MADE EASY

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Detailed Solutions

ESE-2022 Mains Test Series

Mechanical Engineering Test No : 8

Section A : Machine Design + Mechatronics & Robotics

Section B : IC Engine + Renewable Sources of Energy-2 + Industrial and Maintenance Engg.-2

Section : A

1. (a)

Given : P = 100 kN, τ = 120 N/mm^2

Let 't' be the throat thickness of weld.

$$\text{Primary shear stress, } \tau_1 = \frac{P}{A} = \frac{100 \times 10^3}{2 \times 400 \times t}$$

or

$$\tau_1 = \frac{125}{t} \text{N/mm}^2$$

$$\text{Bending stress, } \sigma_b = \frac{M_b y}{I},$$

The moment of inertia of two welds about the x-axis is given by

$$I = 2 \times \left[\frac{t(400)^3}{12}\right] = 10.66 \times 10^6\, t \text{ mm}^4$$

$$\therefore \quad \sigma_b = \frac{(100 \times 10^3 \times 300) \times 200}{10.66 \times 10^6 \times t} = \frac{562.85}{t} \text{N/mm}^2$$

Now, maximum shear stress in the weld,

$$\tau_{max} = \sqrt{\left(\frac{\sigma_b}{2}\right)^2 + \tau_1^2} = \sqrt{\left(\frac{562.85}{2t}\right)^2 + \left(\frac{125}{t}\right)^2}$$

$$\tau_{max} = \frac{307.93}{t} \text{N/mm}^2$$

∴ For size of weld, (h),

$$(\tau_{max})_{ind} \leq \tau_{per}$$

$$\frac{307.93}{t} \leq 120$$

$$\Rightarrow \quad t \geq 2.56 \text{ mm}$$

$$\therefore \quad h = \frac{2.56}{0.707}$$

$$\Rightarrow \quad h = 3.62 \text{ mm}$$ **Ans.**

1. (b)

On the basis of kinematic structure, robots can be classified into 3 categories :

1. Serial robots
2. Parallel robots
3. Hybrid robots

1. Serial robots :

- A serial robot consists of several links connected in series by various types of joints, typically revolute and prismatic. One end of the robot is attached to the ground and the other end is free to move in space. The fixed link is called base, and the free end where a gripper or a mechanical hand is attached, the end effectors.
- Kinematic structure of serial robot is in the form of open loop.
- Payload capacity of serial robot is relatively less and its workspace is relatively larger than other types of robot.
- Serial robot is used in most of the industrial applications such as welding, painting, assembling etc.

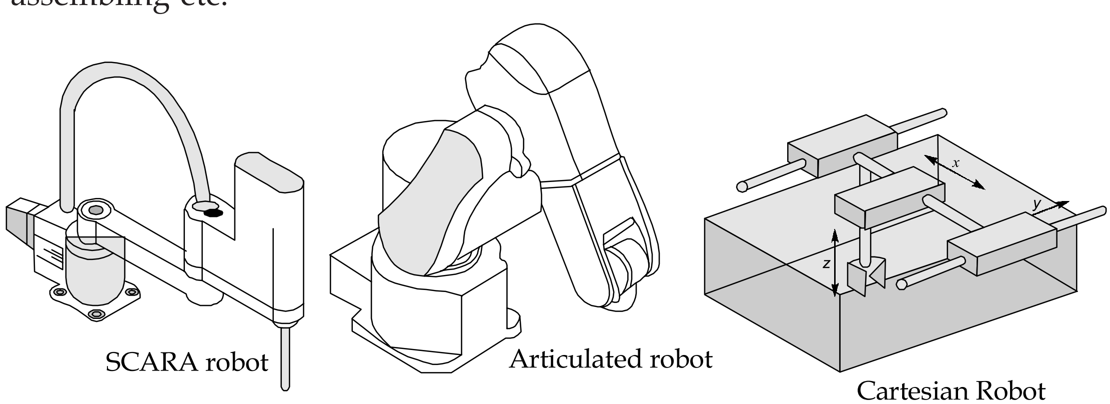


Fig. Serial robots

2. Parallel robots

- A parallel robot or parallel manipulator consists of several computer controlled links connected in parallel between a fixed base and a single platform or end effectors.
- In comparison to serial robots, parallel robots have higher stiffness, higher payload capacity and lower inertia moving platform.

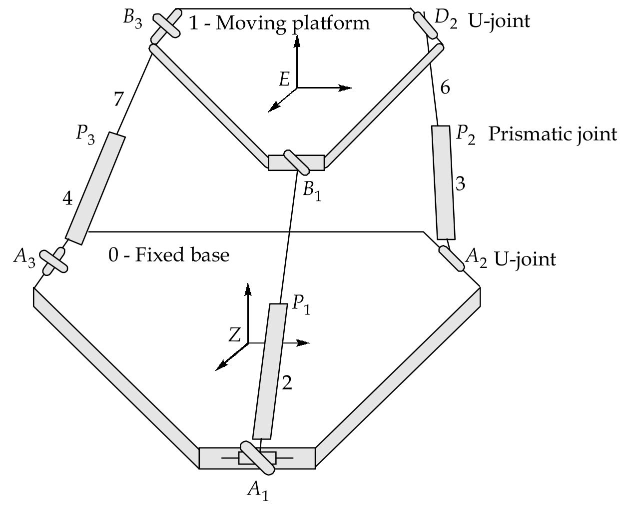


Fig. Parallel Robot

- Parallel robots are generally used in flight simulation, adjustable articulated trusses, mining machine, pointing devices, walking machine, machining centre etc.
- Kinematic structure of parallel robots is in the form of closed loop.

3. Hybrid robot

- In these type of robots, both serial and parallel configurations are used.
- It consists of both open loop and closed loop chains.

Application of Hybrid robot: Many industrial robots employ this type of robot construction.

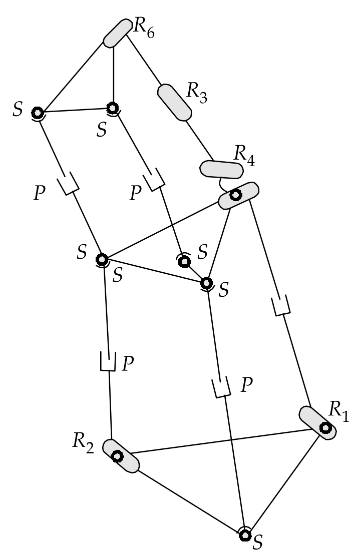
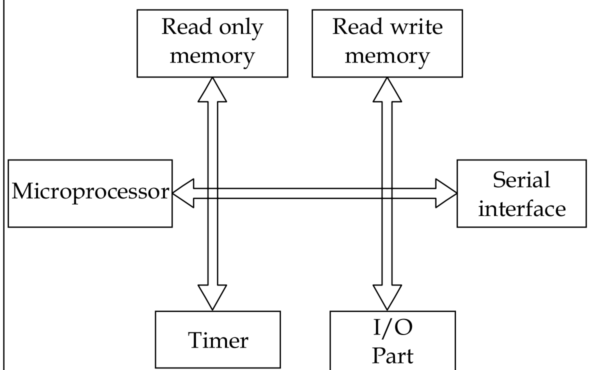


Fig. Hybrid Robot

1. (c)

Microprocessor



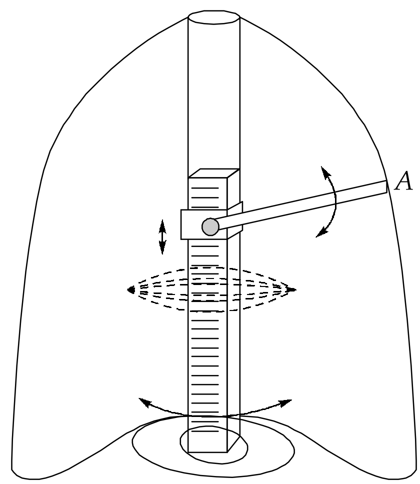
Micro Controller

Microcontroller	Read only memory	Read write memory
Timer	I/O Port	Serial interface

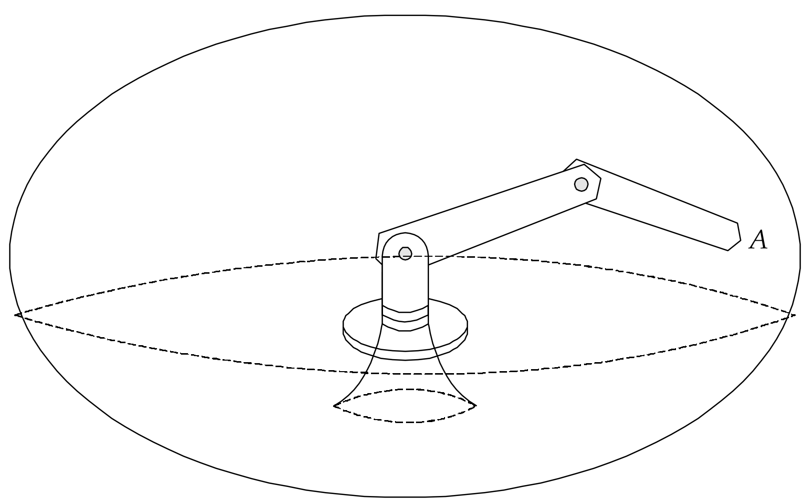
Microprocessor	Micro Controller
• Microprocessor is heart of a computer system.	• Microcontroller is heart of an embedded system.
• CPU is stand-alone, RAM, ROM, I/O timer are separate.	• A CPU, RAM, ROM, I/O and timer are all on a single chip.
• Since memory and I/O has to be connected externally the circuit becomes large.	• Since memory and I/O are present internally, the circuit is small.
• Cannot be used in compact system and hence inefficient.	• Can be used in compact system and hence it is an efficient technique.
• Cost of entire system is high.	• Cost of entire system is low.
• Due to external components, the entire power consumption is high. Hence it is not suitable to be used with devices running on stored power like batteries.	• Since external components are low, total power consumption is less and can be used with devices running on stored power like batteries.
• Most of the microprocessor do not have power saving features.	• Most of the micro controllers have power saving modes like idle mode and power saving mode. This helps to reduce power consumption even further.
• Speed is slow.	• Speed is fast.
• Microprocessor are based on Von-Neumann model/ architecture where program and data are stored in same memory module.	• It is based on Harvard architecture where program memory and data memory are separate.
• Mainly used in personal computers.	• Used mainly in washing machine, MP3 player.

