

Production & Industrial Engineering

General Engineering Vol. III : Machine Design



Comprehensive Theory
with Solved Examples and Practice Questions





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**General Engineering : Vol. III
Machine Design**

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General Engineering

Machine Design

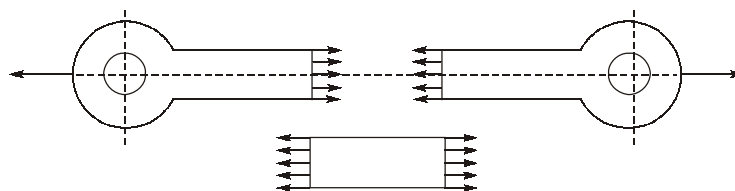
INTRODUCTION

Machine Design or mechanical design is primarily concerned with the systems by which the energy is converted into useful mechanical forms and of mechanisms required to convert the output of the machine to the desired form. The design may lead to an entirely new machine or an improvement on an existing one.

Thus machine design is the production or creation of the right combination of correctly proportioned moving and stationary components so constructed and joined as to enable the liberation, transformation, and utilization of energy.

3.1 Loading of Machine Elements

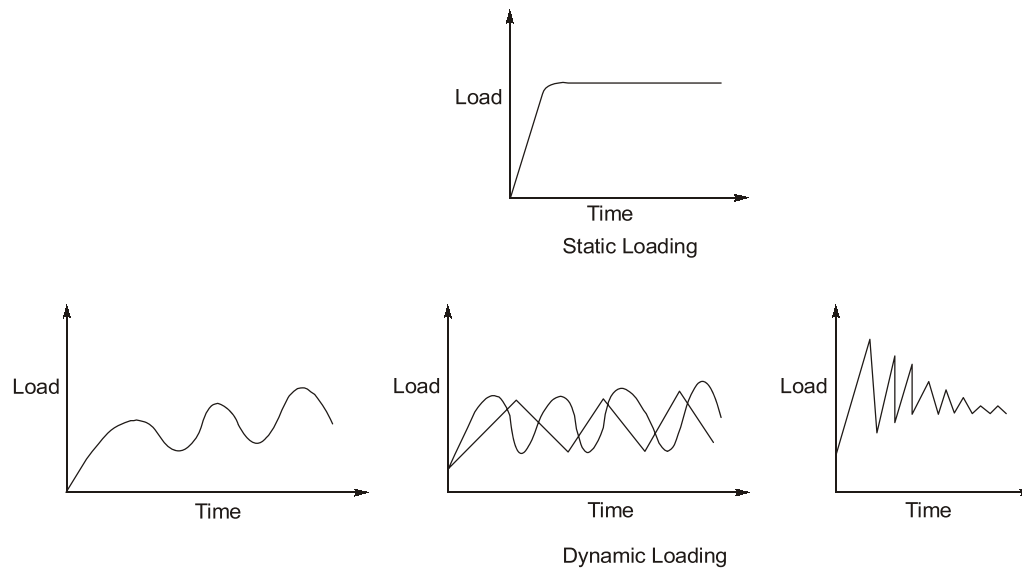
Machine parts fail when the stresses induced by external forces exceed their strength. The external loads cause internal stresses in the elements and the component size depends on the stresses developed. Stresses developed in a link subjected to uniaxial loading is shown in figure. Loading may be due to: (a) The energy transmitted by a machine element; (b) Dead weight; (c) Inertial forces; (d) Thermal loading; (e) Frictional forces.



Stresses developed in a link subjected to uniaxial loading

In another way, load may be classified as:

- (a) **Static load** : Load does not change in magnitude and direction and normally increases gradually to a steady value.
- (b) **Dynamic load** : Load may change in magnitude for example, traffic of varying weight passing a bridge. Load may change in direction, for example, load on piston rod of a double acting cylinder. Vibration and shock are types of dynamic loading. Figure shows load vs time characteristics for both static and dynamic loading of machine elements.

