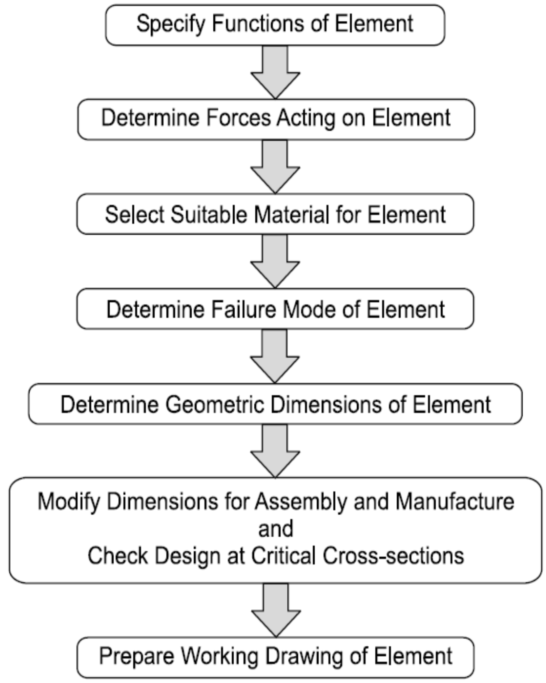
BAPATLA ENGINEERING COLLEGE (AUTONOMOUS), BAPATLA
DEPARTMENT OF MECHANICAL ENGINEERING

Design of Machine Elements - I (18ME503)
(Key)

1.	a)	1. Adoptive Design 2. Development Design 3. New Design Depending on the Method 1. Rational Design 2. Empirical Design 3. Industrial Design 4. Optimum Design 5. System Design 6. Element Design 7. Computer aided Design (Any two designs)	1M
	b)	Preferred numbers are used to decide a size of product with in specific range. The function of preferred numbers to cover a certain range with minimum no of sizes. Eg: R5, R10, R20, R40	1M
	c)	While designing a component, it is necessary to provide sufficient reserve strength in case of an accident. This is achieved by taking a suitable factor of safety (FS). It is defined as Factor of Safety = Maximum or Failure Stress / Design or Working or Allowable Stress	1M
	d)	The factors that affect endurance limit of a machine part are Load factor, Size factor, Surface Finish factor, Reliability factor etc.	1M
	e)	It is a method to increase the shock absorbing capacity of bolts. It can be done by reducing the shank area to core area of threads or increase the core diameter to shank diameter.	1M
	f)	The types of riveted joint failures are 1. Tearing failure 2. Shear failure 3. Crushing failure of rivet/plate 4. Marginal failure	1M
	g)	If the length of weld is perpendicular to the applied load such joint is known as transverse fillet weld and if the length of weld is parallel to the applied load it is known as parallel fillet weld. The transverse weld always subjected to tensile stress and parallel fillet weld is subjected to shear stress. (Any one difference)	1M
	h)	Shaft is a rotating member which is used to transmit power from one place to the another place	1M
	i)	A feather key is a parallel key which is fixed either to the shaft or to the hub and which permits axial movement between them. It is used in clutches and gear shifting devices.	1M
	j)	Couplings are classified in to Rigid Couplings and Flexible Couplings. A rigid coupling does not permit any misalignment between the shafts. The flexible couplings permit the misalignment between the shafts.	1M
2	a)	Engineering Materials are basically classified in to 1. Metals and their alloys such as iron, steel, copper, aluminium etc. 2. Nonmetals such as glass, rubber, plastic etc. The metals classified in to 1. Ferrous materials those which have iron as their main constituent such as cast iron, wrought iron, steel 2. Nonferrous materials are those which have a metal other than iron as their main constituent such as copper, aluminium, brass, tin, zinc etc. According to percentage of carbon the steel is classified in to 1. Mild Steel 2. Low carbon steel 3. Medium carbon steel 4. High carbon steel (Any two classification)	4M
2	b)	Design of machine elements is the most important step in the complete procedure of machine design. In order to ensure the basic requirements of machine elements, calculations are carried out to find out the dimensions of the machine elements. The basic procedure of the design of machine elements is illustrated in the Flow Chart. It consists of the following steps: <u>1. Specification of Function:</u> It decides the purpose or function of element. For example the bearing is to support the rotating shaft and key is to transmit torque between the shaft and adjoining part like gear	6M