1. (d)

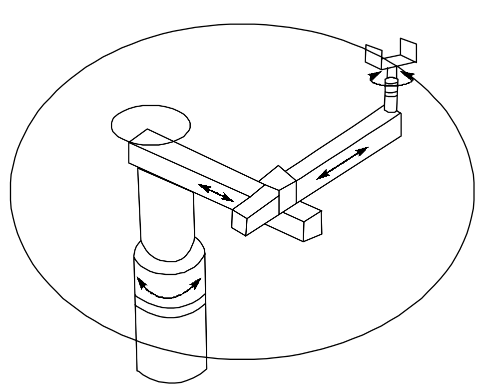
(i)



(ii)



(iii)



1. (e)

Let $\frac{d}{D} = x$

For uniform wear theory,

$$M_t = \frac{\pi\mu P_a D}{8}(D^2 - d^2) \quad \text{...(a)}$$

Substituting $\frac{d}{D} = x$, in above equation,

$$M_t = \frac{\pi\mu P_a D^3}{8}\left[x(1-x^2)\right] \quad \text{...(b)}$$

For maximum torque capacity

$$\frac{\partial}{\partial x}(M_t) = 0 \text{ or } \frac{\partial}{\partial x}\left[x(1-x^2)\right] = 0$$

$\therefore$ $$1 - 3x^2 = 0$$

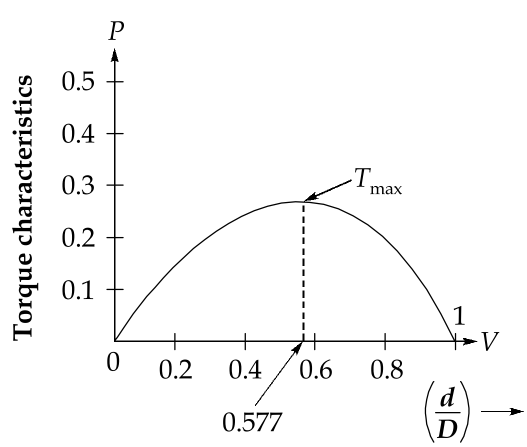
or $$x = \frac{1}{\sqrt{3}} = 0.577$$

or $$\frac{d}{D} = 0.577$$ Hence, proved

Now, rearranging equation (b), we get

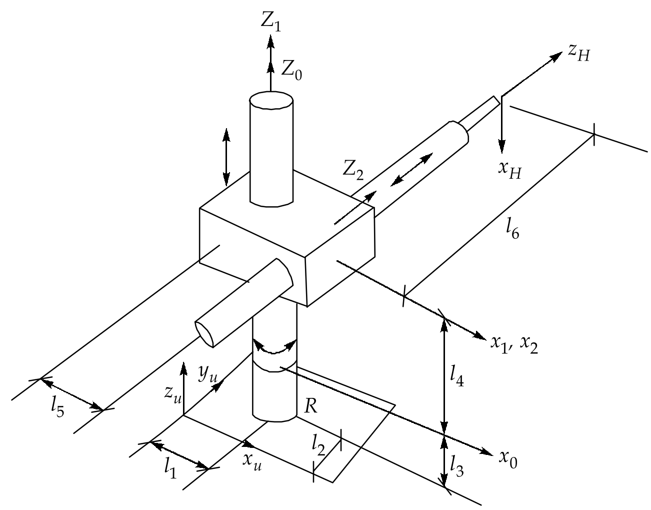
$$\frac{8M_t}{\pi\mu P_a D^3} = x(1-x^2)$$

The left hand side is called the torque characteristics. The variation of the torque characteristics against 'x' is shown below.



Variation of torque against $\frac{d}{D}$

2. (a)



Now, $${}^{U}T_H = {}^{U}T_R \, {}^{R}T_H = {}^{U}T_R A_1 A_2 A_3$$

$$\Rightarrow \quad {}^{U}T_H = \begin{bmatrix} 1 & 0 & 0 & l_1 \\ 0 & 1 & 0 & l_2 \\ 0 & 0 & 1 & l_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c & -s_1 & 0 & 0 \\ s_1 & c_1 & 0 & 0 \\ 0 & 0 & 1 & l_4 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & l_5 \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 0 & -1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & l_6 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

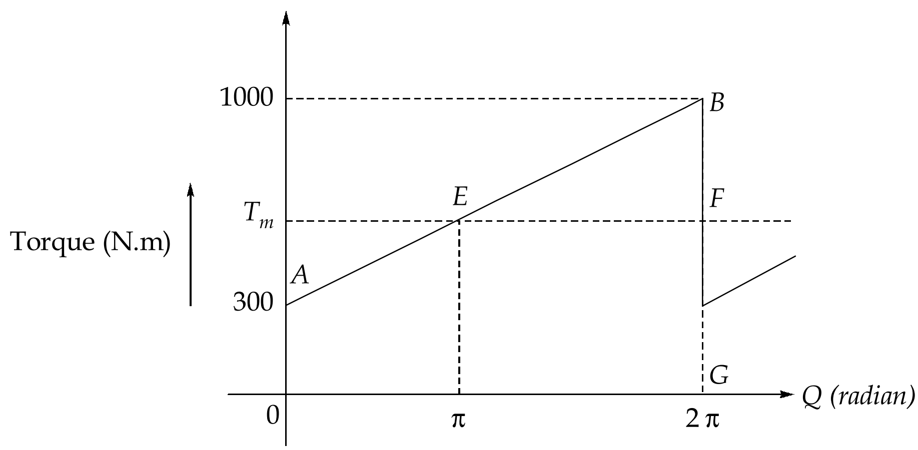
$$= \begin{bmatrix} 0 & -c_1 & -s_1 & -s_1 l_6 + c_1 l_5 + l_1 \\ 0 & s_1 & c_1 & c_1 l_6 + s_1 l_5 + l_2 \\ -1 & 0 & 0 & l_3 + l_4 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Note : The locations of the origins of some of the frames are arbitrary. Therefore, intermediate matrices might be different for each case. However the final answer should be same.

2. (b)

Given ω = 50 rad/s, c_s = 0.2, t = 25 mm, μ = 0.3, ρ = 7800 kg/m^3

The turning moment diagram is shown in figure



Turning moment diagram

The mean torque T_m supplied by motor is given by

$$T_m = \frac{\text{Area OAGB}}{\text{Length OG}} = \frac{\left(\frac{300+1000}{2}\right)\times 2\pi}{2\pi}$$

$$T_m = 650 \text{ Nm}$$

$\therefore$ Fluctuation of energy, E = Area ΔEBF

$$E = \frac{1}{2}(1000-650)\times\pi$$

$$= 175\pi \text{ Nm or J}$$

or $$I\omega^2 c_s = 175\pi$$

$$I = \frac{175\pi}{\omega^2 c_s} = \frac{175\times\pi}{50^2\times 0.2}$$

$$I = 1.099 \text{ kgm}^2$$

For solid disk flywheel

$$I = \frac{\pi}{2}\rho t R^4$$

$$1.099 = \frac{\pi}{2}\times 7800\times(0.025)\times R^4$$

$\therefore$ $$R = 0.245 \text{ m}$$

or $$R = 245 \text{ mm}$$ **Ans.**

Now, the tangential and radial stresses are maximum at the centre of the disk.

$$\Rightarrow \quad (\sigma_t)_{max} = (\sigma_r)_{max} = \frac{\rho v^2}{10^6}\left(\frac{\mu+3}{8}\right)$$

$$\sigma_{max} = \frac{(7800)(50\times 0.245)^2}{10^6}\left(\frac{0.3+3}{8}\right)$$

$$\sigma_{max} = 0.48 \text{ N/mm}^2$$ **Ans.**

2. (c)

Given : M_b = 500 kNm, S_{ut} = 500 MN/m², S_{ut} = 350 MN/m², S_e' = 210 MN/m², q = 0.8, k_a = 0.79, k_b = 0.75, k_c = 0.897

Since, $$\frac{r_f}{d} = \frac{8}{300} = 0.02667$$

∴ From table

$$k_t = 2.05 + \frac{2.6-2.05}{0.05-0.025}(0.05-0.02667)$$

$$k_t = 2.563,\ q = 0.8$$

$$k_f = 1 + q(k_t - 1)$$
$$= 1 + 0.8(2.563 - 1) = 2.25$$

$$\therefore \quad k_d = \frac{1}{k_f} = \frac{1}{2.25} = 0.444$$

Corrected endurance limit,

$$S_e = k_a k_b k_c k_d S_e'$$
$$= 0.79 \times 0.75 \times 0.897 \times 0.444 \times 210$$
$$= 49.5 \text{ N/mm}^2$$

$$M_b = 500 \text{ kNm}$$

$$\sigma_b = \frac{32\times M_b}{\pi d^3} = \frac{32\times 500\times 10^6}{\pi(300)^3} = 188.63 \text{ N/mm}^2$$

