

UNIT-III

Keys.

A key is a piece of mild steel inserted between the shaft and hub or boss of the pulley to connect these together in order to prevent relative motion between them. It is always inserted parallel to the axis of the shaft. Keys are used as temporary fastenings and are subjected to considerable crushing and shearing stresses. A key way is a slot or recess in a shaft and hub of the pulley to accommodate a key.

Types of keys:-

The following types of keys are important from subject point of view.

1. Sunk keys
2. Saddle keys,
3. Tangent keys,
4. Round keys.
5. Splines.

1. Sunk keys:-

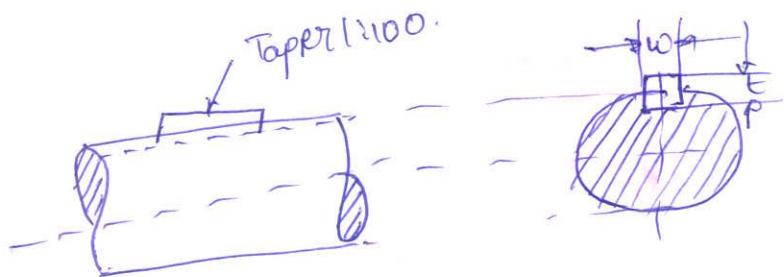
The sunk keys are provided half in the keyway of the shaft and half in the keyway of the hub or boss of the pulley.

(a) Rectangular Sunk key: A rectangular sunk key is shown in figure. The usual proportions of this key are.

$$\text{width of key } w = d/4$$

$$\text{thickness of key } t = 2w/3 = d/6.$$

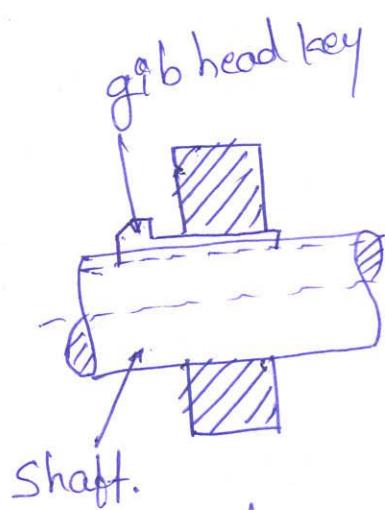
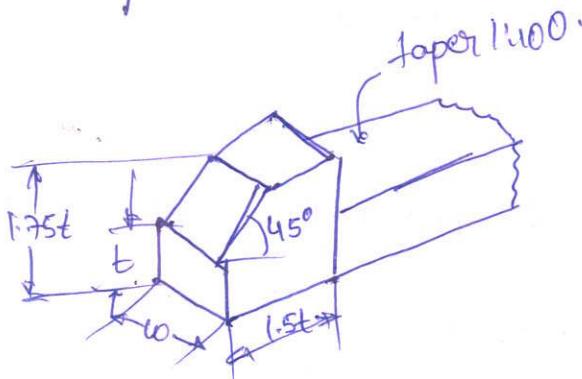
d = Diameter of the shaft or dia of the hole in the hub.



b) Square sunk key :- The only difference between a rectangular sunk key and a square sunk key is that its width and thickness are equal, i.e $w = t = d/4$.

c) Parallel sunk key :- The parallel sunk key may be of rectangular or square section uniform in width and thickness throughout. It may be noted that a parallel key is a taperless and is used where the pulley, gear or other and is used where the pulley, gear or other mating piece is required to slide along the shaft.

d) Gib-head key :- It is a rectangular sunk key with a head at one end known as gib head. It is usually provided to facilitate the removal of key.



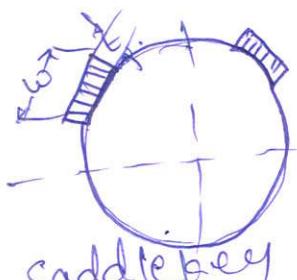
The usual proportions of the gib head key are:
width $w = d/6$.

thickness at longer end $t = 2w/3 = d/9$.

Q. Saddle keys:- The saddle keys are of the following two types.

1. Flat saddle key
2. Hollow saddle key.

A flat saddle key is a taper key which fits in a key way in the hub and is flat on the shaft as shown in fig. It is likely to slip round the shaft under load. Therefore it is used for comparatively light loads.



saddle key

hollow saddle key

A hollow saddle key is a taper key which fits in a key way in the hub and the bottom of the key is shaped to fit the curved surface of the shaft. Since hollow saddle keys hold on by friction, therefore these are suitable for light loads. It is usually used as a temporary fastenings in fixing and setting eccentric, cams etc.

