

# UNIT - 5. SHAFTS AND SHAFT COUPLINGS.

5.

shaft:- shafts are defined as rotating machine members which are used for power transmission from one place to another. They are subjected to various loads such as tension, compression, bending, twisting or combination of these loads.

1. crankshaft in an I.C engine.
2. lathe spindle: in lathe machines.
3. milling machine arbors.
4. spindle of drilling machine.
5. cam shaft in automobiles, etc.

Stresses are induced in shafts:-

the stresses induced in the shafts are:-

1. shear stress during the transmission of torque.
2. Bending stress due to the forces acting upon the machine members like gears, pulleys etc., and also due to the weight of the shaft.
3. stresses developed because of combined, torsional and bending loads.

Requirements of a Gasket:-

1. It should be stable even at higher temperatures.
2. It should possess good compatibility towards the fluid that is to be sealed.
3. Loss of bolt tension must be low during its maintenance.
4. Good joint design providing a provision for gasket.

## practical applications of couplings:-

1. connection between output shaft of electric motor and input shafts of compressor.

2. joint between gear box output shaft and end of propeller shaft and connection between other end of propeller shaft and differential in automobile transmission.

3. joint between the shafts of vertically turbines.

the stresses induced in the shaft are,

1. shear stress during transmission of torque.

2. bending stress due to the force acting

upon the machine methods like gears, pulleys etc, and also due to own weight of the shaft.

3. stresses developed because of combined torsional and bending loads.

A shaft is said to have failed when it does not perform its function i.e., transmission of torques satisfactorily.

1. failure of shaft by elastic deflection.

2. failure of shaft by yielding.

3. failure of the shaft by elastic fracture.

Following are the cause of failure of the shaft.

1. failure of the shaft due to fatigue loads, is one of the common failures.

2. failure of shafts also occurs because of certain features of the shaft acting as stress raisers leading to them stress concentration some of them are keyways, grooves, splines, notches, quench, corners, welding defects etc.

3. Joint between the shafts of vertical turbines  
 4. misalignment caused by the mismatch of mating parts may often lead to the failure of the shaft.

1. find the diameter of a solid steel shaft to transmit 20 kw at 200 r.p.m. The ultimate shear stress for the steel may be taken as 360 MPa and a factor of safety as 8. If a hollow shaft is to be used in place of the solid shaft, find the inside and outside diameter when the ratio of inside to outside diameters is 0.5.

A Given that,

Power transmitted,  $P = 20 \text{ kw} = 20 \times 10^3 \text{ W}$ ,

speed,  $N = 200 \text{ rpm}$ .

ultimate shear stress,  $\tau_u = 360 \text{ MPa} = 360 \text{ N/mm}^2$

factor of safety, F.S = 8.

Ratio of diameters,  $k = \frac{d_i}{d_o} = 0.5$

Power transmitted,

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

$$20 \times 10^3 = \frac{2\pi \times 200 \times T}{60}$$

$$T = \frac{20 \times 10^3 \times 60}{2 \times \pi \times 200}$$

$$T = 954.929 \text{ N-m}$$

$$T = 954.929 \times 10^3 \text{ N-mm}$$

permissible shear stress,

$$\tau = \frac{\tau_u}{F.S} = \frac{360}{8}$$

$$\tau = 45 \text{ N/mm}^2$$

$\therefore$  diameter of solid shaft,  $d = 18\text{ mm}$ .

Diameter of hollow shaft:-  
Torque transmitted by the hollow shaft,

$$T = \frac{\pi}{16} \times \gamma \times d_o^3 (1 - k^4)$$

$$79577 \times 10^3 = \frac{\pi}{16} \times 80 \times d_o^3 \times (1 - 0.15)^4$$

$$d_o^3 = \frac{99.577 \times 10^3}{14726}$$

$$d_o = \sqrt[3]{5403.843}$$

$$d_o = 17.548\text{ mm} \approx 18\text{ mm.}$$

thus,

$$\frac{d_i}{d_o} = 0.5$$

$$d_i = 0.5 \times 18$$

$$d_i = 9\text{ mm.}$$

$\therefore$  outer diameter of hollow shaft,  $d_o = 18\text{ mm}$ .

$\therefore$  Inner diameter of hollow shaft,  $d_i = 9\text{ mm.}$

Circlip:- Circlip is a rotating ring, which is used to fasten the components such as machined collars on shafts or washer.