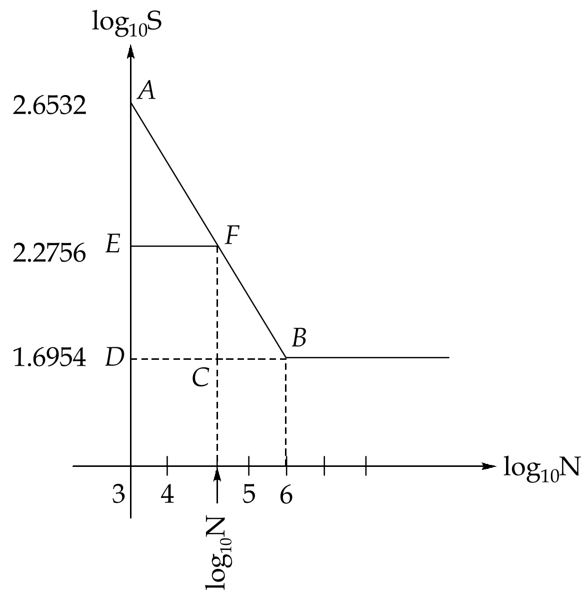
$$0.9S_{ut} = 0.9 \times 500 = 450 \text{ N/mm}^2$$

$$\log_{10}(0.9S_{ut}) = \log_{10}(450) = 2.6532$$

$$\log_{10}(S_e) = \log_{10}(49.5) = 1.695$$

$$\log_{10}(\sigma_b) = \log_{10}(188.63) = 2.2756$$

The S-N curve for the shaft is shown in figure below



From figure,

$$\overline{EF} = \frac{\overline{DB}\times\overline{AE}}{\overline{AD}} = \frac{(6-3)(2.6532-2.2756)}{(2.6532-1.695)}$$

$$\overline{EF} = 1.18221$$

Therefore,
$$\log_{10}N = 3+\overline{EF} = 3+1.182 = 4.182$$

$$N = 15205.47 \text{ cycles}$$ **Ans.**

3. (a)

Given : S_{ut} = 700 N/mm^2, S_{yt} = 460 N/mm^2, P = 30 kW, n = 600 rpm, $k_b = k_t = 1.5$

D_G = 250 mm, D_P = 420 mm

Permissible shear stress,

$$\tau_{per} = 0.3\ S_{yt} = 0.3 \times 460 = 138 \text{ MPa}$$

or
$$\tau_{per} = 0.18\ S_{ut} = 0.18 \times 700 = 126 \text{ MPa}$$

The lower of the two values is 126 MPa.

Hence, for design criteria,

$$\tau_{per} = 126 \text{ MPa}$$

Now, torsional moment,
$$M_t = \frac{60\times10^6}{2\pi N}\times\dot{P} = \frac{60\times10^6\times30}{2\pi(600)}$$

$$M_t = 477.7 \text{ Nm}$$

Bending moment, $(P_1 - P_2) \times 0.21 = 477.7$

$$P_1 - P_2 = 2274.76$$

or $$3P_1 - P_2 = 2274.76 \qquad (\because P_1 = 3P_2)$$

$\therefore$ $$P_2 = 1137.38 \text{ N}$$

and $$P_1 = 3412.14 \text{ N}$$

$\therefore$ $$P_1 + P_2 = 4549.52 \text{ N}$$

For gear, $$F_t \times 0.125 = 477.7$$

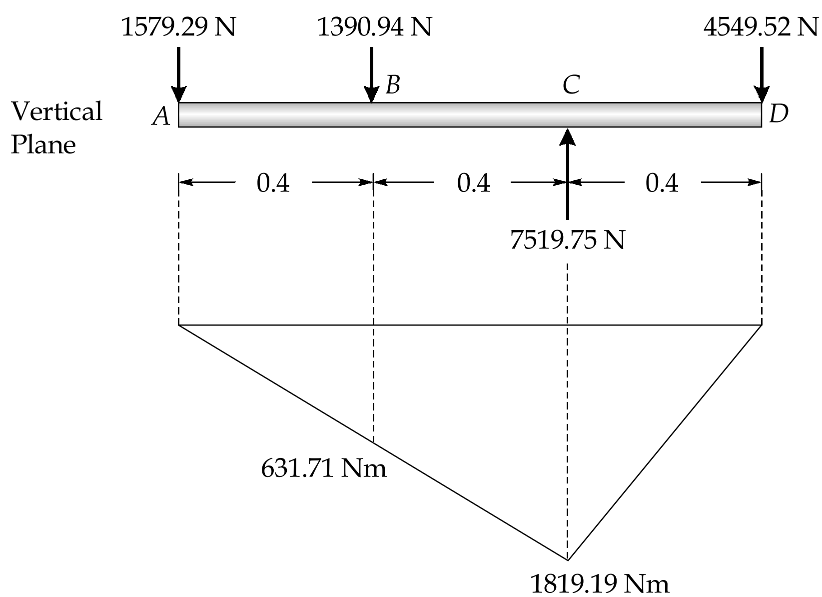
$\therefore$ $$F_t = 3821.6 \text{ N}$$

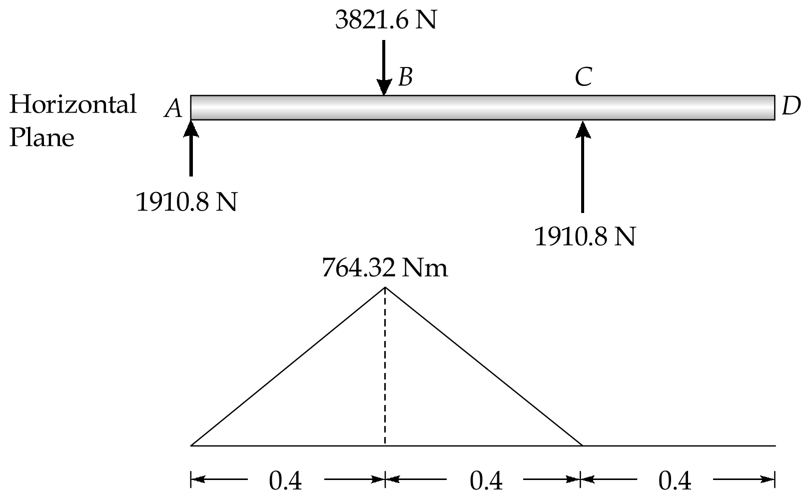
and $$F_r = F_t \tan 20°$$

$$F_r = 3821.6 \tan 20°$$

$$F_r = 1390.94 \text{ N}$$

The forces and bending moments in vertical and horizontal plane is shown below.





From bending moment diagram, we get at 'C'

$$(M_{\max})_C = 1819.8 \text{ Nm} = M_b$$

$\therefore$ Shaft diameter as per MSST,

$$d^3 = \frac{16}{\pi\tau_{per}}\sqrt{(k_b M_b)^2 + (k_t M_t)^2}$$

$$d^3 = \frac{16}{\left(\pi \times 126 \times 10^6\right)}\sqrt{(1.5 \times 1819.8)^2 + (1.5 \times 477.7)^2}$$

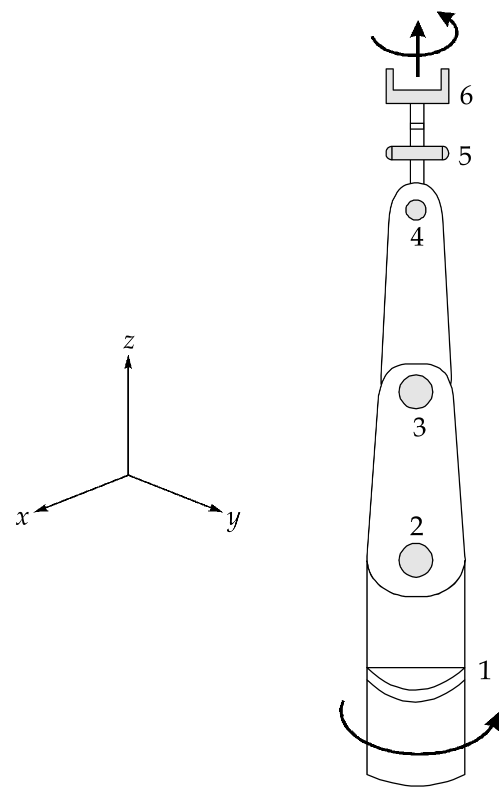
$$d^3 = 1.141 \times 10^{-4}$$

or $d = 48.5$ mm **Ans.**

3. (b)

(i)

Degeneracy occurs when the robot loses a degree of freedom and therefore, cannot perform as desired. This occurs under two conditions : (1) when the robot's joints reach their physical limits and as a result, cannot move any further, (2) a robot may become degenerate in the middle of its workspace if the z-axes of two similar joints become collinear. This means that, at this instant, whichever joint moves, the same motion will result, and consequently, the controller does not know which joint to move. Since in either case the total number of degrees of freedom available is less than six, there is no solution for the robot. In the case of collinear joints, the determinant of the position matrixed is zero as well. Figure shows a simple robot in a vertical configuration, where joints 1 and 6 are collinear. As you can see, whether joint 1 or joint 6 rotate, the end effector will rotate the same amount. In practice, it is important to direct the controller to take an emergency action; otherwise the robot will stop. Please note that this condition occurs if the two joints are similar. Otherwise, if one joint is prismatic and one is revolute (as in joints 3 and 4 of the Stanford arm), although the *z*-axes are collinear, the robot will not be in degenerate condition. Paul has shown that if sin α_4, sin α_5 or sin α_6 are zero, the robot will be degenerate (this occurs if joints 4 and 5, or 5 and 6 are parallel, and therefore, result in similar motions). Obviously, α_4 and α_5 can be designed to prevent the degeneracy of the robot. However, anytime θ_5 approaches zero or 180°, the robot will become degenerate.



An example of a robot in a degenerate position

We should be able to position and orientate a 6-DOF robot at any desired location within its work envelope by specifying the position and the orientation of the hand. However, as the robot gets increasingly closer to the limits of its workspace, it will get a point where, although it is possible to locate it at a desired point, it will be impossible to orientate it at desired orientations. The volume of points where we can position the robot as desired but not orientate it is called nondexterous volume.