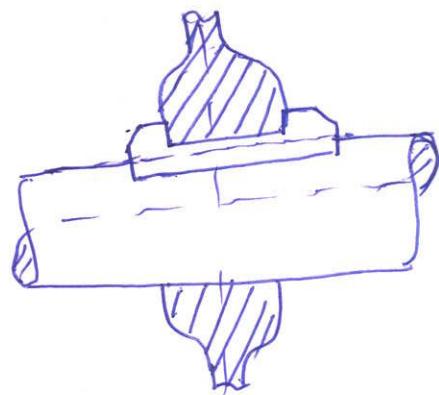
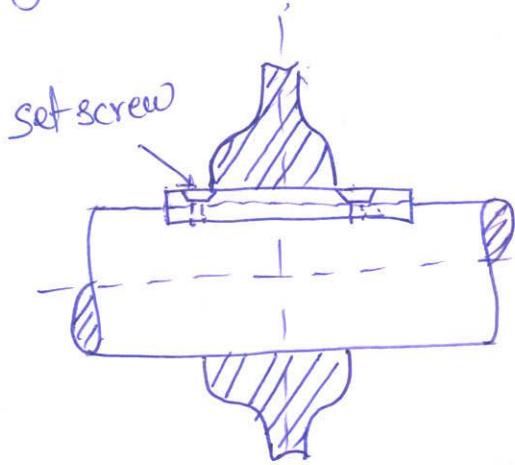
3. Tangent keys:-

The tangent keys are fitted in pair at right angles as shown in figure. Each key is to withstand torsion in one direction only. These are used in large heavy duty shafts.

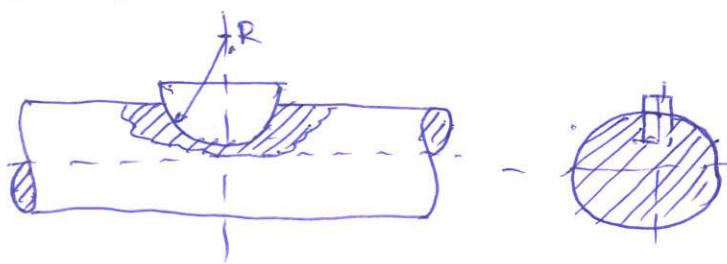
4. Round key:-

The round keys, as shown in figure are circular in section and fit into holes drilled partly in the shaft and partly in hub. They have the advantage that their keyways may be drilled and reamed after the mating parts have

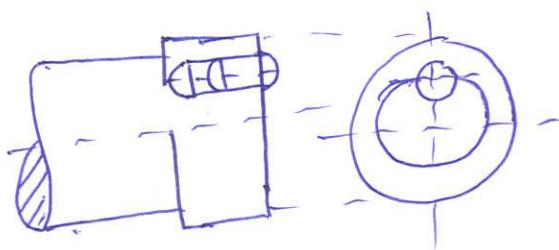
5. Feather key: A key attached to one member of a pair and which permits relative axial movement is known as feather key. It is a special type of key which transmits a turning moment and also permits axial movement. It is fastened either to the shaft or hub. The key being a sliding fit in the key way of the moving piece. The feather key may be screwed to the shaft or it may have double gib heads. The various proportions of a feather key are same as that of rectangular sunk key and gib head key.



6. Woodruff key: A woodruff key is an easily adjustable key. It is a piece from a cylindrical disc having segmental cross-section in front view. A woodruff key is capable of fitting in a recess milled out in the shaft by a cutter having the same curvature as the disc from which the key made. This key is largely used in machine-tool and automobile construction.



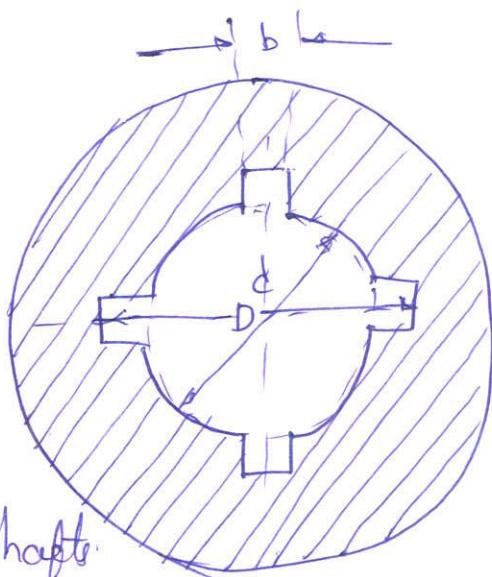
been assembled. Round keys are usually considered to be most appropriate for low power drives.



