UNIT – II

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Syllabus

Design of solid and hollow shafts based on strength, rigidity and critical speed – Design of keys, key ways and splines – Design of crankshafts – Design of rigid and flexible coupling.

Topics:

1. Coupling
2. Key
3. Crank shaft
4. Shaft

Introduction

- Shafts are usually available upto 7 metres length due to inconvenience in transport.
- In order to have a greater length, it becomes necessary to join two or more pieces of the shaft by means of a coupling.
- It is used to connect two shafts.

Flange coupling

Flange coupling is a rigid coupling, it consists of two hubbed flanges. One is keyed to driving shaft and other to the driven shaft.

Flange Coupling

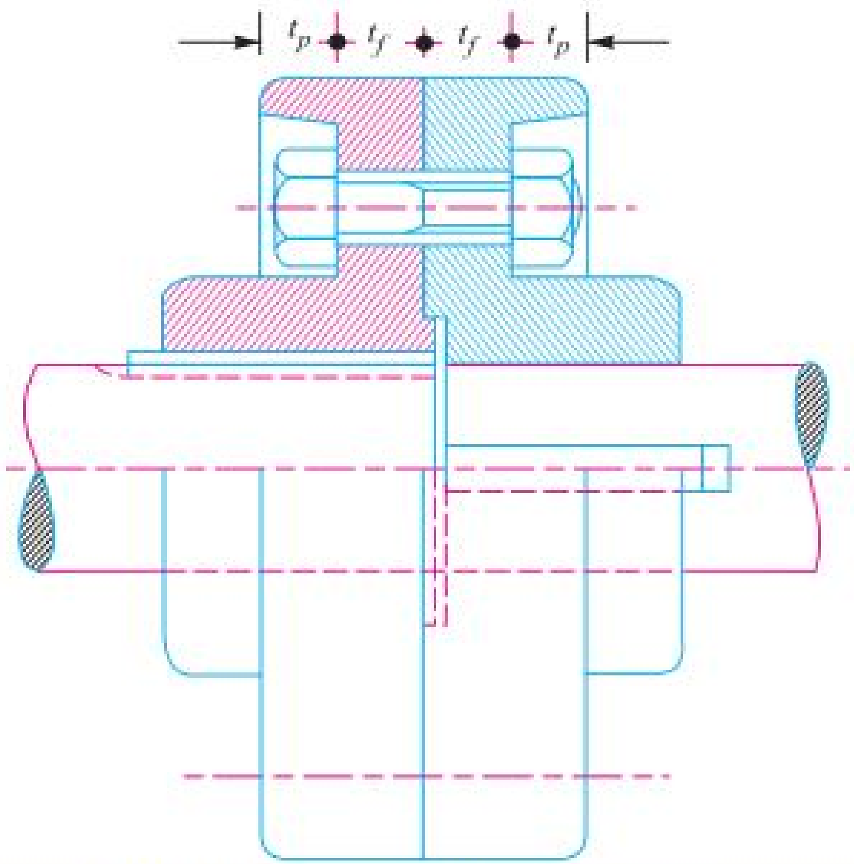


Fig. 13.13. Protective type flange coupling.

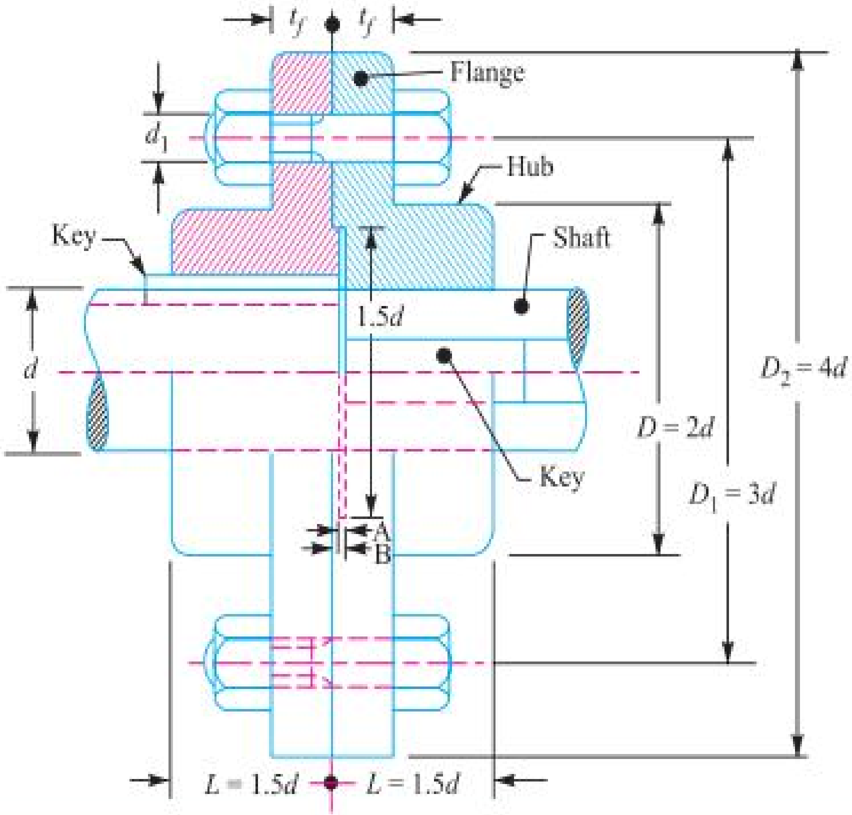


Fig. 13.12. Unprotected type flange coupling.