2. Determine the Forces: at this step the forces acting on the machine element can be determined with the help of free body diagrams
3. Selection of material: Suitable material can be selected by considering mechanical properties, cost, availability and manufacturing considerations.
4. Failure Mode: Before finding out the dimensions of the component, it is necessary to know the type of failure that the component may fail when put into service. The machine component is said to have failed when it is unable to perform its functions satisfactorily. Generally a component may fail due to elastic deflection, yielding or fracture.
5. Determining Dimensions: Depending on the operating conditions and shape of the adjoining element, the shape of the machine element is decided and a rough sketch is prepared. The geometric dimensions of the component are determined on the basis of failure criterion. In simple cases, the dimensions are determined on the basis of allowable stress or deflection



6. Design Modifications: The geometric dimensions of the machine element are modified from assembly and manufacturing considerations. The process is continued till the desired values of operating capacity, factor of safety and stresses at critical cross-sections are obtained.
7. Working Drawing: The last step in the design of machine elements is to prepare a working drawing of the machine element showing dimensions, tolerances, surface finish grades, geometric tolerances and special production requirements like heat treatment [Flow Chart 2M + Explanation 4M]

3 a) 4M

Maximum Principal Stress Theory: It states that the failure of the mechanical component subjected to bi-axial or tri-axial stresses occurs when the maximum principal stress reaches the yield or ultimate strength of the material. If σ_1, σ_2 and σ_3 are the three principal stresses at a point on the component and $\sigma_1 > \sigma_2 > \sigma_3$ then according to this theory, the failure occurs whenever

$$\sigma_1 = \frac{S_{yt}}{FS}$$

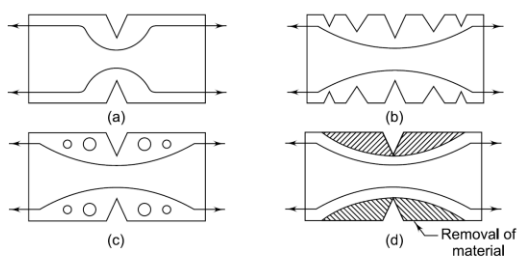
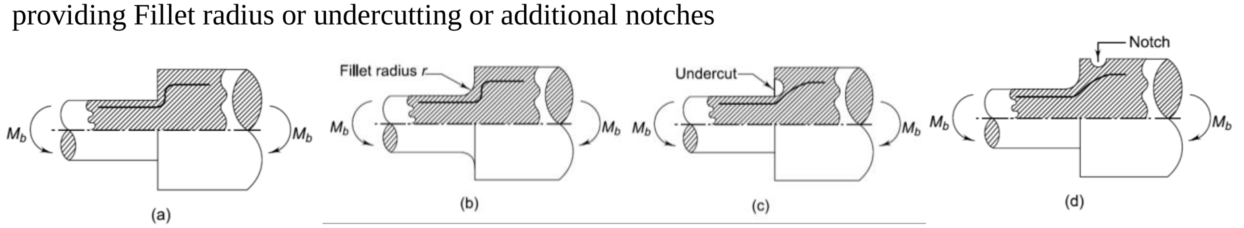
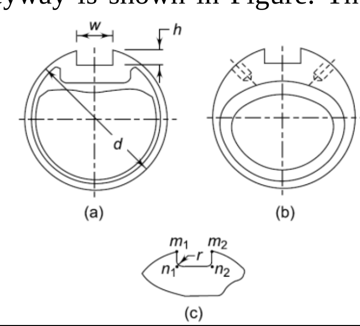
Maximum Shear Stress Theory: It states that the failure of a mechanical component subjected to bi-axial Stresses in Simple Tension Test or tri-axial stresses occur when the maximum shear stress at any point in the component becomes equal to the maximum shear stress in the standard specimen of the tension test, when yielding starts. Suppose σ_1, σ_2 and σ_3 are the three principal stresses at a point on the component. According to maximum shear stress theory

$$\frac{S_{yt}}{FS} = Max[(\sigma_1 - \sigma_2), (\sigma_2 - \sigma_3), (\sigma_1 - \sigma_3)]$$