7. Splines :-

Sometimes, keys are made integral with the shaft which fits in the keyways broached on the hub. Such shafts are known as splined shafts. These shafts are usually have four, six, ten or sixteen splines. The splined shafts are relatively stronger than shaft having a single key way.

The splined shafts are used when the force to be transmitted is large in proportion to the size of the shaft as in automobile transmission and sliding gear transmissions. By using splined shafts, we obtain axial movement as well as positive drive is obtained.



Strength of a sunk key:-

A key connecting the shaft and hub is shown in fig.

T = torque transmitted by the shaft

F = Tangential force acting at the circumference of the shaft.

d = Dia of shaft.

l = Length of key

w = width of key

t = thickness of key and

τ_{qc} : shear and crushing stresses for the key material.

A little consideration will show that due to the power transmitted by the shaft, the key may fail due to shearing or crushing.

Consider shearing of the key, the tangential shearing force acting at circumference of the shaft.

F = Area resisting shearing \times Shear stress.

$$F = l \times w \times \tau_p$$

\therefore Torque transmitted by the shaft

$$T = F \times \frac{d}{2} = l \times w \times \tau_p \times \frac{d}{2}. \quad \text{---(1)}$$

Considering crushing of the key, the tangential crushing force acting at the circumference of the shaft

F = Area resisting crushing \times Crushing stress

$$F = l \times \frac{t}{2} \times \sigma_c.$$

\therefore Torque transmitted by the shaft.

$$T = F \times \frac{d}{2} = l \times \frac{t}{2} \times \sigma_c \times \frac{d}{2}. \quad \text{--- (2)}$$

The key is equally strong in shearing and crushing.

$$l \times w \times \gamma \times \frac{d}{2} = l \times \frac{t}{2} \times \sigma_c \times \frac{d}{2}.$$

$$\boxed{\frac{w}{t} = \frac{\sigma_c}{\gamma}} \quad \text{--- (3)}$$

The permissible crushing stress for usual key material is atleast twice the permissible shear stress. We know $w=t$. In other words, a square key is equally strong in shear and crushing.

In order to find the length of the key to transmit full power of the shaft, the shearing strength of the key is equal to the torsional shear strength of shaft.

We know that the shearing strength of key

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

and torsional shear strength of the shaft

$$T = \frac{\pi}{16} \times \gamma_I \times d^3$$

$$l \times w \times \gamma \times \frac{d}{2} = \frac{\pi}{16} \times \gamma_I \times d^3 \cdot 2$$

$$l = \frac{\pi}{8} \times \frac{\gamma_I d^2}{w \times \gamma} = \frac{\pi d}{2} \times \frac{\gamma_I}{\gamma} \quad [\text{Taking } w=d/4]$$

$$l = 1.571 d \times \frac{\gamma_I}{\gamma}$$

When the key material is same as that of the shaft, then $\gamma_I = \gamma$

$$\boxed{l = 1.571 d.}$$

Q Design the rectangular key for a shaft of 50mm diameter. The shearing and crushing stresses for the key material are 42 MPa and 70 MPa.

Given that $d = 50\text{ mm}$

$$\tau_s = 42 \text{ MPa} = 42 \text{ N/mm}^2$$

$$C_c = 70 \text{ MPa} = 70 \text{ N/mm}^2$$

$$\therefore \text{width of key } w = d/4 = 50/4 = 16 \text{ mm.}$$

$$\rightarrow \text{thickness of key } t = d/6 = 50/6 = 10 \text{ mm.}$$

Consider shearing of key. We know that shearing strength of key

$$T = l \times w \times \tau_s \times d/2 = l \times 16 \times 42 \times \frac{50}{2} = 16800l \text{ N-mm.} \quad \text{Eqn ①}$$

and torsional shear strength of the shaft

$$T = \frac{\pi}{16} \times \tau_t \times d^3 = \frac{\pi}{16} \times 42 \times (50)^3 = 1.03 \times 10^6 \text{ N-mm.} \quad \text{Eqn ②.}$$

$$\text{Eqn ①} = \text{Eqn ②.}$$

$$16800l = 1.03 \times 10^6$$

$$\therefore l = 61.31 \text{ mm.}$$

Now considering crushing of the key.