(ii)

We have,

$$T = \left[\begin{array}{ccc|c} 0.527 & -0.574 & 0.628 & 2 \\ 0.369 & 0.819 & 0.439 & 5 \\ -0.766 & 0 & 0.643 & 3 \\ \hline 0 & 0 & 0 & 1 \end{array}\right]$$

We know,

$$T = \left[\begin{array}{c|c} R & P_{avg} \\ \hline 0 & 1 \end{array}\right]$$

So,

$$T^{-1} = \left[\begin{array}{c|c} R^T & -R^T P_{avg} \\ \hline 0 & 1 \end{array}\right]$$

Now,

$$-R^T P_{avg} = \begin{bmatrix} -0.527 & -0.369 & +0.766 \\ +0.574 & -0.819 & 0 \\ -0.628 & -0.439 & -0.643 \end{bmatrix}\begin{bmatrix} 2 \\ 5 \\ 3 \end{bmatrix}$$

$$= \begin{bmatrix} -0.601 \\ -2.947 \\ -5.38 \end{bmatrix}$$

and

$$R^T = \begin{bmatrix} 0.527 & 0.369 & -0.766 \\ -0.574 & 0.819 & 0 \\ 0.628 & 0.439 & 0.643 \end{bmatrix}$$

Then,

$$T^{-1} = \begin{bmatrix} 0.527 & 0.369 & -0.766 & -0.601 \\ -0.574 & 0.819 & 0 & -2.947 \\ 0.628 & 0.439 & 0.643 & -5.38 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

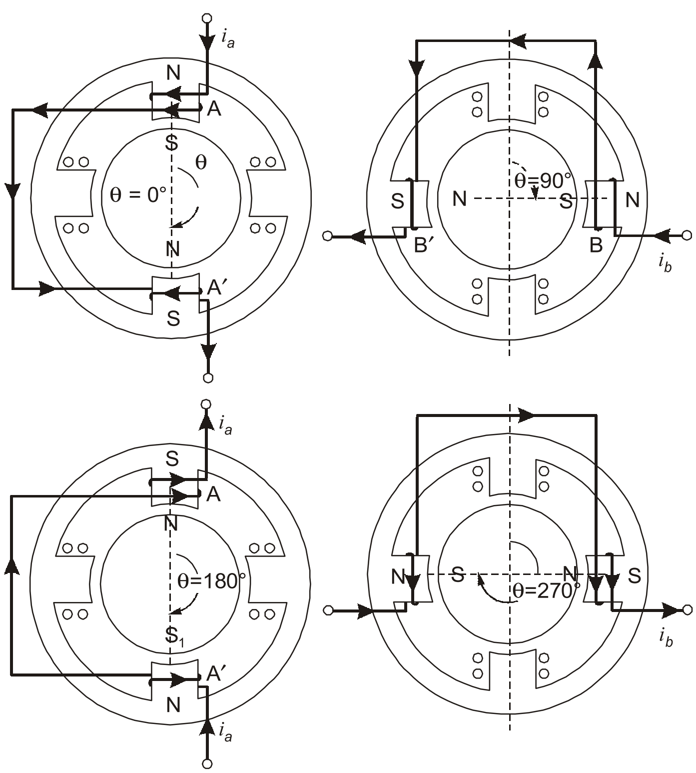
3. (c)

A stepper motor is a pulse-driven motor that changes the angular position of the rotor in steps. Due to this nature of a stepper motor it is widely used in low cost, open loop position control systems. A stepper motor is basically a brushless DC- motor whose rotor rotates in discrete angular movements when its winding is energized in a programmed manner. In stepper motor a full rotation is divided into a number of equal steps.

Permanent magnet (PM) stepper motor: The stator of permanent magnet stepper motor consists of salient poles with concentrated windings. The rotor as the name of this motor suggest, consists of permanent magnet poles. For the illustration of the working principle of PMSM an elementary form of 2-phase 4/2 pole stepper motor is considered here. The concentrated winding on diametrically opposite poles are connected in series so as to result in 2-phase winding on the stator. The rotor is magnetized to give two permanent magnets.

Working: Two coils *AA'* connected in series constitute phase *A* winding. When this winding is excited with current i_a, the stator produced poles attract the rotor permanent magnet poles so that their magnetic axis coincides. Let this exciting of phase A winding be denoted by +*A*.

Now the current in phase *A* winding is reduced to zero while phase *B* winding is excited with current i_b. Stator produced poles now attract the rotor poles, causing a CW step rotation through θ = 90°. Let the exciting of phase *B* winding be denoted by +*B*.



Internal structure of Permanent Magnet (PM) Stepper Motor

Now the phase winding *A* is again excited but with current opposite to i_a that is $-i_a$ this time. Now rotor poles further move through a step of 90° CW so that θ =180°. This step of exciting phase winding be denoted by –*A*.

Now the phase winding B is made to carry exciting current opposite to that of i_b that is $-i_b$ this time. The rotor again executes further step of 90° CW so that θ = 270°. This method of exciting phase B winding be designated as $-B$.

For further 90° CW step phase winding B is de-energized and phase winding A is energized. This shows that four steps complete one revolution of the rotor movement.

So here by the application of each current pulse to the stator winding in proper sequence, the rotor can be made to execute discrete angular steps of 90°. Sequence of exciting the stator phase winding is $+A$, $+B$, $-A$, $-B$, $+A$ for CW rotor movement. For CCW rotor rotation, sequence of exciting stator phase winding is $+A$, $-B$, $-A$, $+B$, $-B$.

If both the stator windings are excited in the sequence $+A$ together with $+B$, then the resultant stator field is along the interpolar axis, the rotor therefore moves a step of 45° CW. This shows for obtaining the angular step of 45° CW the switching sequence should be as $+A$, $(+A +B)$, $+B$, $(+B -A)$, $-A$, $(-A - B)$, $-B$, $(-B +A)$, $+A$.

This method of reducing step angle to half the normal step is called half step mode of excitation.

Advantages of stepper motors:

- Low cost
- Ruggedness
- Simplicity of construction
- Low maintenance
- Less likely to stall or slip
- Will work in any environment
- Excellent start stop and reversing responses

Disadvantages of stepper motor:

- Low torque capacity compared to DC motors.
- Limited speed.
- During overloading, the synchronization will be broken. Vibration and noise occur when running at high speed.

4. (a)

Given : n = 1450 rpm, z_p = 24, z_g = 48, m = 5 mm, b = 40 mm, c_s = 1.75, FOS = 1.5, BHN = 400, s_{ut} = 600 MPa

$\because$ For same material, pinion is weaker

$\therefore$ Beam strength, $S_b = \sigma_b \cdot m \cdot b \cdot y$

$$S_b = \left(\frac{600}{3}\times 5\times 40\times 0.36\right)$$

$$= 14400 \text{ N}$$

$$\text{Wear strength, } Q = \frac{2z_g}{z_g + z_p} = \frac{2\times 48}{48+24} = 1.333$$

$$k = 0.16\left(\frac{BHN}{100}\right)^2 = 0.16\left(\frac{400}{100}\right)^2 = 2.56$$

$$D_P = mz_p = 5 \times 24 = 120$$

$\Rightarrow$ $$s_w = QD_P kb$$

$$s_w = 1.333 \times 120 \times 2.56 \times 40$$

$$= 16379.9 \text{ N}$$

Now, $$V = \frac{\pi D_P N}{60} = \frac{\pi\times 120\times 1450\times 10^{-3}}{60}$$

$$V = 9.106 \text{ m/s}$$

$$C_V = \frac{3}{3+v} \qquad (\because\ V < 10 \text{ m/s})$$

$$= \frac{3}{3+9.106} = 0.247$$

$\therefore$ $$\text{Effective load, } P_{\text{eff}} = \frac{C_s}{C_v}\times P_t = \frac{1.75}{0.247}\times P_t$$

$$P_{\text{eff}} = 7.085\, Pt$$

Since, beam strength is lower than the wear strength. Therefore, beam strength is the criterion of design.

$\therefore$ $$S_b = P_{eff} \times \text{FOS}$$

$$14400 = 7.085P_t \times 1.5$$

$\therefore$ $$P_t = 1354.97 \text{ N}$$

$\therefore$ $$\text{Rated power, } P = P_t\times\frac{D_P}{2}\times\frac{2\pi N}{60}$$

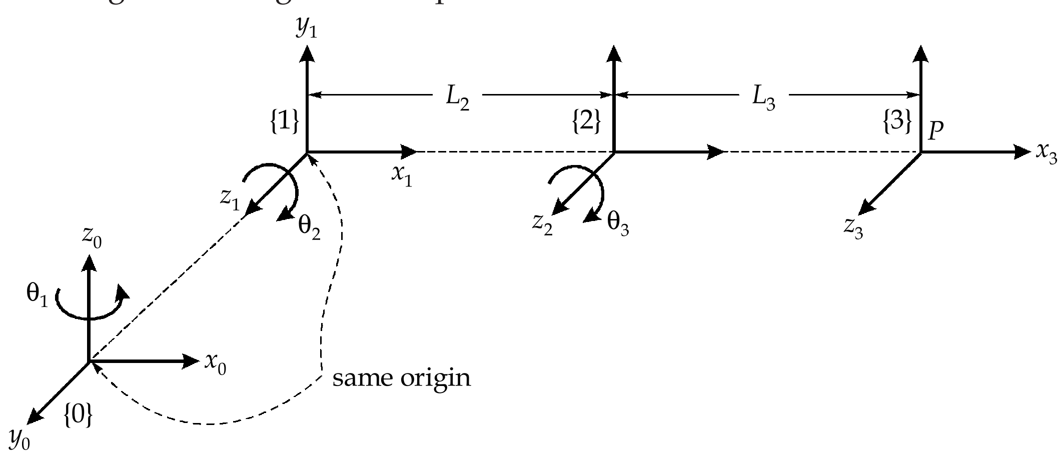
$$= 1354.97\times\frac{120}{2}\times\frac{2\pi\times 1450}{60}$$

$$= 12.34 \text{ kW}$$

4. (b)

Suppose we have robot whose configuration is known. This means that all the link lengths and joint angles of the robot are known. Calculating the position and orientation of the hand of the robot is called forward kinematic analysis. In other words, if all robot joint variables are known, using forward kinematic equations, we can calculate where the robot is at any instant. However, if we want to place the hand of the robot at a desired location and orientation, we need to know how much each link length or joint angle of the robot must be such that - at those values - the hand will be at the desired position and orientation. This is called inverse kinematic analysis. This means that instead of substituting the known robot variables in the forward kinematic equations of the robot, we need to find inverse of these equations to enable us to find the necessary joint values to place the robot at the desired location and orientation. In reality, the inverse kinematic equations are more important since the robot controller will calculate the joint values using these equations and it will run the robot to the desired position and orientation. We will first develop the forward kinematic equations of robots; then, using these equations, we will calculate the inverse kinematic equations.

