOQ = \sqrt{\frac{2DC_0}{C_h}} = \sqrt{\frac{2 \times 240 \times 10000}{6}} = 894.42 \text{ components} / \text{procurement}$$