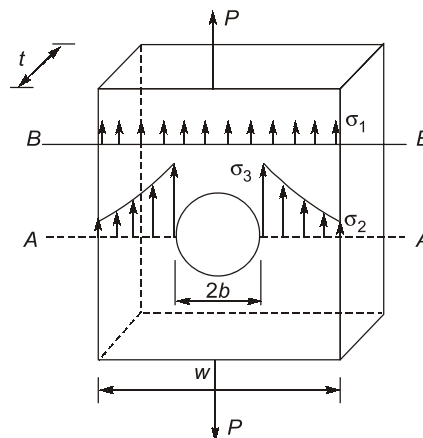


Types of loading on machine elements

3.2 Concept of Stress Concentration

In developing a machine it is impossible to avoid changes in cross-section, holes, notches, shoulders etc. Any such discontinuity in a member affects the stress distribution in the neighbourhood and the discontinuity acts as a stress raiser. Consider a plate with a centrally located hole and the plate is subjected to uniform tensile load at the ends. Stress distribution at a section A-A passing through the hole and another section B-B away from the hole are shown in figure below.

Stress distribution away from the hole is uniform but at AA there is a sharp rise in stress in the vicinity of the hole. Stress concentration factor k_1 is defined as $k_1 = \frac{\sigma_3}{\sigma_{av}}$, where σ_{av} at section AA is simply $\frac{P}{t(w-2b)}$ and $\sigma_1 = \frac{P}{tw}$. This is the theoretical or geometric stress concentration factor and the factor is not affected by the material properties.



Stress concentration due to a central hole in a plate subjected to an uni-axial loading.

It is possible to predict the stress concentration factors for certain geometric shapes using theory of elasticity approach. For example, for an elliptical hole in an infinite plate, subjected to a uniform tensile stress σ_1 as shown in figure, stress distribution around the discontinuity is disturbed and at points remote from the discontinuity the effect is insignificant. According to such an analysis

$$\sigma_3 = \sigma_1 \left(1 + \frac{2b}{a} \right)$$

If $a = b$ the hole reduces to a circular one and therefore $\sigma_3 = 3\sigma$ which gives $k_t = 3$. If, however 'b' is large compared to 'a' then the stress at the edge of transverse crack is very large and consequently k is also very large. If 'b' is small compared to a then the stress at the edge of a longitudinal crack does not rise and $k_t = 1$.

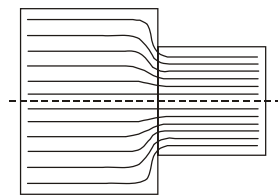
Stress concentration factors may also be obtained using any one of the following experimental techniques:

1. Strain gage method
2. Photoelasticity method
3. Brittle coating technique
4. Grid method

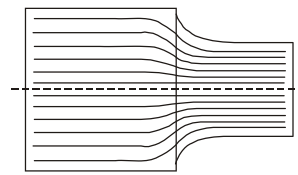
3.2.1 Methods to Reduce Stress Concentration

A number of methods are available to reduce stress concentration in machine parts. Some of them are as follows :

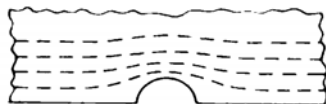
1. Provide a fillet radius so that the cross-section may change gradually.
2. Sometimes an elliptical fillet is also used.
3. If a notch is unavoidable it is better to provide a number of small notches rather than a long one. This reduces the stress concentration to a large extent.
4. If a projection is unavoidable from design considerations it is preferable to provide a narrow notch than a wide notch.
5. Stress relieving groove are sometimes provided. These are demonstrated in figure.



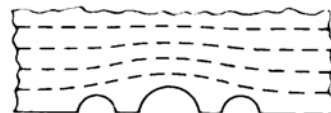
(a) Force flow around a sharp corner



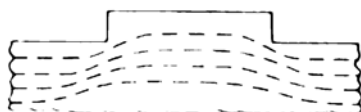
Force flow around a corner with fillet:
Low stress concentration.