Frame assignment for given manipulator is



Let link lengths are L_1, L_2 and L_3 respectively.

Now, D-H parameters,

Link	a_i	d_i	θ_i	α_i
1	0	0	θ_1	90
2	L_2	0	θ_2	0
3	L_3	0	θ_3	0

Now, link transformation matrices are

$$^0T_1(\theta_1) = \begin{bmatrix} c_1 & 0 & s_1 & 0 \\ s_1 & 0 & -c_1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^1T_2(\theta_2) = \begin{bmatrix} c_2 & -s_2 & 0 & L_2c_2 \\ s_2 & c_2 & 0 & L_2s_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$^3T_2(\theta_3) = \begin{bmatrix} c_3 & -s_3 & 0 & L_3c_3 \\ s_3 & c_3 & 0 & L_3s_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

So, overall transformation matrix is,

$$^0T_3 = {}^0T_1\,{}^1T_2\,{}^2T_3 = \begin{bmatrix} c_1c_{23} & -c_1s_{23} & s_1 & c_1(L_3c_{23}+L_2c_2) \\ s_1c_{23} & -s_1s_{23} & -c_1 & s_1(L_3c_{23}+L_2c_2) \\ s_{23} & c_{23} & 0 & L_3s_{23}+L_2s_2 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

where, c_{23} and s_{23} refers to $\cos(\theta_2 + \theta_3)$ and $\sin(\theta_2 + \theta_3)$ respectively.

4. (c)

Given : C_o = 50 kN, C = 68 kN

For part I

$$\frac{F_a}{F_r} = \frac{12.5}{45} = 0.277$$

and $$\frac{F_a}{C_o} = \frac{12.5}{50} = 0.25$$

From table, $e = 0.37$

$$\therefore \quad \frac{F_a}{F_r} < e$$

$\therefore \quad x = 1, y = 0$

$$P_1 = F_r = 45000 \text{ N}$$

Also, $$N_1 = \frac{25}{60} \times 720 = 300 \text{ rev}$$

For part II

$$\frac{F_a}{F_r} = 0.416$$

and $$\frac{F_a}{C_o} = \frac{6.25}{50} = 0.125$$

From table, $e = 0.31$ (approximately) and $\frac{F_a}{F_r} > e$

Assuming linear interpolation

$$y = 1.6 - \frac{(1.6-1.4)}{(0.13-0.07)} \times (0.125-0.07)$$

$$y = 1.416 \text{ and } x = 0.56$$

$\therefore$ $$P_2 = xF_r + yF_a$$

$$= 0.56(15000) + 1.416(6250)$$

$$= 17250 \text{ N}$$

$$N_2 = \frac{35}{60} \times 1440 = 840 \text{ rev}$$

$\therefore$ $$N_1 + N_2 = 300 + 840 = 1140 \text{ rev}$$

Equivalent load,

$$P_e = \left(\frac{N_1P_1^3 + N_2P_2^3}{N_1 + N_2}\right)^{1/3}$$

$$= \left(\frac{300 \times 45000^3 + 840 \times 17250}{300 + 840}\right)^{1/3}$$

$$= 30279.76$$

Bearing life, $$L_{10} = \left(\frac{C}{P_c}\right)^3 = \left(\frac{68000}{30279.76}\right)^3$$

$$= 11.325 \text{ million rev}$$

$\therefore$ Life in hours

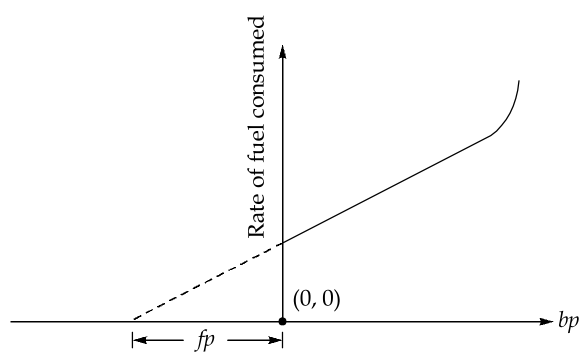
$$L_{10h} = \frac{L_{10} \times 10^6}{60 \times n} = \frac{11.325 \times 10^6}{60 \times 1140}$$

$$= 165.57 \text{ h}$$ **Ans.**

Section : B

5. (a)

Willan's Line Method: This is method of determining the friction power and hence the indicated power ($ip = bp + fp$) of an unthrottled compression ignition engine. This method is not suitable for use with petrol engines. It is based on the fact that at light loads a relatively small amount of fuel is pumped into the air charge. Hence, there is plenty of air available for complete combustion within the engine cylinder. Therefore, at a given engines speed in the light load region, a straight line law exists between the rate at which fuel is consumed and the engine load or brake power. This straight line is Willan's line and is shown in figure. By extrapolation, the fuel flow rate to given zero brake power can be determined. This is the fuel flow rate necessary to overcome friction and consequently, the amount of negative brake power at zero rate of fuel consumption represents the friction power. From this, the indicated power and mechanical efficiency can be evaluated.



The rapid increase in slope of the line at the high load end denotes a progressive reduction in combustion efficiency as more and more fuel is pumped into the given volume of air. It is therefore important that the extrapolation of Willan's line is carried out as accurately as possible and that sufficient readings at light load are taken to define the line.

Since a petrol engine is throttled to maintain a high fuel/air ratio with load, combustion is not complete within the cylinder and a plot of brake power versus the rate of fuel consumption does not yield a straight line. Hence extrapolation is virtually impossible.

The morse test: This method is applicable to reciprocating multi-cylinder engines. The engine is run at a particular speed and the torque is measured by cutting out the firing of each cylinder in turn and noting the fall in the brake power each time, while maintaining the set engine speed by reducing load. The observed difference in brake power between all cylinders firing and with one cylinder cut out is the indicated power of the cut-out cylinder.

If there are k cylinders and all are firing.

$$ip = bp + fp$$

or $$\sum_{i=1}^{k} ip_i = \sum_{i=1}^{k} bp_i + \sum_{i=1}^{k} fp_i \quad ...(i)$$

With the first cylinder cut out, it will not produce ip and theoretically there will be no contribution to bp from the first cylinder. However, there will be almost the same *fp*.

$$\sum_{i=2}^{k} ip_i = \sum_{i=2}^{k} bp_i + \sum_{i=1}^{k} fp_i \quad ...(ii)$$

Subtracting eq. (ii) from eq.(i) yields the ip of the first cylinder, i.e.

$$ip_1 = \sum_{i=1}^{k} ip_i - \sum_{i=2}^{k} ip_i = \sum_{i=1}^{k} bp_i - \sum_{i=2}^{k} bp_i \quad ...(iii)$$

Thus, the ip of each cylinder in turn can be obtained, and hence the sum of these values will give the ip of the engine with all *k* cylinders firing.

$$ip = ip_1 + ip_2 + ... + ip_k \quad ...(iv)$$

It is assumed that the friction power remains constant and has the same value in both eq. (i) and (ii). Strictly, this cannot be true. The temperature and pressure of the cut-out cylinder will be low. A reduced temperature will cause an increase in viscous drag on the piston, however a reduced pressure will reduce the frictional force on bearings and piston rings. These two effects tend to cancel out, but cannot do so exactly.

A petrol engine cylinder can be cut out by placed between its or a special high tension switch can be used. With CI engines, it may be possible to hold the fuel pump plunger off its cam with a suitable tool, so as to prevent fuel delivery to a particular cylinder.

Motoring test: In the motoring test, the engine is first run at a given speed and load conditions for sufficient time so that the temperature of the engine components, lubricating oil and cooling water reaches a steady state. A swinging field type electric dynamometer is used to absorb the power during this period. The ignition is then switched off and by suitable electric switching devices the dynamometer is converted to run as a motor. The motoring is done to crank the engine at the same speed at which it was operating previously. The test is conducted as rapidly as possible. The torque is measured under firing and under motoring conditions from which the bp and fp are evaluated. Then the ip and mechanical efficiency are determined.

The friction power determined by this method is reasonably good, but not very accurate. Although the coolant temperature will change little during changeover, the piston and cylinder wall temperature of the working parts within the engine is low, and it is temperature of the working parts which affects the viscous drag and hence the friction power. Also in absence of the exhaust blow-down, the pumping losses are not representative.

The motoring method is suitable for assessing the relative contribution to the friction power of the many moving parts within an engine. Components such as piston rings, valve gear, the camshaft and all accessories can be removed in turn and the motor torque measured.

Comparison of methods of measuring fp: The Willan's line method and Morse tests are very cheap and easy to conduct. However, both these tests give only an overall idea of the losses whereas motoring test gives a very good insight into the various causes of losses and is much more power tool. As for as accuracy is concerned the IP-BP method is most accurate if carefully done. Motoring method usually gives a higher value for f.p. as compared to that given by the Willan's line method.