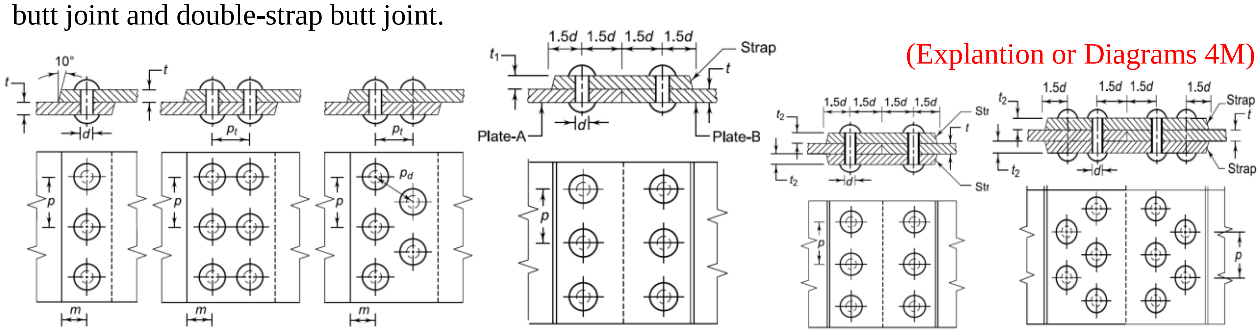
Distortion Energy Theory: The theory states that the failure of the mechanical component subjected to bi-axial or tri-axial stresses occurs when the strain energy of distortion per unit volume at any point in the component, becomes equal to the strain energy of distortion per unit volume in the standard specimen of tension-test, when yielding starts. According to maximum shear stress theory

$$\frac{S_{yt}}{FS} = \sqrt{\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2]}$$

(Any Two Theories)

3	b)	<u>Given Data</u>: S_{yt} = 380 N/mm^2, σ_X = 100 N/mm^2, σ_y = 40 N/mm^2, τ_{xy} = 80 N/mm^2, FS = ? $\sigma_1 = \left(\frac{\sigma_x+\sigma_y}{2}\right) + \sqrt{\left(\frac{\sigma_x-\sigma_y}{2}\right)^2 + \tau_{xy}^2} = 155.44\ N/mm^2$ $\sigma_2 = \left(\frac{\sigma_x+\sigma_y}{2}\right) - \sqrt{\left(\frac{\sigma_x-\sigma_y}{2}\right)^2 + \tau_{xy}^2} = -15.44\ N/mm^2$ [2M] i) According to Maximum Principal Stress Theory $\sigma_1 = \frac{S_{yt}}{FS} \Longrightarrow FS = \frac{380}{155.44} = 2.44$ ii) According to Maximum Shear Stress Theory $\sigma_1 - \sigma_2 = \frac{S_{yt}}{FS} \Longrightarrow FS = \frac{380}{155.44+15.44} = 2.22$ [2M] iii) According to Maximum Distortion Energy Theory $\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2 = \left(\frac{S_{yt}}{FS}\right)^2 \Longrightarrow FS = \frac{380}{163.7} = 2.32$ [2M]	6M
4	a)	It is not possible to completely eliminate the effect of stress concentration, there are some methods to reduce stress concentrations. (i) <u>Additional Notches and Holes in Tension Member</u>: A flat plate with a V-notch subjected to tensile force is shown in Figure (a). It is observed that a single notch results in a high degree of stress concentration. The severity of stress concentration is reduced by three methods: (a) use of multiple notches (b) drilling additional holes and (c) removal of undesired material.  (ii) <u>Fillet Radius, Undercutting and Notch for Member in Bending</u>: A bar of circular cross-section with a shoulder and subjected to bending moment is shown in Figure Ball bearings, gears or pulleys are seated against this shoulder. The shoulder creates a change in cross-section of the shaft, which results in stress concentration. There are three methods to reduce stress concentration at the base of this shoulder. By providing Fillet radius or undercutting or additional notches  (iii) <u>Drilling Additional Holes for Shaft</u>: A transmission shaft with a keyway is shown in Figure. The keyway is a discontinuity and results in stress concentration at the corners of the keyway and reduces torsional shear strength Rounding corners at two points, viz., n1 and n2 by means of a fillet radius can reduce the stress concentration. In addition to giving fillet radius at the inner corners of the keyway, there is another method of drilling two symmetrical holes on the sides of the keyway These holes press the force flow lines and minimise their bending in the vicinity of the keyway.  (Any two Methods Explanation)	4M