This is the alternate method of fastening the components, that reduces the material wastage due to single fastening method.

There are two types of circlips,

a, Internal circlips

$$p = b$$

these types of circlips are used inside a bore or hole. It is made up inside a bore or hole. It is made up of a semi-flexible metal that used to close the circlips with the help of circlip pliers. Internal circlips prevents the lateral movement of the shaft and allows the rotating movement.

b, External circlips:-



External circlips are used outside of the shaft or over the shaft. It is made up of a semi-flexible metal. They can be opened with the help of circlip pliers. These type of circlips prevent the lateral movement of the shaft and allows the rotating movement.

The smooth surface of the circlip is placed in contact with shaft, while the rough surface is not in contact with the shaft or component. During reassembly and installation, circlips becomes weak and deforms. Hence they must be replaced while reassembly.





key:-

key is a type of fastener which is used to connect rotating machine elements such as gears, pulleys, sprockets, cam, flywheel, etc., to the transmission shaft in order to transmit the power from shaft to rotating elements. Keys also prevents relative vibrational movement between a shaft and parts mounted on it. Keys are selected based on the magnitude of torque transmitted, type of loading such as steady, variable or oscillatory fit required, limited shaft stress, cost, etc.

knuccle joint:-

Knuckle joints is used to join two rods subjected to axial tensile force whose axes lie in one plane and either intersect or coincide.

1. connection between links of a cycle chain.

2. joint between suspension bridge links.

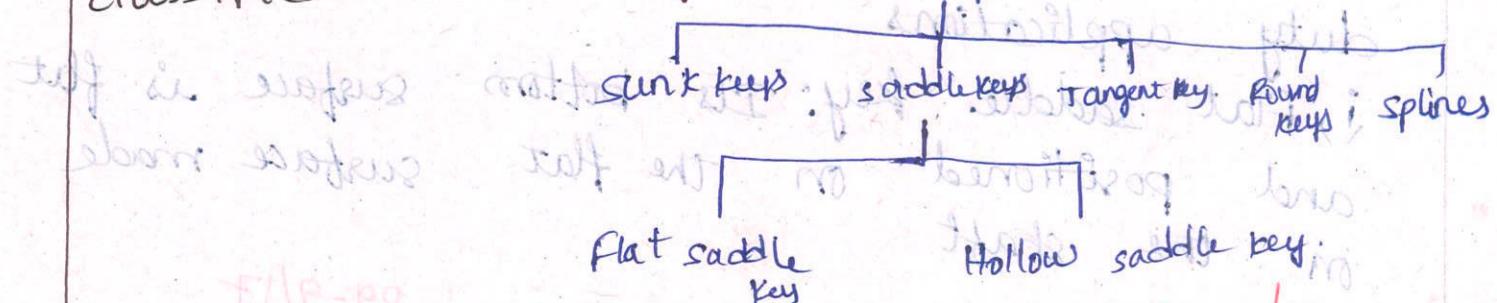
3. joint between tie rods & roof joint.

4. joint between valve rod and eccentric rod.

5. fulcrum for lever arm between base and top.

6. pump rod joint between base and top.