5. (b)

Given : time, t = 10000 hours, Reliability, R = 0.92, Availability, A = 0.95

We know that, $$R = e^{-\lambda t}$$

$$0.92 = e^{-\lambda \times 10000}$$

∴ Failure rate, $\lambda = 8.33 \times 10^{-6}$ per hour

Mean time between failure,

$$\text{MTBF} = \frac{1}{\lambda} = \frac{1}{8.33 \times 10^{-6}}$$

$$\text{MTBF} = 120048 \text{ hours}$$

$$\text{Availability, } A = \frac{MTBF}{MTBF + MTTR}$$

$$0.95 = \frac{120048}{120048 + MTTR}$$

or $0.95 \times 120048 + 0.95\,MTTR = 120048$

∴ $MTTR = 6318.31$ hours **Ans.**

Reliability that machine will run for 15000 hours

$$R = e^{-\lambda(t)} = e^{-8.33 \times 10^{-6} \times 15000}$$

$R = 0.88$ **Ans.**

5. (c)

$$\text{Fuel consumption} = 10 \times 0.78 = 7.8 \text{ kg/hr}$$

$$\text{Air supply/hr} = 7.8 \times 18 = 140.4 \text{ kg/hr}$$

$$\text{Total charge} = 7.8 + 140.4 = 148.2 \text{ kg/hr}$$

Mass of charge at standard temperature and pressure corresponding to swept volume,

$$\dot{m} = \frac{\text{Total charge}}{\eta_v}$$

$$= \frac{148.2}{0.87} = 170.344 \text{ kg/hr}$$

Now, $PV = mRT$ per cylinder

$$1.013 \times 10^2 \times V = \frac{170.344}{2} \times 0.287 \times 298$$

$$V = 71.909 \text{ m}^3\text{/hr}$$

Volume swept by piston per stroke,

$$V_S = \frac{71.909 \times 10^6}{60 \times 4000} \qquad \text{(Two stroke engine)}$$

$$= 299.620 \text{ cc}$$

$$\text{and piston speed} = [\text{Length of stroke} \times 2] \times 4000$$

$$\therefore \quad L = \frac{900}{2 \times 4000} \times 10^2 = 11.25 \text{ cm}$$

$$\text{Now, swept volume} = \frac{\pi}{4} d^2 L = 299.620$$

$$\Rightarrow \quad \frac{\pi}{4} d^2 (11.25) = 299.620$$

$$\Rightarrow \quad d = 5.82 \text{ cm}$$

Now,

$$ip = 2 \times 5.4 \times 10^2 \times 299.62 \times 10^{-6} \times \frac{4000}{60}$$

$$= 21.567 \text{ kW}$$

and,

$$bp = \eta_m (ip) = 0.85(21.567) = 18.33 \text{ kW}$$

$$\text{Thermal efficiency} = \frac{18.33 \times 3600}{7.8 \times 44000}$$

$$\eta_{th} = 0.1922 = 19.22\%$$

5. **(d)**

Given : R = 20 m, r = 5 m, A = 5 km^2, η = 0.7, ρ = 1025 kg/m^3

$$\text{Average power, } P_{avg} = 0.225 \times A(R^2 - r^2) \text{ Watts}$$
$$= 0.225 \times 5 \times 10^6 \times (20^2 - 5^2)$$
$$= 421.87 \text{ MW}$$

$$\text{Energy available in single emptying} = \frac{1}{2}\rho g A(R^2 - r^2)$$
$$= \frac{1}{2} \times 1025 \times 9.81 \times 5 \times 10^6 (20^2 - 5^2)$$
$$= 9.42 \times 10^6 \text{ MJ}$$

$$\text{One ebb cycle duration} = 12\text{h } 25 \text{ min}$$
$$= 12.42 \text{ h}$$

$$\text{Number of ebb cycles in a year} = \frac{365 \times 24}{12.42}$$
$$N = 705.5$$
$$N \simeq 706$$

$$\therefore \text{ Average annual energy generation} = \frac{9.42 \times 10^6 \times 706 \times 0.7}{3.6}$$
$$= 12.93 \times 10^8 \text{ kWh}$$ **Ans.**

5. **(e)**

In hit and miss governing when the speed tends to rise above the governed value further induction strokes are omitted, giving a dead cycle, until the required speed is restored. In this case actual number of working cycles are counted over a measured period of time and the average taken.

The frictional power is taken as being constant at a given speed, and is independent of load. It can be calculated for no-load test.

Net imep per working cycle = Working loop mep – pumping loop mep

= 6.2 – 0.35 = 5.85 bar

$$\text{Dead cycles per minute} = \frac{400}{2} - 49 = 151$$

In dead cycle there is no *bp* output

$\therefore$ *fp* = net *ip* – pumping power of dead cycles

$$fp = (5.85\times10^2)\left(\frac{\pi}{4}(0.180)^2(0.320)\times\frac{49}{60}\right) - 0.62\times10^2\left(\frac{\pi}{4}(0.180)^2(0.320)\right)\times\frac{151}{60}$$

$$= 3.8903 - 1.2705 = 2.6197 \text{ kW}$$

At full load the engine fires regularly every two revolutions, and there are therefore 200 firing strokes per minute,

$\therefore$ Indicated power $= P_m LAN$

$$= \left(5.85\times10^2\right)\left(\frac{\pi}{4}(0.18)^2(0.32)\right)\times\frac{200}{60}$$

$$= 15.8788 \text{ kW}$$

Hence, $bp = ip - fp$

$$= 15.8788 - 2.6197$$

$$= 13.2591 \text{ kW}$$

and mechanical efficiency $= \dfrac{bp}{ip} = \dfrac{13.2591}{15.8788}$

$$\eta_m = 0.8350 = 83.50\%$$

6. **(a)**

Gas required for cooking for family = 10 × 0.227 = 2.27 m^3/day

Gas required for lighting = 0.126 × 3 × 3

= 1.134 m^3/day

Total daily gas requirement of the family = (2.27 + 1.134) m^3/day = 3.404 m^3/day

Let 'n' be the number of cows,

Cow dung produced = 10n kg/day

Collectable cow dung = 7n kg/day

Weight of dry solid mass in cow dung = 0.18 × 7n kg/day

Gas production per day = 0.34 × 0.18 × 7n

= 0.4284 n

At equilibrium,

Gas production = Gas required

$0.4284\, n = 3.404$

$n = 7.94 \simeq 8$

Thus 8 cows are required. **Ans.**

Daily feeding of cow dung = 8 × 7 = 56 kg

Daily feed of slurry = 56 + 56 = 112 kg

For 50 days retention time, volume of slurry in digester = $\frac{112 \times 50}{1090} = 5.139 \text{ m}^3$

As about 90% volume is occupied by the slurry, the required volume of digester

$$= \frac{5.137}{0.9} = 5.7 \text{ m}^3$$ **Ans.**

6. (b)

Stoichiometric equation can be written as

$$C_8H_{18} + x\left(O_2 + \frac{79}{21}N_2\right) \rightarrow aCO_2 + bH_2O + cN_2$$

Here, $a = 8$, $b = 9$

and $2a + b = 2x$

$\Rightarrow$ $2(8) + 9 = 2x$

$\Rightarrow$ $x = 12.5$

then, $c = x\left(\frac{79}{21}\right) = 12.5\left(\frac{79}{21}\right) = 47$

Now, $C_8H_{18} + 12.5\left(O_2 + \frac{79}{21}N_2\right) \rightarrow 8CO_2 + 9H_2O + 47N_2$

$$\text{Stoichiometric A/F ratio} = \frac{12.5\left(32 + \frac{79}{21}(28)\right)}{12(8) + 1 \times 18}$$

$$= 15.06$$

With the given A/F ratio (14 : 1); the mixture is rich in fuel and combustion will be incomplete.

So, chemical reaction becomes

$$C_8H_{18} + y\left(O_2 + \frac{79}{21}N_2\right) \rightarrow xCO + (8 - x)CO_2 + 9H_2O + y\left(\frac{79}{21}\right)N_2$$

Now, $$\text{A/F} = \frac{y\left(O_2 + \frac{79}{21}N_2\right)}{12(8) + 1(18)} = 14$$

$$\Rightarrow \qquad \frac{y\left(32+\frac{79}{21}(28)\right)}{12\times(8)+1\times(18)} = 14$$

$$\Rightarrow \qquad y = 11.62$$

By oxygen balance:

$$y = \frac{x}{2}+8-x+\frac{9}{2}$$

$$11.62 = \frac{x}{2}+8-x+4.5$$

$$\Rightarrow \qquad x = 1.76$$

Now, chemical reaction becomes:

$$C_8H_{18}+11.62\left(O_2+\frac{79}{21}N_2\right)\rightarrow 1.76CO+6.24CO_2+9H_2O+43.71N_2$$

and, number of moles before combustion = $1+11.62\left(1+\frac{79}{21}\right) = 56.33$

Number of moles after combustion = 1.76 + 6.24 + 9 + 43.71 = 60.71

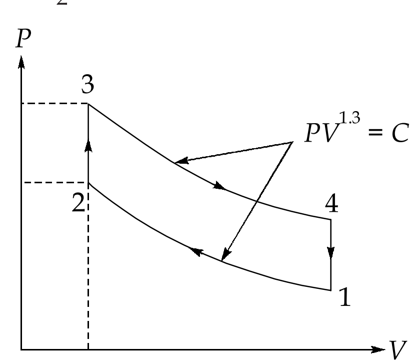
So molecular expansion = $\frac{60.71-56.33}{56.33}\times 100 = 7.77\%$

(i) Without considering the molecular expansion,

$$P_1 = 1 \text{ bar}, T_1 = 333 \text{ K}, \; n = 1.3$$

$$\Rightarrow \qquad \frac{T_2}{T_1} = (r)^{n-1} = \frac{T_2}{333} = (9)^{1.3-1}$$

$$\Rightarrow \qquad T_2 = 643.75 \text{ K}$$



and $$q_{2\text{-}3} = mC_V(T_3 - T_2)$$

$$m_f CV = (m_f + m_a)C_V(T_3 - T_2)$$

$$CV = \left(1 + \frac{m_a}{m_f}\right)C_V(T_3 - T_2)$$

$$44000 = (1 + 14) \times 0.71 \times (T_3 - 643.75)$$

$$T_3 = 4775.20 \text{ K}$$

and, assuming, mixture as an ideal gas

We have, $$P_2 = (r)^n P_1$$

$$= (9)^{1.3}(1) = 17.39 \text{ bar}$$

and process 2 - 3 is constant volume process, so

$$\frac{P_3}{P_2} = \frac{T_3}{T_2}$$

$\Rightarrow$ $$P_3 = \frac{4775.20}{643.75} \times 17.39$$

$$P_3 = 129.06 \text{ bar}$$

Since, the mass of the reactants and products is the same and specific heats are assumed same, the temperature of the products with molecular expansion will remain the same as without molecular expansion, only pressure will change,

$$T_3 = 4775.20 \text{ K}$$

Since, $$PV = n\bar{R}T$$

$\Rightarrow$ $$P \propto n$$

then, $$\frac{P_3'}{P_3} = \frac{n'}{n}$$

where n' = moles of products and n = moles of reactants.