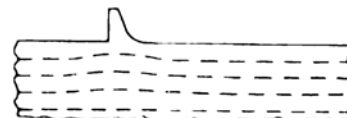
(b) Force flow around a large notch



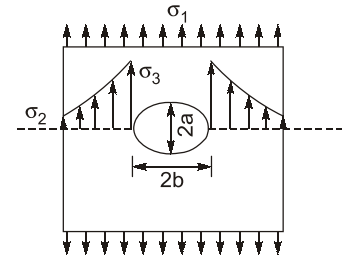
Force flow around a number of small notches: Low stress concentration.



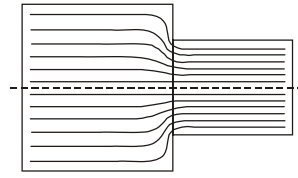
(c) Force flow around a wide projection



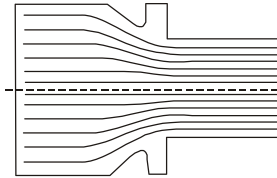
Force flow around a narrow projection:
Low stress concentration.



Stress concentration due to a central elliptical hole in a plate subjected to a uni-axial loading



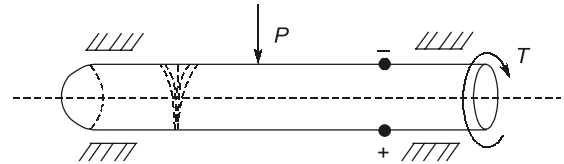
(d) Force flow around a sudden change in diameter in a shaft



Force flow around a stress relieving groove

Illustrations of different methods to reduce stress concentration**3.3 Dynamic Loading**

Conditions often arise in machines and mechanisms when stresses fluctuate between an upper and a lower limit. For example in figure, the fiber on the surface of a rotating shaft subjected to a bending load, undergoes both tension and compression for each revolution of the shaft.

**Stresses developed in a rotating shaft subjected to a bending load**

Any fiber on the shaft is therefore subjected to fluctuating stresses. Machine elements subjected to fluctuating stresses usually fail at stress levels much below their ultimate strength and in many cases below the yield point of the material too. These failures occur due to very large number of stress cycle and are known as fatigue failure. These failures usually begin with a small crack which may develop at the points of discontinuity, an existing subsurface crack or surface faults. Once a crack is developed it propagates with the increase in stress cycle finally leading to failure of the component by fracture. There are mainly two characteristics of this kind of failures:

- (a) Progressive development of crack.
- (b) Sudden fracture without any warning since yielding is practically absent.

Fatigue failures are influenced by :

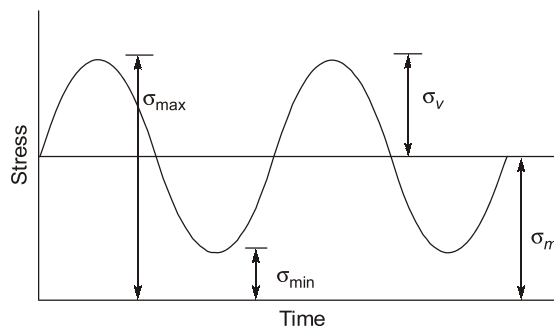
- (i) Nature and magnitude of the stress cycle.
- (ii) Endurance limit.
- (iii) Stress concentration.
- (iv) Surface characteristics

3.3.1 Stress Cycle

A typical stress cycle is shown in figure where the maximum, minimum, mean and variable stresses are indicated. The mean and variable stresses are given by

$$\sigma_{\text{mean}} = \frac{\sigma_{\text{max}} + \sigma_{\text{min}}}{2}$$

$$\sigma_{\text{variable}} = \frac{\sigma_{\text{max}} - \sigma_{\text{min}}}{2}$$