4	b)	Given Data: S_{ut} = 500 N/mm^2, S_{yt} = 300 N/mm^2, T_{max} = + 400 Nm, T_{min} = − 100 Nm, FS = 2, R = 90%, K_s = 0.577, K_{sz} = 0.85, K_{sur} = 0.8, K_r = 0.897, d = ? $T_m = \frac{T_{max}+T_{min}}{2} = 150 * 10^3 Nmm \quad and \quad T_a = \frac{T_{max}-T_{min}}{2} = 250 * 10^3 Nmm$ $\tau_m = \frac{16\,T_m}{\pi\,d^3} = \frac{763.94 * 10^3}{d^3}\ N/mm^2 \quad and \quad \tau_a = \frac{16\,T_a}{\pi\,d^3} = \frac{1273.24 * 10^3}{d^3}\ N/mm^2$ [2M] $S'_e = 0.5 * S_{ut} = 250\ N/mm^2$ $S_{es} = S'_e * K_s * K_{sz} * K_{sur} * K_r = 87.988\ N/mm^2$ $S_{ys} = 0.577 S_{yt} = 173.1\ N/mm^2$ [2M] According to Soderberg's Criteria $\frac{1}{FS} = \frac{\tau_m}{S_{ys}} + \frac{\tau_a}{S_{es}} \implies \frac{1}{2} = \frac{763.94 * 10^3/d^3}{173.1} + \frac{1273.24 * 10^3/d^3}{87.988} \implies d = 33.55\ mm$ [2M]	6M
5	a)	Procedure to determine the size of the bolt when the bracket carries an eccentric load perpendicular to the axis of the bolt 1. Calculate Primary Shear Load using the Formula $P'_1 = P'_2 = P/n$ 2. Calculate Secondary Tensile Load for bolt which is having more distance with corner using the formula $P''_1 = C\,l_1 \ \ and\ P''_2 = C\,l_2$ Where C = Torsional load per unit length $= \frac{P\,e}{2(l_1^2+l_2^2)}$ $l_1\ and\ l_2$ are the distance between corner to row 1 and row 2 bolts respectively e = distance between center of gravity of joint to eccentric load 3. Calculate equivalent load $P_{te} = \frac{1}{2}\left(P''_1 + \sqrt{(P''_1)^2 + 4(P'_1)^2}\right) \quad and \ \ P_{se} = \frac{1}{2}\sqrt{(P''_1)^2 + 4(P'_1)^2}$ 4. Determine the core diameter of the bolt using the relations $P_{te} = \left(\frac{\pi}{4}d_c^2\right)\sigma_t \quad or \ \ P_{se} = \left(\frac{\pi}{4}d_c^2\right)\tau$	4M
5	b)	Given Data: P = 3 kN = 3x10^3 N, e = 200+50 = 250 mm, S_{yt} = 380 N/mm^2, FS = 2, d = ? The Primary shear load on each bolt is = $P'_1 = P'_2 = P'_3 = P'_4 = P/n = 750\ N$ [2M] $l_1 = l_2 = l_3 = l_4 = \sqrt{50^2+50^2} = 70.71\ mm$ $C = \frac{P\,e}{(l_1^2+l_2^2+l_3^2+l_4^2)} = \frac{3 * 10^3 * 250}{4 * 70.71^2} = 37.5\ N/mm$ $P''_2 = P''_4 = C\,l_2 = 2651.625\ N$ $cos\,\theta_2 = \frac{h_2}{l_2} = \frac{50}{70.71} = 0.707$ $R_2 = R_4 = \sqrt{(P'_2)^2 + (P''_2)^2 + 2P'_2P''_2\cos\theta_2} = 3225.78\ N$ [2M] $\tau = \frac{S_{ys}}{FS} = \frac{S_{yt}}{2\,FS} = 95\ N/mm^2$ $P_s = \left(\frac{\pi}{4}d_c^2\right)\tau \implies d_c = 6.575\ mm$ $d = \frac{d_c}{0.8} = 8.218 = M9$ [2M]	6M