$\Rightarrow$ $$P_3' = P_3 \times \frac{n'}{n}$$

$$= 129.06 \times \frac{60.71}{56.33}$$

$$= 139.095 \text{ bar}$$

So, maximum pressure considering the molecular expansion is 139.095 bar.

6. (c)

Condition based maintenance: It is also known as predictive maintenance. It is a philosophy that uses the actual operating condition of plant equipment and systems to optimize total plant operation. When the machine is running, it gives us certain signal, which convey the present condition of the machine. Signals are analyzed using real time data to prioritize and optimize maintenance resources. In this way, we take care of system's health and maintenance is carried out only when need arises.

A signal may be in any form such as visual, tactile, electrical, vibration and sound etc.

Classification of CBM:

1. **On-load monitoring techniques**: It refers to monitoring techniques performed during operation of a system.
   i. Visual inspection of accessible component.
   ii. Vibration monitoring.
   iii. Noise monitoring.
   iv. Motor current signature analysis.
2. **Off-load Monitoring techniques**: It refers to monitoring techniques performed during non-operational period of a system.
   i. Wear Debris analysis
   ii. Visual inspection of inaccessible or moving parts.
   iii. Crack detection.
   iv. Leak detection.

Techniques used for CBM:

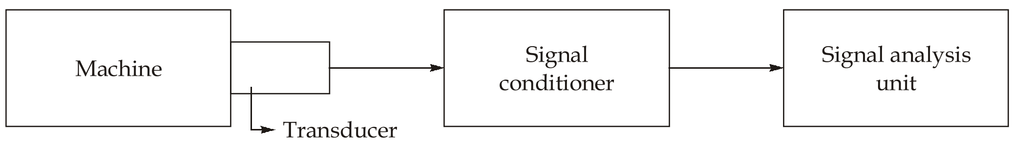
1. Vibration monitoring
2. Noise monitoring
3. Wear Debris Analysis
4. Oil analysis
5. Motor current signature analysis
6. Thermography
7. NDT techniques

Benefits of CBM:

1. Reduced maintenance cost
2. Improved system reliability
3. Intervention based on forewarning

4. Continuous availability of machine
5. Maintenance can be planned on holidays (Undisturbed production)
6. Longer machine life
7. Reduced small part inventory
8. Improved operator safety

Essential elements of CBM:



Good CBM system should have:

1. User friendly hardware and software
2. Automated data acquisition
3. Automated data management and trading
4. Flexibility
5. Reliability
6. Accuracy

7. (a)

Given : $\Delta H° = -65.7$ kcal/mol or -275.94 kJ/mol; $\Delta h° = \Delta G = -46.23$ kcal/mol or -194.166 kJ/mol

Also, $\Delta W_{max} = -\Delta G = -194.166$ kJ/mol

That means, 194.166 kJ electrical work is produced from 1 mole (i.e. 32g) of methanol and $\frac{3}{2}$ mole (i.e. 1.5 × 32g) of oxygen.

$\therefore$ Required flow rate of methanol for producing 200 kW $\left(\dot{M}_{methanol}\right) = \frac{32 \times 200}{194.166}$

$$\therefore \quad \left(\dot{M}_{methanol}\right) = 32.96 \text{ g/s}$$

$$\text{or} \quad \left(\dot{M}_{methanol}\right) = 118.66 \text{ kg/hr}$$ **Ans.**

Similarly, $$\dot{M}_{O_2} = \frac{48 \times 200}{194.166}$$

or $\dot{M}_{O_2} = 178$ kg/hr **Ans.**

Heat transferred, $\Delta Q = \Delta H - \Delta G$

$\Delta Q = -275.94 + 194.166$

$= -81.77$ kJ/mol

Negative sign indicates that heat is removed from the cell

Thus 1 mole (i.e. 32g) of methanol produces 81.77 kJ of heat.

$\therefore$ Heat rate, $\dot{Q} = \dfrac{81.77 \times 32.96}{32}$

$= 84.22$ kW **Ans.**

Now, theoretical EMF, $E = \dfrac{-\Delta G}{nF} = -\dfrac{(-194.166 \times 10^3)}{6 \times 96500}$

$E = 0.335$ V **Ans.**

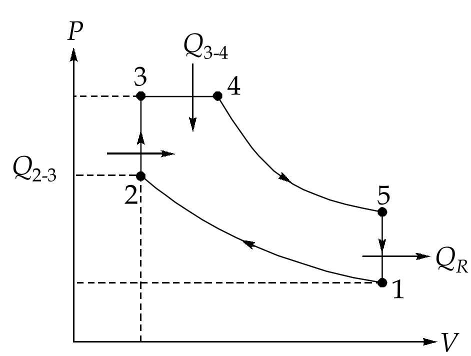
Maximum efficiency, $\eta_{max} = \dfrac{W_{max}}{-\Delta H} = \dfrac{-\Delta h}{-\Delta H}$

$\eta_{max} = \dfrac{194.166}{275.94} \times 100\%$

$\eta_{max} = 0.703\%$ **Ans.**

7. (b)

For dual cycle,



Given : $P_1 = 1$ bar; $T_1 = 47 + 273 = 320$ K; $r = 18$

$Q_{2\text{-}3} + Q_{3\text{-}4} = 2000$ kJ/kg of air

$Q_{2\text{-}3} = Q_{3\text{-}4}$

$\Rightarrow$ $Q_{2\text{-}3} = Q_{3\text{-}4} = \dfrac{2000}{2}$ kJ/kg of air

$$\gamma = 1.4$$

$$C_V = 0.75 + 20 \times 10^{-5}\, T \text{ kJ/kgK}$$

Now, $\dfrac{P_2}{P_1} = (r)^{\gamma}$

$\Rightarrow$ $P_2 = (18)^{1.4}(1)$

$\Rightarrow$ $P_2 = 57.198$ bar

and, $\dfrac{T_2}{T_1} = (r)^{\gamma - 1}$

$\Rightarrow$ $T_2 = (18)^{1.4 - 1}(320)$

$\Rightarrow$ $T_2 = 1016.85$ K

During constant volume process,

$$Q_{2\text{-}3} = \int_{T_2}^{T_3} C_V\, dT$$

$$1000 = \int_{1016.85}^{T_3} (0.75 + 20 \times 10^{-5})\, dT$$

$$1000 = 0.75(T_3 - 1016.85) + 10 \times 10^{-5}(T_3^2 - 1016.85^2)$$

$\Rightarrow$ $0.75T_3 - 1762.64 + 0.0001T_3^2 - 103.39 = 0$

$\Rightarrow$ $0.0001T_3^2 + 0.75T_3 - 1866.03 = 0$

$$T_3 = 1970.384 \text{ K}$$

and, for constant volume process

$\Rightarrow$ $\dfrac{P_3}{P_2} = \dfrac{T_3}{T_2}$

$\Rightarrow$ $P_3 \text{ (maximum pressure)} = \dfrac{1970.384}{1016.85} \times 57.198$

$$P_3 = 110.834 \text{ bar}$$

Now, for constant pressure process,

$$Q_{3\text{-}4} = \int_{T_3}^{T_4} C_P\, dT$$

$$1000 = \int_{1970.384}^{T_4} (C_V + R)\, dT$$

$$1000 = \int_{1970.384}^{T_4} (0.75 + 20\times10^{-5}T + 0.287)dT$$

$$1000 = 1.037(T_4 - 1970.384) + 10^{-4}(T_4^2 - 1970.384^2)$$

$$\Rightarrow \quad 1.037T_4 - 3043.288 + 10^{-4}T_4^2 - 388.241 = 0$$

$$\Rightarrow \quad 0.0001T_4^2 + 1.037T_4 - 3431.529 = 0$$

$$\Rightarrow \quad T_4 = 2638.011 \text{ K}$$

So, for constant pressure process,

$$\frac{V_4}{V_3} = \frac{T_4}{T_3}$$

$$\Rightarrow \quad V_4 = \frac{2638.011}{1970.384}\times V_3$$

$$\Rightarrow \quad V_4 = 1.3388V_2 \qquad [\because V_3 = V_2]$$

Now,

$$\text{Cut off} = \frac{V_4 - V_3}{V_1 - V_2}\times100$$

$$= \frac{1.3388V_2 - V_2}{18V_2 - V_2}\times100$$

$$= 1.9931\% \text{ of stroke}$$

7. (c)

The word gasification (or thermal gasification) implies converting solid fuel into a gaseous fuel by thermochemical method without leaving any solid carbonaceous residue.