**A typical stress cycle showing maximum, mean and variable stresses**

Student's
Assignments

1

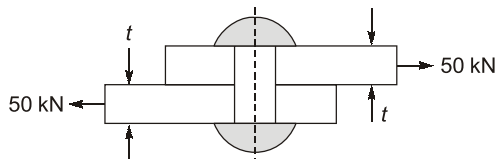
- Q.1** For making a bolt of uniform strength, the diameter of the shank is made equal to the
 (a) Pitch diameter of the threads
 (b) Nominal diameter of the threads
 (c) Core diameter of the threads
 (d) Half of the core diameter of the threads
- Q.2** A key made from a cylindrical disc having segmental cross-section is known as
 (a) Barth key (b) Kennedy key
 (c) Saddle key (d) Woodruff key
- Q.3** If the two pulleys in a belt drive have different values of coefficient of friction, then the design will be based on the pulley for which
 (a) $\mu\theta$ is maximum (b) $\mu\theta$ is minimum
 (c) $\mu\theta = 1$ (d) $\mu\theta > 1$
- Q.4** Consider the following statements
 I : The stiffness of solid shaft is more than the hollow shaft with same weight.
 II : The strength of hollow shaft is more than that of solid shaft with same weight.
 III : Hollow shaft is costlier than solid shaft.
 Which of the statements is/are true?
 (a) I and III (b) I, II and III
 (c) II and III (d) III only
- Q.5** A gear tooth is made up of a material having $S_{ut} = 600 \text{ N/mm}^2$. The modulus, face width and form factor are 3 mm, 40 mm and 0.4 respectively. The beam strength of gear tooth (in N) is
 (a) 9600 (b) 18200
 (c) 28800 (d) 32412
- Q.6** For new clutches and brakes, what is friction radius for 50 mm outer diameter and 30 mm inner diameter?
 (a) 20 mm (b) 24 mm
 (c) 30 mm (d) 32 mm
- Q.7** A feather key of 14 mm wide by 9 mm deep is to transmits 700 Nm of torque from a 40 mm diameter shaft. The steel key has an allowable stress in tension and compression of 110 MPa and an allowable stress in shear of 55 MPa. Required length (in mm) of the key is _____.
- Q.8** A shaft can safely transmit 90 kW while rotating at a given speed. If this shaft is replaced by a shaft of diameter double of the previous one and rotated at half the speed of the previous, the power (in kW) that can be transmitted by the new shaft is _____.
- Q.9** A bolt and a member are subjected to a load of 4 kN tension and it causes the connection to elongate. The stiffness of the bolt and members are 2.5 N/m and 3.2 N/m, respectively. The load carried by the bolt is _____ kN.
 Assume $E = 207 \text{ GPa}$ for bolt and $E = 320 \text{ GPa}$ for member.
- Q.10** In a flat belt drive, if the slip between the driver and belt is 2%, and , between belt and follower is 3%. If the driver and follower pulley diameters are equal, then the velocity ratio of the driver will be _____.
- Q.11** Fit between a roller ball bearing and shaft is an example of
 (a) Shrink fit (b) Interference fit
 (c) Loose fit (d) Snug fit
- Q.12** A double transverse fillet weld of equal leg is subjected to a force 500 kN. The length and leg of weld is 200 mm and 10 mm respectively. The maximum shear stress induced in the weld is _____.
- Q.13** In case of a multiplate clutch, if n_1 is the number of disks on the driver shaft and n_2 is the number of disks on the driven shaft, then the number of pairs of contacting surfaces is
 (a) $n_1 + n_2$ (b) $n_1 + n_2 + 1$
 (c) $n_1 + n_2 - 1$ (d) $n_1 + n_2 - 2$
- Q.14** A pressure vessel has diameter of 1 m and internal pressure of 2.75 N/mm^2 above the atmospheric. If the efficiency of its riveted joint is 80% and the tensile stress in the material is not to exceed 90 MPa, then the plate thickness _____ mm.
- Q.15** A riveted joint has resistances in several modes of failure as 20 kN, 25 kN, 22 kN, 25.6 kN and 19 kN. If the strength of unriveted plate is 30 kN, then the efficiency of the riveted joint is _____ %.