6	a)	Riveted joints used for joining the plates are classified into two groups—lap joint and butt joint. Lap joint consists of two overlapping plates, which are held together by one or more rows of rivets. Depending upon the number of rows, the lap joints are further classified into single-riveted lap joint, double-riveted lap joint or triple riveted lap joint. In double or triple riveted lap joints, the rivets can be arranged in chain pattern or zig-zag pattern. A chain riveted joint is a joint in which the rivets are arranged in such a way that rivets in different rows are located opposite to each other. A zig-zag riveted joint is a joint in which the rivets are arranged in such a way that every rivet in a row is located in the middle of the two rivets in the adjacent row. The butt joint consists of two plates, which are kept in alignment against each other in the same plane and a strap or cover plate is placed over these plates and riveted to each plate. Depending upon the number of rows of rivets in each plate, the butt joints are classifi ed as single-row butt joint and double-row butt joint. Depending upon the number of straps, the butt joints are also classifi ed into single-strap butt joint and double-strap butt joint. (Explantion or Diagrams 4M) 	4M
6	b)	Given Data: D = 1.5m, p_i = 0.95 MPa, double shear, η = 75%, σ_t = 90 MPa, τ = 56 MPa, σ_c = 140 MPa $Thickness\ of\ Plate = t = \frac{p_i\, D}{2\, \sigma_t\, \eta} = 10.55 \simeq 12\ mm$ $Diameter\ of\ Rivet =\ d = 6.07\sqrt{t} = 21.02\ mm \simeq 22\ mm$ [2M] $P_t = P_s \implies (p-22) * 12 * 90 = 2 * 1.875 * \frac{\pi}{4} * 22^2 * 56 \implies p = 95.91\ mm \simeq 96\ mm$ $p_{min} = 2.25\ d = 50\ mm\ \ and\ \ p_{max} = k_1 t + 41 = (3.5 * 12) + 41 = 83\ mm$ $p > p_{min}\ and\ p > p_{max}\ \ so\ pitch = p = 80\ mm$ [2M] $Transverse\ Pitch = p_t = 0.33p + 0.67d = 41.14\ mm \simeq 42\ mm$ $Thickness\ of\ Cover\ Plate = t_1 = 0.625\ t = 7.5\ mm$ $Margin = m = 1.5\ d = 33\ mm$ [2M]	6M
7	a)	Advantages of Welded joints over Riveted joints 1. Welded steel structures are lighter than the Riveted joints 2. Cost of welded assembly is lower than that of riveted joints. 3. The welded assemblies can be easily and economically modified 4. Alterations and additions can be easily made in the existing structure by welding. 5. Welded assemblies are tight and leakproof as compared with riveted assemblies. 6. The production time is less for welded assemblies. 7. Making holes in riveted joints reduce the cross-sectional area of the members and result in stress concentration. There is no such problem in welded connections. 8. A welded structure has smooth and pleasant appearance. The projection of rivet head adversely affects the appearance of the riveted structure. 9. The strength of welded joint is high. Very often, the strength of the weld is more than the strength of the plates that are joined together. 10. Machine components of certain shape, such as circular steel pipes, find difficulty in riveting. However, they can be easily welded. (Any Four Advantages)	4M

7 b) <u>Given Data</u>: w = 100 mm, h = 10 mm, σ_t = 70 MPa, τ = 50 Mpa, l = ? 6M

$Load\ on\ the\ Jonit = P = w * t * \sigma_t = 70 * 10^3\ N$ [2M]

$Strength\ of\ Transverse\ weld = P_1 = w * (0.707\ h) * \sigma_t = 49.49 * 10^3\ N$

$Strength\ of\ Double\ Parallel\ Fillet\ weld = P_2 = 2l * (0.707\ h) * \tau = 707\ l$ [2M]

$Total\ Load = P = P_1 + P_2 = 49.49 * 10^3 + 707\ l$

$\therefore l = \frac{70*10^3 - 49.49*10^3}{707} = 29\ mm$

Adding 15 mm of length for starting and stopping of the weld run. The length of weld becomes

$\therefore l = 29 + 15 = 44\ mm$ [2M]

8 <u>Given Data</u>: P_1 = 2.5 kN = 2.5x10^3 N, $\theta_B = \theta_C = 180^0 = \pi$, μ = 0.24, S_{yt} = 380 N/mm^2, FS = 3, R_1 = 250mm, R_2 = 125mm d = ? 10M