Gasification involves partial combustion (oxidation in restricted quantity of air/oxidant) and reduction operations of biomass. In a typical combustion process, generally the oxygen is surplus, while in a gasification process, the fuel is surplus. The combustion products, mainly carbon dioxide, water vapour, nitrogen, carbon monoxide and hydrogen pass through the glowing layer of charcoal for the reduction process to occur. During this stage, both carbon dioxide and water vapour, oxidize the char to form CO, H_2 and CH_4. The following are the typical reactions, which occur during gasification.

$$C + O_2 \rightarrow CO_2 \qquad \text{(Combustion, 240 kJ/mole)}$$

The moisture available in the biomass is converted to steam and generally no extra moisture is required. Thus the product of combustion of pyrolysis gases results in CO_2 and H_2O and H_2O (steam), which further react with char:

$$C + O_2 \rightarrow 2CO \quad \text{(Boudouard reaction, – 164.9 kJ/mole)}$$

$$C + H_2O \rightarrow CO + H_2 \quad \text{(Water gas reaction – 122.6 kJ/mole)}$$

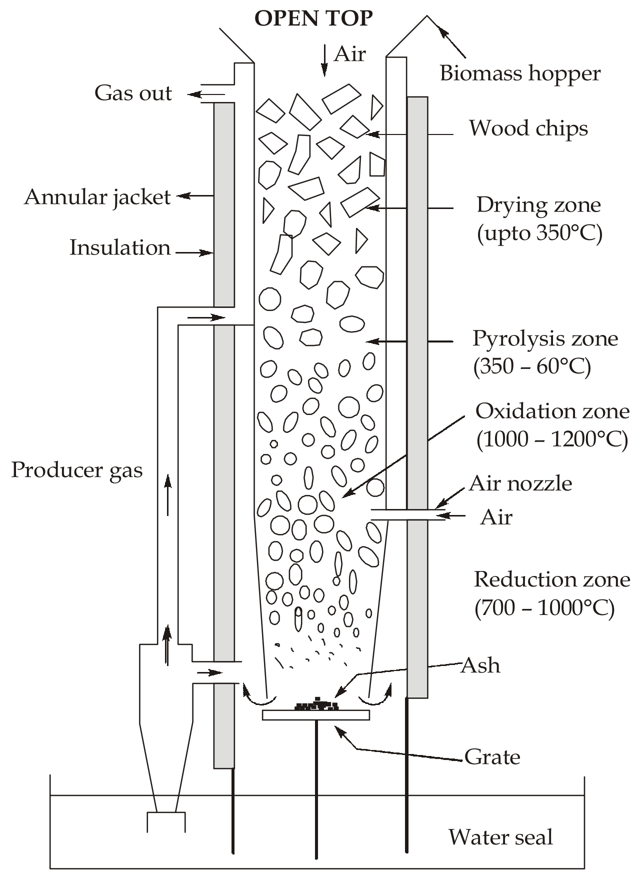
$$CO + H_2O \rightarrow CO_2 + H_2 \quad \text{(Water shift reaction, 40.2 kJ/mole)}$$

$$C + 2H_2 \rightarrow CH_4 \quad \text{(Methane reaction, 83.3 kJ/mole)}$$

The output gas is known as producer gas, a mixture of H_2(15 – 20%), CO(10 – 20%), CH_4(1 – 5%), CO_2(9 – 12%) and N_2(45 – 55%).

Downdraft type gasifier : The downdraft type is best suited for a variety of biomass. Its design forces the raw products to pass through a high-temperature zone so that most of the unburnt pyrolysis products (especially tars) can be cracked into gaseous hydrocarbons, thus producing a relatively clean gas.

In steady-state operation, heat from the combustion zone, near the air nozzle is transferred upwards by radiation, conduction and convection causing wood chips to pyrolyse and lose 70-80% of their weight. These pyrolysed gases burn with air to form CO, CO_2, H_2 and H_2O, thereby raising the temperature to 1000-1200°C. The product gases from the combustion zone further undergo reduction reaction with char to generate combustible products like CO, H_2 and CH_4. Generally about 40-70% air is drawn through the open top depending on the pressure drop conditions due to the size of wood chips and gas-flow rate. This flow of air opposite to the flame front helps in maintaining homogeneous air/gas flow across the bed. Combining the open top with the air nozzle towards the bottom of the reactor helps in stabilizing the combustion zone by consuming the uncovered char left and also by preventing the movement of the flame front to the top.



Downdraft biomass gasification plant

As a consequence, the high-temperature zone spreads above the air nozzle by radiation and conduction, aided by air flow from the top. The tar thus is eliminated in the best possible way by creating a high-temperature oxidizing atmosphere in the reactor itself.

The gas produced is withdrawn from an exit at the bottom and reintroduced in the annular jacket for heat recovery. The hot gas which enters the annular jacket around 500°C, transfers some heat to the wood chips inside, improving the thermal efficiency of the system in addition to drying the wood in this zone. The inner wall temperature reaches more than 350°C after a few hours of operation. This aspect enables the use of wood chips with moisture content as high as 25%. The regenerative heating due to the transfer of heat from hot gas to the biomass moving downwards also increases its residence time in the high temperature zone. This leads to better tar cracking.

8. (a)

Wear debris analysis is the analysis of two things.

1. **Wear particles (contaminants) get deposited in the oil**: Concentration of wear particle, nature of the wear particles and the rate at which it is deposited in the oil gives us some clue about machine condition.
2. **Oil undergo change in its physical and chemical properties**: The properties of virgin oil will get change when machine is running.
   - Unlike in vibration monitoring and noise monitoring, in wear debris analysis, you have to collect the oil in which contaminant is there and given this sample to the lab for analysis. In wear debris analysis In-situ analysis is not possible.
   - Quality and quantity of wear metals allows to set alarm level.
   - Knowledge of metallurgical composition is helpful in localizing source of wear metal production.

Wear debris characteristics:

1. Quantity (it tells about the severity of machine component).
2. Size of the particle.
3. Morphology (shape/structure).
4. Composition (It tells about the source i.e. parent material from where wear takes place).

Wear Mechanism:

1. Abrasive wear	2. Adhesive wear
3. Diffusion wear	4. Oxidation/corrosion

Wear mode:

1. Running in (during infant mortality zone of bathtub curve).
2. Steady wear (during the useful life of machine).
3. Wear out (towards the end of the life of the machine).

4. Pitting (it is the surface failure of a material as a result of stresses that exceed the endurance limit of the material).
5. Scuffing (due to insufficient lubrication between the mating part).

Wear Debris analysis method:

1. Ferrography:

  i. Analytical ferrography
  ii. Direct reading ferrography

2. Spectrophotometric technique:

  i. Atomic absorption spectroscopy (AAS)
  ii. Atomic emission spectroscopy (AES)
  iii. X-ray fluorescence (XRF)
  iv. Inductively coupled plasma (ICP)
  v. Direct current plasma (DCP)
  vi. Energy dispersive x-ray analysis(EDX)

8. (b)

Reasons for looking for alternate fuels:

- Demand of fuel is increasing day to day, gasoline and diesel will become scarce and more costly in near future.
- Due to high cost of petroleum products, alternate fuels become good option for many developing countries.
- Gasoline and diesel engine emission combined with other air polluting systems are major contributor to the air quality problem of the world, so use of alternate fuels becomes necessary for longer period of time.
- A large percentage of crude oil must be imported from other countries which control larger oil fields, which makes the use of alternate fuel development necessary for importer country.

Possible alternate fuels:

1. Alcohol:
   Eg. : Methyl alcohol and ethyl alcohol.
2. Vegetable oils
   Eg. Waste vegetable oils, pure plant oil etc.
3. Biodiesel
   Eg. : Animal fat based oil.

4. Hydrogen
5. Natural gases
   Eg. : LPG (Liquefied petroleum gas)
   CNG (Compressed natural gas) etc.
6. Biogas

LPG as an alternate fuel: Propane and butane are obtained from oil and gas wells. They are also the products of the petroleum refining process. For automobile engines, two types of LPG are used. One is propane and the other is butane. Sometimes, a mixture of propane and butane is used as liquid petroleum gas in automobile engines. Liquid petroleum gases serve as fuel in place of petrol. They are used widely in buses, cars and trucks. Liquid petroleum gases are compressed and cooled to form liquid. This liquid is kept in pressure tanks which are sealed.

Advantages and Disadvantages of LPG

Liquefied petroleum gas has higher potential as an alternate fuel for IC engines. The advantages and disadvantages of using LPG are :

Advantages:

(i) LPG contains lesser carbon than petrol. LPG powered vehicle produces 50 percent less carbon monoxide per kilometre, though only slightly less nitrogen compounds. Therefore emission is much reduced by the use of LPG.
(ii) LPG mixes with air at all temperatures.
(iii) In multi-cylinder engines a uniform mixture can be supplied to all cylinders.
(iv) Since the fuel is in the form of vapour, there is no crankcase dilution.
(v) Automobile engines can use propane, if they have high compression ratio (10 : 1).
(vi) LPG has high antiknock characteristics.
(vii) Its heat energy is about 80 percent of gasoline, but its high octane value compensates the thermal efficiency of the engine.
(viii) Running on LPG translates into a cost saving of about 50%.
(ix) The engine may have 50 percent longer life.

Disadvantages:

(i) Engines are normally designed to take in a fixed volume of the mixture of fuel and air. Therefore, LPG will produce 10 percent less horse power for a given engine at full throttle.
(ii) The ignition temperature of LPG is somewhat higher than petrol. Therefore running on LPG could lead to a five percent reduction in valve life.

(iii) A good cooling system is quite necessary, because LPG vaporizer uses engine coolant to provide the heat to convert the liquid LPG to gas.
(iv) The vehicle weight is increased due to the use of heavy pressure cylinders for storing LPG.
(v) A special fuel feed system is required for liquid petroleum gas.

8. (c)

Hydraulic power required to pump water,

$$\dot{m}gh = \frac{1000 \times 10}{3600} \times 9.81 \times 4 = 109 \text{ Watt}$$

$$\text{Mechanical power required} = \frac{109}{0.5 \times 0.8} = 272.5 \text{ W}$$

$$\text{Power available in wind} = \frac{1}{2}\rho A V^3$$

$$= \frac{1}{2} \times 1.2 \times \pi r^2 \times 12^3$$

$$= 3255.55\, r^2$$

$$\text{Power extracted} = C_p \times \text{Power available in wind}$$

or $$272.5 = 0.3 \times 3255.55\, r^2$$

$$r = \sqrt{\frac{272.5}{0.3 \times 3255.55}}$$

$$r = 0.528 \text{ m}$$ **Ans.**

Now, $$\text{Tip speed ratio, } \lambda = \frac{r\omega}{V}$$

$$2 = \frac{0.528 \times \omega}{12}$$

∴ $$\omega = 45.45 \text{ rad/s}$$ **Ans.**

Tip speed ratio for optimum output,

$$\lambda_0 = \frac{4\pi}{n}$$

or $$\frac{\omega_0 \times r}{V} = \frac{4\pi}{n}$$

$$\omega_0 = \frac{4\pi V}{r \times n} = \frac{4\pi \times 12}{0.528 \times 3}$$

$$\omega_0 = 95.15 \text{ rad/s}$$ **Ans.**

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