**Student's
Assignments**

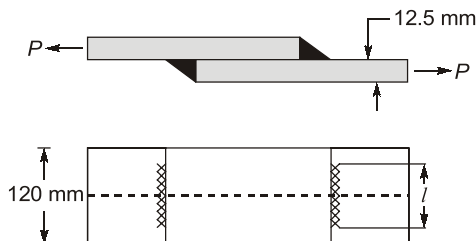
2

- Q.16** Two plates, subjected to a tensile force of 50 kN, are fixed together by means of three rivets as shown in figure. The plates and rivets are made of plain carbon steel with a tensile yield strength of 250 N/mm^2 . The yield strength in shear is 50% of the tensile yield strength, and the factor of safety is 2.5. Width of plate is 200 mm. Neglecting stress concentration, the ratio of diameter of the rivets to the thickness of plates is



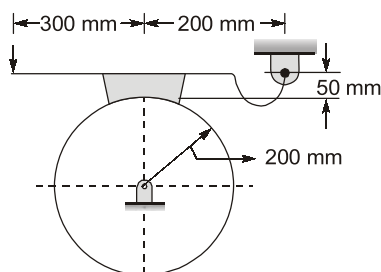
- (a) 3.21 (b) 5.69
(c) 7.82 (d) 9.21

- Q.17** Two steel plates, 120 mm wide and 12.5 mm thick, are jointed together by means of double transverse fillet weld as shown in figure. What is the required length of the weld (l) if the permissible shear stress in the weld is 55 N/mm^2 ?



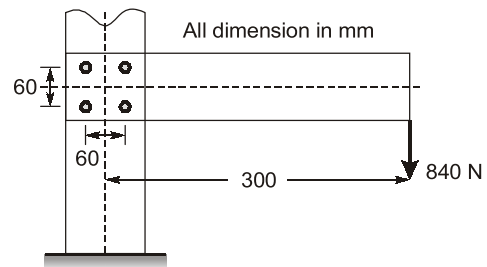
- (a) 70.21 mm (b) 84.87 mm
(c) 96.21 mm (d) 102.28 mm

- Q.18** A single block brake with a torque capacity of 250 Nm is shown in figure. The brake drum rotates at 100 rpm and the friction coefficient is 0.35. The hinge-pin reaction for clockwise rotation of the drum is

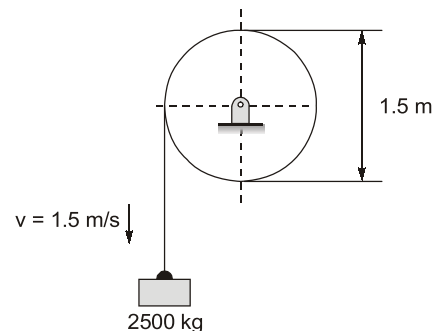


- (a) 2375 N (b) 2575 N
(c) 3220 N (d) 3730 N

- Q.19** A rectangular steel plate is joined to a vertical post using four identical rivets arranged as shown in below in the figure. The shear load on the worst loaded rivet approximately is _____ N.

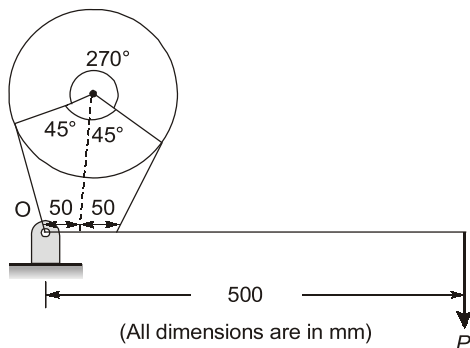


- Q.20** A mass of 2500 kg is lowered at a velocity of 1.5 m/s from the drum as shown in figure. The mass of the drum is 50 kg and its radius of gyration can be taken as 0.7 m. On applying the brake, the mass is brought to rest in a distance of 0.5 m. The energy absorbed by brake is __ J.