$P_2 = \frac{P_1}{e^{\mu\theta}} = 1176.22\ N$

$T = (P_1 - P_2) * R_1 = 330.945 * 10^3\ Nmm$

$T = (P_3 - P_4) * R_2 \implies 330.945 * 10^3\ Nmm = (P_3 - P_4) * 125$

$P_3 = e^{\mu\theta} * P_4 = 2.125 P_4 \implies Sovling\ P_3 = 5000\ N\ \&\ P_4 = 2353.39\ N$

$\therefore P_{BV} = P_1 + P_2 = 3676.22\ \&\ P_{CH} = P_3 + P_4 = 7353.39\ N$ [2M]

<u>Vertical Bending Moment Diagram</u>

$R_{AV} + R_{DV} = P_{BV} = 3676.22\ N$

Taking moments about A

$(R_{DV} * 1000) - (P_{BV} * 200) = 0$

$R_{DV} = 735.24\ N\ \&\ R_{AV} = 2940.98\ N$

Bending moments due to vertical loads

$M_{DV} = M_{AV} = 0$

$M_{CV} = R_{DV} * 200 = 147.048 * 10^3\ Nmm$

$M_{BV} = R_{DV} * 800 = 588.192 * 10^3\ Nmm$ [2M]

<u>Horizontal Bending Moment Diagram</u>

$R_{AH} + R_{DH} = P_{CH} = 7353.39\ N$

Taking moments about A

$(R_{DH} * 1000) - (P_{CH} * 800) = 0$

$R_{DH} = 5882.712\ N\ \&\ R_{AH} = 1470.678\ N$

Bending moments due to Horizontal loads

$M_{DH} = M_{AH} = 0$

$M_{CH} = R_{DH} * 200 = 1176.54 * 10^3\ Nmm$

$M_{BH} = R_{AH} * 200 = 24.136 * 10^3\ Nmm$ [2M]

Resultant Bending moments

$M_D = M_A = 0$

$M_C = \sqrt{M_{CH}^2 + M_{CV}^2} = 1.1857 * 10^6\ Nmm$

$M_B = \sqrt{M_{BH}^2 + M_{BV}^2} = 0.658 * 10^6\ Nmm$

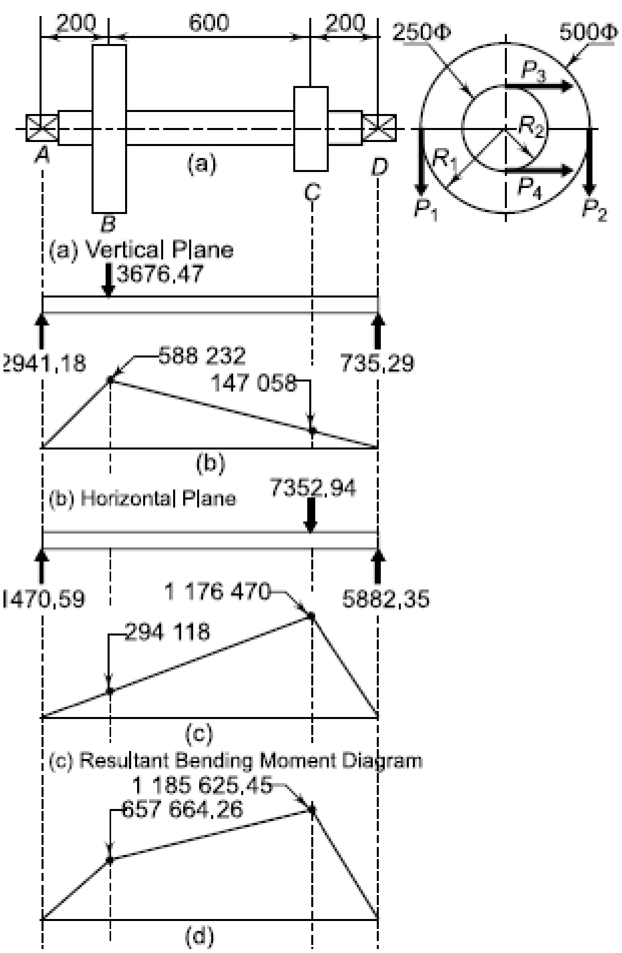
$M = Max\,(M_A, M_B, M_C, M_D) == 1.1857 * 10^6\ Nmm$