classification of keys



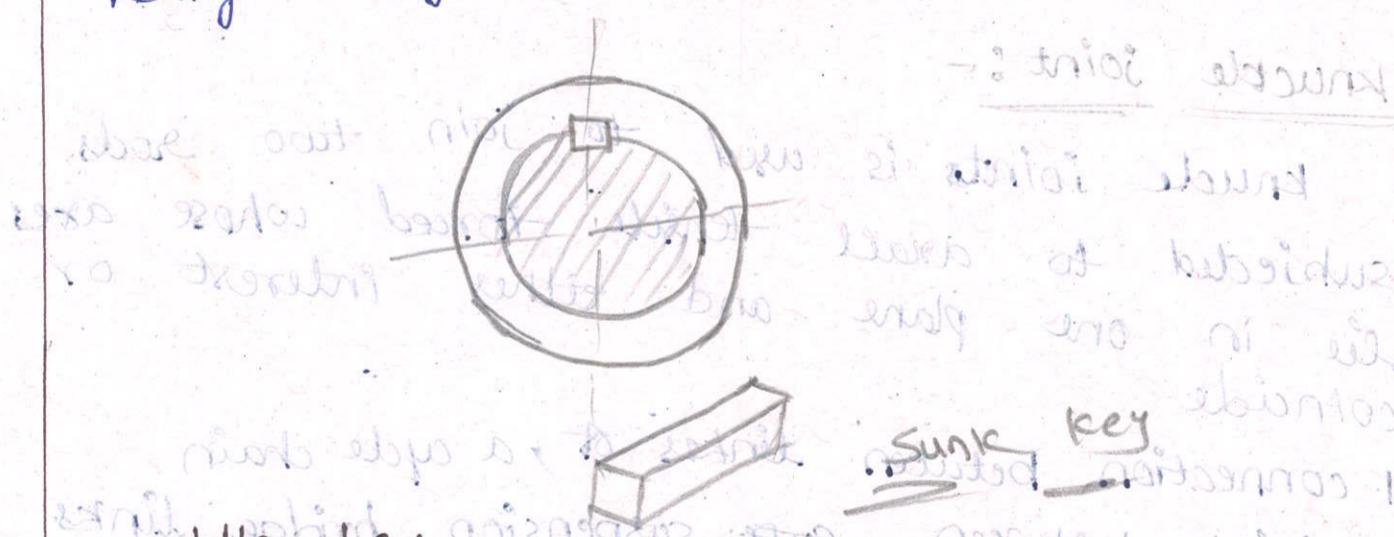
sunk keys

rectangle, square, Gibhead, feathers, woodruff key

sunk key

It is inserted between the shaft and the hub to prevent relative motion between them. The half of the key is provided in the key way of the shaft and the half in the key way of the hub. These key may be of rectangular, square, semi-circular in cross-sections.

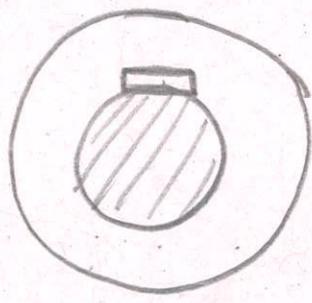
Sunk keys are most popularly used for heavy duty applications.



saddle key

This key fits into the keyway provided in the hub only. These keys are further classified into two types as flat saddle key and hollow saddle key. Flat and hollow saddle keys are usually used for light duty applications.

i) flat saddle key: Its bottom surface is flat and positioned on the flat surface made on the shaft.



Flat saddle key

Hollow saddle key: Its bottom surface is made concave so that it sits on the circular surface of the shaft. It has a flange at the top which resists axial sliding forces.



Hollow Saddle key

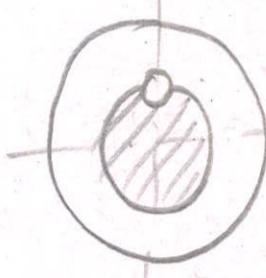
Tangent keys

They are used in pairs at right angles to each other, where each key has to withstand torsion in one direction. They are usually employed for large heavy duty shafts.



Round keys:

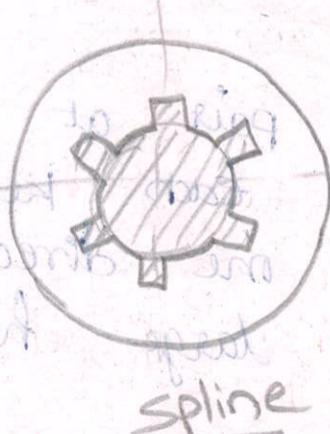
These keys are of circular cross-section and fit in the hole drilled partly in the shaft and partly in the hub. These are used for low power drives. Appropriately compared with other types of keys.



Round key

Splines:

In this type, the keys are made integral with the shaft and fit in the hub. Splines are generally stronger than the shafts provided with single keyway. The splines provided on the shaft may be 4, 6, 10 or 16. Splines are used when it is required to transmit greater torque in proportion to shaft size.