$$T = l \times \frac{t}{2} \times C_c \times \frac{d}{2} \times \frac{d}{2} = l \times \frac{10}{2} \times 70 \times \frac{50}{2} \\ = 8750l \text{ N-mm.} \quad \text{Eqn ③.}$$

$$\text{Eqn ①} = \text{Eqn ③.}$$

$$l = \frac{1.03 \times 10^6}{8750} = 117.7 \text{ mm.}$$

\therefore Taking longer of the two values, we have

length of key

$$l = 117.7 \text{ say } 120 \text{ mm.}$$

Q) A 45 mm diameter shaft is made of steel with a yield strength of 400 MPa. A parallel key of size 14 mm wide and 3 mm thick, made of steel with a yield strength of 300 MPa, is to be used. Find the required length of 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.

$$d = 45 \text{ mm}; \sigma_{yt} \text{ for shaft} = 400 \text{ MPa} \\ = 400 \text{ N/mm}^2$$

$$\sigma_{yt} \text{ for key} = 300 \text{ MPa} = 340 \text{ N/mm}^2$$

$$w = 14 \text{ mm}; t = 3 \text{ mm}, F.S = 2$$

According to max. shear stress theory, the max. shear stress for the shaft

$$\tau_{max} = \frac{\sigma_{yt}}{2 \times F.S} = \frac{400}{2 \times 2} = 100 \text{ N/mm}^2$$

and max. shear stress for the key

$$\tau_k = \frac{\sigma_{yt}}{2 \times F.S} = \frac{340}{2 \times 2} = 85 \text{ N/mm}^2$$

We know the max. torque transmitted by the shaft

$$\text{and key } T = \frac{\pi}{16} \times \sigma_{max} \times d^3 = \frac{\pi}{16} \times 100 \times (45)^3 = 1.8 \times 10^6 \text{ N-mm.}$$

Now considering failure of key due to crushing.
We know that the max. torque transmitted

by the shaft and key (T)

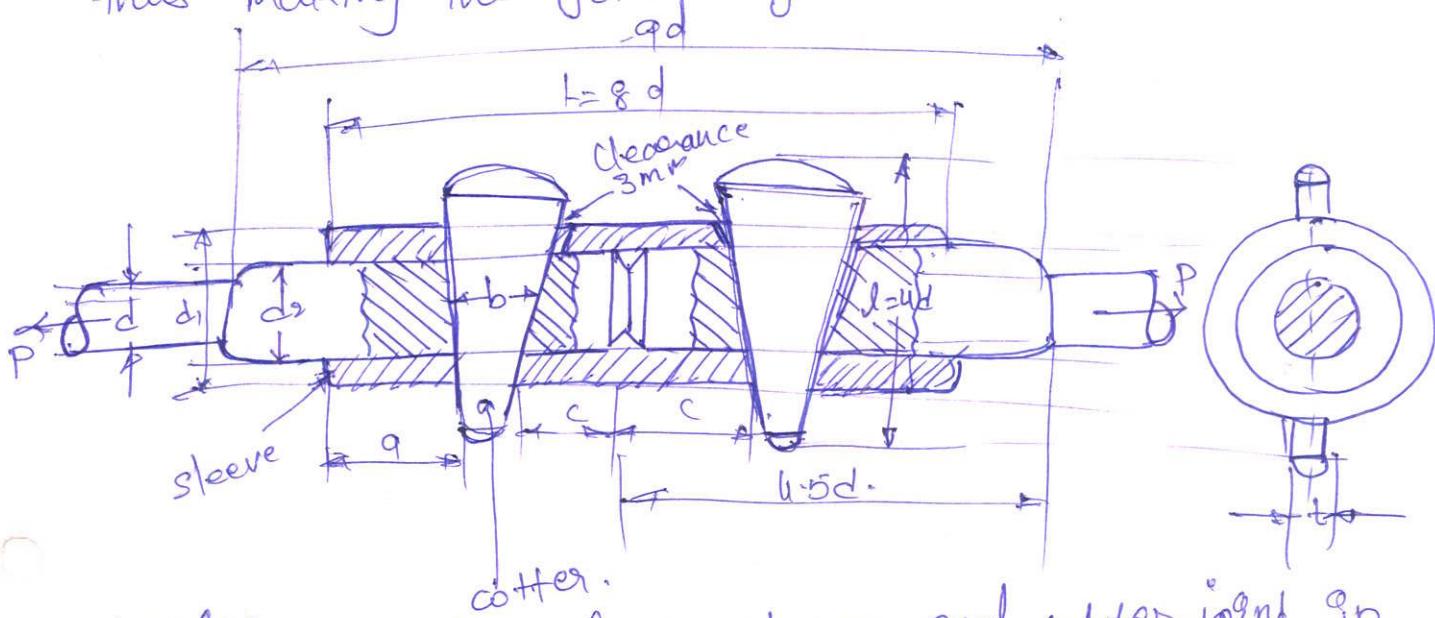
$$1.8 \times 10^6 = d \times \frac{t}{2} \times \sigma_{ck} \times \frac{d}{2} = d \times \frac{9}{2} \times \frac{340}{2} \times \frac{45}{2} \\ = 17213 d.$$