$T_e = \sqrt{M^2 + T^2} = 1.23 * 10^6\ Nmm$

$\tau_{max} = \frac{S_{ys}}{FS} = \frac{S_{yt}}{2*FS} = 63.33\ N/mm^2$

$\tau_{max} = \frac{16 * T_e}{\pi * d^3} \implies d = 46.248\ mm$ [2M]

$\simeq 50mm$



[Diagram 2M]

9	Given Data: $P = 37.5$ kW = 37.5x103 W, N = 180 rpm, $T_{max} = 1.5T_{mean}$, $S_{yt} = 380$ N/mm^2, FS = 2.5, $(S_{yt})_{key} = (S_{yt})_{bolt} = 400$ N/mm^2, $FS_{key} = FS_{bolt} = 2.5$, $(S_{ut})_{flange} = 200$ N/mm^2 , $FS_{flange} = 6$ Design of Shaft $\mathrm{P} = \frac{2 * \pi * \mathrm{N} * \mathrm{T_{mean}}}{60} \implies \mathrm{T_{mean}} = 1989.44 * 10^3\ \mathrm{Nmm}$ $\mathrm{T_{max}} = 1.5\ \mathrm{T_{mean}} = 2.98 * 10^6\ \mathrm{Nmm} = \mathrm{T}$ $\tau = \frac{\mathrm{S_{ys}}}{\mathrm{FS}} = \frac{0.5 * \mathrm{S_{yt}}}{\mathrm{FS}} = 76\ \mathrm{N/mm^2}$ $\tau = \frac{16 * \mathrm{T}}{\pi * \mathrm{d}^3} \implies \mathrm{d} = 58.45\ \mathrm{mm} \simeq 60\mathrm{mm}$ [2M] Design of Hub Inside diameter of Hub = D = d = 60 mm, Outside diameter of Hub = $\mathrm{D_1} = 2\mathrm{D} = 120\ \mathrm{mm}$ Length of Hub = $L = 1.5D = 90\ mm$ $Allowable\ Shear\ stress\ in\ Hub = \tau_s = \frac{S_{us}}{FS} = \frac{0.5 * S_{ut}}{FS} = 16.67\ N/mm^2$ $Shear\ Stress\ in\ Hub = \tau = \frac{16 * T}{\pi * D_1^3 * (1 - k^4)} = 9.37\ N/mm^2$ [2M] Design of Flange Outside diameter of Flange = $D_3 = 4D = 240\ mm$, Thickness of Flange= $t_f = 0.5D = 30\ mm$ $Shear\ stress\ at\ junction\ of\ hub\ and\ flange = \tau_f = \frac{2 * T}{\pi * D_1^2 * t} = 4.4\ N/mm^2$ [2M] Design of Key Width of Key = b = d/4 = 15 mm, Thickness of Key = h = d/6 = 10 mm, Length of Key = l = 1.5d = 90 mm $Allowable\ Shaer\ stress\ in\ Key = \tau_k = \frac{S_{us}}{FS} = \frac{0.5 * S_{ut}}{FS} = 80\ N/mm^2$ $Shear\ Stress\ in\ Key = \tau = \frac{2 * T}{b * l * d} = 73.58\ N/mm^2$ $Allowable\ Crushing\ stress\ in\ Key = \sigma_{ck} = \frac{S_{us}}{FS} = 160\ N/mm^2$ $Crushing\ Stress\ in\ Key = \sigma = \frac{4 * T}{h * l * d} = 220.74\ N/mm^2$ $Modified\ thickness\ of\ key = h = \frac{4 * T}{\sigma_c * l * d} = 13.79\ mm \simeq 14\ mm$ [2M] Design of Bolts Number of Bolts = $i = 0.02D + 3 = 4$, Pitch Circle diameter of Bolts = $D_2 = 3D = 180\ mm$ $T = \frac{\tau\, \pi\, i\, d^2\, D_2}{8} \implies \mathrm{d} = 11.48 \simeq 12\ mm\ or\ M12$ $Crushing\ stress\ in\ bolts = \sigma_c = \frac{2 * T}{i * t * d * D_2} = 23\ N/mm^2$ [2M]	10M