Spline

- A 45mm diameter shaft is made of steel with a yield strength of 400 MPa. A parallel key of size 14mm width and 9mm thickness made of steel with a yield strength of 340 MPa is to be used. Find the required length of the key, if the shaft is loaded to transmit the maximum permissible torque. Use maximum shear stress theory and assume a factor of safety of 2.
- Given that,  $d = 45\text{ mm}$ ,  $a = 14\text{ mm}$ ,  $t = 9\text{ mm}$ ,  $\sigma_y = 400\text{ MPa}$ ,  $\sigma_{ys} = 340\text{ MPa}$ ,  $F.S. = 2$ .

yield strength of shaft,  $S_{YTS} = 400 \text{ MPa}$ .

yield strength of key,  $S_{YTK} = 340 \text{ MPa}$

width of key,  $w = 10 \text{ mm}$

thickness of key,  $t = 9 \text{ mm}$

factor of safety,  $F.S = 2$

According to maximum shear stress theory, maximum shear stress,

for shaft,

$$\tau_s = \frac{S_{YTS}}{2 \times F.S} = \frac{400}{2 \times 2}$$

$$\tau_s = 100 \text{ N/mm}^2$$

for key

shear stress  $\tau_k = \frac{S_{YTK}}{2 \times F.S} = \frac{340}{2 \times 2}$  not yet calculated so  
allowable stress  $\tau_k = 85 \text{ N/mm}^2$  transmitted by the shaft and  
maximum torque transmitted by the shaft.

key.

$$T = \frac{\pi}{16} d^3 \times \tau_{max} = \frac{\pi}{16} \times 45^3 \times 100$$

$$T = 1789.235 \times 10^3 \text{ N-mm}$$

Considering shearing failure of key,

maximum torque transmitted,

$$T = l \times w \times \tau_k \times \frac{d}{2}$$

$$l = \frac{2 \times T}{w \times \tau_k \times d}$$

$$l = \frac{2 \times 1789.235 \times 10^3}{14 \times 85 \times 45}$$

$$l = 66.824 \approx 67 \text{ mm}$$

Considering crushing failure of key,

maximum torque transmitted,

$$T = l \times \frac{t}{2} \times \sigma_c \times \frac{d}{2}$$

unit-5, Pg-12/17

$\sigma_c = \frac{Syt_c}{F.S} = \frac{340}{2} \text{ MPa} = 170 \text{ MPa}$  (allowable stress)

But,

$$\sigma_c = \frac{Syt_c}{F.S} = \frac{340}{2} \text{ MPa} = 170 \text{ MPa}$$

maximum  $\sigma_c = 170 \text{ MPa/mm}^2$  maximum of problem

then,

$$l = \frac{\pi \times 1789.235 \times 10^3}{9 \times 100 \times 45} = 103.949 \text{ mm}$$

Considering the larger of the two values,  
length of the key,  $l = 104 \text{ mm}$ .

- 2 Select a key for a 100 mm diameter shaft transmitting 750 kW at 1000 rpm. The allowable shear stress in the key is 100 MPa, and the allowable compressive stress is 200 MPa.

A Given that,

Diameter of shaft,  $d = 100 \text{ mm}$

Power transmitted,  $P = 750 \text{ kW} = 750 \times 10^3 \text{ W}$

speed,  $n = 1000 \text{ rpm}$ .

Allowable shear stress,  $\tau = 100 \text{ MPa}$  problem

Allowable compressive stress,  $\sigma_c = 200 \text{ MPa}$  problem

using relation,

$$\frac{P}{t} = \frac{\sigma_c}{2\tau}$$

$$\frac{W}{t} = \frac{200}{2 \times 100}$$

$$\frac{W}{t} = 1$$

Therefore, square key is used for this application for square key

$$w = t = \frac{d}{q} = \frac{100}{q} = 25 \text{ mm}$$

Using relation,

$$P = \frac{2\pi NT}{60}$$

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

$$T = \frac{60 \times 760 \times 10^3}{2\pi \times 1000}$$

$$T = 7161.972 \text{ N-m}$$

$$T = 7161.972 \times 10^3 \text{ N-m}$$

Considering shear failure of key, torque transmitted

$$T = w \times t \times \frac{d}{2}$$

$$t = \frac{2 \times T}{w \times d} = \frac{2 \times 7161.972 \times 10^3}{25 \times 100 \times 100}$$

$$t = 57.295 \text{ mm} \approx 58 \text{ mm.}$$

Considering crushing failure of key, torque transmitted

$$T = t \times \frac{\frac{d}{2}}{2} \times \frac{d}{2}$$

$$t = \frac{4 \times T}{\pi \times d^3} = \frac{4 \times 7161.972 \times 10^3}{\pi \times 25^3 \times 100}$$

$$t = 57.295 \text{ mm} \approx 58 \text{ mm.}$$

$\therefore$  length of key,  $t = 58 \text{ mm.}$

key suitable for this application is,

Square key of dimensions,  $w \times t \times l = 25 \times 25 \times 58 \text{ mm}^3.$

3. A rectangular sunk key 10 mm wide, 10 mm thick and 25 mm long is required to transmit 1200 N-m torque from a 50mm diameter solid shaft. Determine whether the length is sufficient or not, if the permissible shear stress and crushing stress

are limited to 56 MPa and 168 MPa respectively.