- Q.21** The standard cross-section for a flat key is $14 \times 9 \text{ mm}$ which is used to connect a pulley to a 45 mm diameter shaft. The key is made of commercial steel ($S_{yt} = S_{yc} = 230 \text{ N/mm}^2$) and factor of safety is 3. Find the length of key (in mm) if 15 kW power at 360 rpm is transmitted through the keyed joint.
- (a) 51.26 (b) 33
(c) 512.6 (d) 20

- Q.22** A simple band brake as shown below, has a drum diameter of 500 mm. The drum rotates at 300 rpm. The angle of wrap is 270° .



Find, the minimum force (in N) for its direction required at the end of the brake lever to stop the drum, if 50 kW power is to absorbed

[Take, $\mu = 0.2$]

- (a) 1475 N in clockwise direction
- (b) 575 N in anticlockwise direction
- (c) 1475 N in anticlockwise direction
- (d) 575 N in clockwise direction

Q.23 A belt is required to transmit 9 kW from a pulley 120 cm diameter running at 200 rpm. The angle embraced is 165° and the coefficient of friction 0.3. If the safe working stress for a leather is 1.4 N/mm^2 , the weight of 1 cm^3 of leather = 0.01 N and the thickness of belt = 10 mm , then the value of width of belt will be required taking into account the centrifugal force is _____ cm.

Q.24 A journal bearing is loaded with a radial load of 30 kN. The journal diameter and length both are 100 mm and it rotates at 1200 rpm. The heat is dissipated from the surface at the rate of $96 \text{ J/m}^2/\text{sec.}/^\circ\text{C}$. The bearing housing is 20 times the projected area. If coefficient of friction is 0.003 and room temperature is 35°C , then the surface temperature of the bearings is _____ $^\circ\text{C}$.

Q.25 A spherical vessel of a 1000 mm inner diameter is subjected to an internal pressure which varies from 5 MPa to 10 MPa. The material of the vessel is cold drawn steel having ultimate strength 450 MPa and yield strength 240 MPa. If the reliability of the vessel is 90% and required factor of safety is 2, the thickness of pressure vessel for an infinite life period is _____ mm. [Assume, $\sigma_e = 0.5 \sigma_u$]

ANSWERS

1. (c) 2. (d) 3. (b) 4. (c)
5. (a) 6. (a) 7. (70) 8. (360)
9. (1.75) 10. (0.95) 11. (b) 12. (151)
13. (c) 14. (19) 15. (63.33) 16. (b)
17. (b) 18. (b) 19. (1640.23) 20. (15124)
21. (a) 22. (d) 23. (9.967) 24. (64.45)
25. (21.8)

HINTS

4. (c)

- (i) The stiffness of solid shaft is less than the hollow shaft with same weight.
- (ii) Due to manufacturing constraints, hollow shaft is difficult to make and hence is costlier.

5. (a)

We know that endurance or bending strength is approximately one-third of the ultimate tensile strength.

$$\sigma_b = \frac{S_{ut}}{3} = \frac{600}{3} = 200 \text{ N/mm}^2$$

$$\therefore S_b = \sigma_b b m y = 200 \times 3 \times 40 \times 0.4 = 9600 \text{ N}$$

6. (a)

$$r_m = \frac{1}{3} \left(\frac{D^3 - d^3}{D^2 - d^2} \right) = \frac{1}{3} \left(\frac{50^3 - 30^3}{50^2 - 30^2} \right) = 20.42 \text{ mm}$$

7. 70 (69 to 71)

Since the key is wider than its depth or thickness, it fail due to compression, before it will fail due to shear.

$$T = F \times \frac{d}{2} = \left(l \times \frac{t}{2} \right) \times \sigma_c \times \frac{d}{2}$$

$$\Rightarrow 700 = \left(l \times \frac{0.009}{2} \right) \times 110 \times 10^6 \times \frac{0.04}{2}$$

$$\Rightarrow l = 0.07 \text{ m} = 70 \text{ mm}$$