$$d = \frac{1.8 \times 10^6}{17213} = 104.6 \text{ mm.}$$

∴ The length of key is $= 104.6 \text{ mm}$

Sleeve and cutter Joint

Sometimes, a sleeve and cutter joint as shown in figure is used to connect two round rods or bars. In this type of joint, a sleeve or muff is used over the two rods and then two cutters (one on each rod end) are inserted in holes provided for them in the sleeve and rods. The taper of cutter is usually $1\text{ in } 12$. It may be noted that the taper sides of the two cutters should face each other as shown in fig. The clearance is so adjusted that when the cutters are driven in, the rods come closer to each other thus making the joint tight.



Various properties of the sleeve and cutter joint in terms of the dia of rod d are as follows.

$$\text{Outside dia of sleeve } d_1 = 2.5d$$

$$\begin{aligned} \text{Dia of enlarged end of rod } d_2 &= \text{Inside dia of sleeve} \\ &= 1.25d. \end{aligned}$$

$$\text{Length of sleeve } L = 8d$$

$$\text{Thickness of cutter } t = d/12 \text{ or } 0.31d.$$

$$\text{Width of cutter } b = 1.25d.$$

$$\text{Length of cutter } l = 4d.$$

Distance of rod end (O) from the beginning to the cutter hole (single sleeve end) = Distance of the rod end (C) from its end to the cutter hole
 $= 1.25d.$

Design of sleeve and cutter joints

P = load carried by the rods,

d = dia of the rods

d_1 = outside dia of sleeve.

d_2 = Dia of the enlarged end of rod.

t = thickness of cutter.

l = length of cutter.

b_2 width of cutter

a = Distance of the rod end from the beginning to the cutter hole.

c = Distance of the rod end from its end to the cutter hole.

$\sigma_f, \gamma_f, \sigma_c$ = permissible tensile, shear and crushing

stresses respectively for the material of the rods and cutter.

1. Failure of the rods in tension

The rods may fail in tension due to the tensile load (P)

$$\therefore \text{Tearing strength of the rod } (P) = \frac{\pi}{4} \times d^2 \times \sigma_f.$$

2. Failure of the rod in tension across the weakest section (i.e slot).

The tearing strength of the rod across the

$$\text{weakest section } (P) = \left[\frac{\pi}{4} (d_2)^2 - d_2 \times t \right] \times \sigma_f.$$

Note: thickness of cutter is usually taken as $d_2/4$.

3. Failure of the rod (or) cutter in crushing.

The crushing strength of the rod (or) cutter.

$$\therefore P = (d_2 \times t) \times \sigma_c.$$

4) Failure of sleeve in tension across the slot.

∴ The tearing strength of sleeve in tension across the slot.

$$P = \left[\frac{\pi}{4} [(d_1^2 - d_2^2)] - (d_1 - d_2)t \right] \times \sigma_t.$$

5. Failure of cotter in shear

∴ The shear strength of cotter

$$P = 2bxt \times \gamma.$$

6. Failure of rod end in shear

The shear strength of rod end

$$P = 2axd_2 \times \gamma.$$

7. Failure of sleeve end in shear

∴ The shear strength of sleeve end

$$P = 2(d_1 - d_2) \times C \times \gamma.$$

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