Given that,

length of sunk key,  $l = 75 \text{ mm}$

width of sunk key,  $w = 14 \text{ mm}$

thickness of sunk key,  $t = 10 \text{ mm}$

torque transmitted by the shaft,  $T = 1200 \text{ Nm}$

$$= 1200000 \text{ N-mm}$$

diameter of the solid shaft,  $d = 50 \text{ mm}$

allowable shear stress,  $\tau = 56 \text{ MPa} = 56 \text{ N/mm}^2$

allowable crushing stress,  $\sigma_c = 168 \text{ MPa} = 168 \text{ N/mm}^2$

considering shear failure of key, torque transmitted

$$T = f \times w \times t \times \frac{d}{2}$$

$$\tau = \frac{2T}{\pi d^3} = \frac{T}{\pi d^2}$$

$$T = \frac{\pi d^2 \tau}{2}$$

$\therefore$  Induced shearing stress,  $\tau = 45.714 \text{ N/mm}^2$

considering crushing failure of key, torque transmitted,

$$T = f \times \frac{l}{2} \times \sigma_c \times \frac{d}{2}$$

$$\sigma_c = \frac{4T}{\pi d^3}$$

$$\sigma_c = \frac{4 \times 1200000}{\pi d^3}$$

$$\sigma_c = 128 \text{ N/mm}^2$$

Induced crushing stress,  $\sigma_c = 128 \text{ N/mm}^2$

Since, the induced shearing and crushing stresses are less than their allowable stresses, the design of key is safe.

4. cotter joint - A cotter joint is a temporary joint which connects two co-axial rods subjected to axial tensile or compressive forces by a fastener called cotter. A cotter is a flat wedge shaped piece of rectangular cross section and its width is tapered from one end to another for an easy adjustment. Value of taper lies within the range of 1 in 48 to 1 in 24. In some cases it may be increased up to 1 in 8, but such case requires locking device. At bottom of the cotter, the cotter is usually made up of mild steel or wrought iron.

- there are 3 types of cotter joints used to connect two rods by a cotter pin.
  1. socket and spigot cotter joint
  2. sleeve and cotter joint
  3. gib and cotter joint

socket and spigot cotter joint.

It consists of two rods A and B. A hole is drilled in rod A and a rectangular slot is provided for alignment of rod B. A rectangular slot is provided in rod B to facilitate driving of rod A through it. A rectangular slot is provided in rod A to facilitate driving of rod B through it.

• The components of this joint are the socket, spigot and cotter. The end of rod A is provided with a rectangular slot and the end of rod B is provided with a spigot as shown in figure. A rectangular cross section hole is made for both socket and spigot, a wedge shape piece of mild steel is driven tightly through a hole to make the temporary joint between two rods.

the load is applied in axial direction hence the corner joint must be designed to carry both compressive and tensile forces.

### 5. knuckle joint:

Knuckle joint connects two rods whose axes lie in one plane and either intersect or coincide. It is used to join rods subjected to axial tensile force and if guided can also used to connect rods under axial compressive force.

1. fork 2. Eye 3. knuckle pin 4. split pin.

Knuckle joint of rod-A and rod-B is as shown in figure (2). The end of rod-A is formed into a fork and the end of rod-B is formed into an eye. Each leg of fork is provided with an eye. Fork and eye are positioned so that their holes are coaxial. Thus, a knuckle pin is allowed to pass through the fork holes and eye hole. A split pin is allowed to pass through the knuckle pin at bottom of fork, to prevent turning of pin. Functions of each element of knuckle joint are.

1. fork: - To accommodate pin through holes in each of its leg and to resist tensile and shear forces.

2. Eye: - To accommodate pin through its hole and to resist tensile and shear forces.

3. knuckle pin: - To pass through both the fork holes and split to resist crushing and bending.

4. split pin: - To prevent pin from turning.