Continue…

Let

d = Diameter of shaft (mm)

D = Outer diameter of hub (mm)

L = Length of hub in each flange (mm)

d_b = Diameter of bolts (mm)

D_p = Pitch circle diameter of bolts (mm)

D_o = Outer diameter of flange (mm)

t_f = Thickness of flange (mm)

P = Power transmitted (W)

N = Speed (rpm)

$[\tau_{sh}]$ = Permissible shear stress of shaft material (N/mm^2)

Continue…

$[\tau_f]$ = Permissible shear stress of flange material (N/mm^2)

$[\tau_k]$ = Permissible shear stress of key material (N/mm^2)

$[\tau_b]$ = Permissible shear stress of bolt material (N/mm^2)

$[\sigma_{cb}]$ = Permissible crushing stress of bolt material (N/mm^2)

$[\sigma_{ck}]$ = Permissible crushing stress of key material (N/mm^2)

Design of Shaft and Hub

Power transmitted by a s**o**lid shaft (P)

$$P = 2\pi NT/60$$

P = Power transmitted by the shaft

(Watt (or) N-m/s)

T = Torque (or) twisting moment (or) Turning moment (N-m)

N = Speed of the shaft (rpm)

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

T = Twisting moment (or) Turning moment (N-mm)

$[\tau_{sh}]$ = Maximum shear stress (N/mm^2)

d = Diameter of the shaft (mm)

D = Diameter of hub = 2d

L = Length of the hub = 1.5d

Check Hub for shear

$$\tau_f = \frac{16 \times T \times D}{\pi\left(D^4 - d^4\right)} \text{ N/mm}^2$$

τ_f = Allowable shear stress for flange material (N/mm^2)

T = Twisting moment (or) Turning moment (N-mm)

D = Diameter of hub (mm)

d = Diameter of the shaft (mm)

Design of Flange

D_o = Outer diameter of flange = 4d

t_f = Thickness of flange = 0.5d

t_p = Thickness of protected circumferential flange = 0.25d.

Checking flange for shear

$$\tau_f = \frac{2T}{\pi D^2 t_f} \text{ (N/mm}^2\text{)}$$

τ_f = Allowable shear stress for flange material (N/mm^2)

T = Twisting moment (or) Turning moment

(N-mm)

D = Diameter of hub (mm)

t_f = Thickness of flange (mm)

Design of Key

- From PSGDB: 5.16, width (w) and thickness (t)Can be determined.
- If length of key is given assume length of the key is equal to length of hub.
- Length of key (l) = Length of the hub (L)

Checking for shear stress:

$$\tau_k = \frac{2T}{l \times d \times w} \quad (\text{N/mm}^2)$$

Checking for crushing stress

$$\sigma_{ck} = \frac{4T}{l \times d \times t} \ (\text{N/mm}^2)$$

τ_k = Allowable shear stress for key material, (N/mm^2)

T = Twisting moment (or) Turning moment, N-mm

l = Length of the key (mm)

t = Thickness of key (mm)

d =Diameter of the shaft (mm)

w = Width of the key (mm)

Design of Bolts

$$d_b = \sqrt{\frac{8T}{\pi \times [\tau_b] \times n \times d_p}} \quad \text{(mm)}$$

T = Twisting moment (or) Turning moment (N-mm)

d_b =Diameter of bolt (mm)

d_p=Pitch circle diameter of bolts (mm)

n = Number of bolts.

Checking crushing for bolts

$$\sigma_{cb} = \frac{2T}{d_b \times t_f \times n \times d_p} \text{ N/mm}^2$$

σ_{cb} = Allowable shear stress for key material (N/mm^2)

T = Twisting moment (or) Turning moment (N-mm)

d_b =Diameter of bolt (mm)

d_p = Pitch circle diameter of bolts (mm)

n = Number of bolts

t_f = Thickness of flange (mm)

Problems (Protected type flange)

1. Design a rigid flange coupling to connect two shafts to transmit 7.5 kW at 750 rpm. The permissible shear stress for shaft, bolt and key materials is 40 N/mm^2, Permissible crushing strength for bolt and key material is 60 N/mm^2 and permissible shear stress for flange material is 20 N/mm^2.

Continue…

Design a cast Iron (C.I) flange coupling for a mild steel shaft transmitting 90 kW at 250 rpm. The allowable shear stress in the shaft is 40 MPa and the angle of twist is not be exceed 1^o in a length of 20 diameters. The allowable shear stress in the coupling bolts is 30 MPa.

Note:

For unprotected type flange coupling the all properties are same, except that $D_o = 3d$.

Marine type Flange coupling

- In a marine type flange coupling the flanges are forged integral with the shafts as shown in fig.
- The flanges are held together by means of tapered headless bolts, numbering from 4 to 12 depending upon the diameter of shaft.
- The number of bolts may be chosen from the following table

Shaft diameter (mm)	35 to 55	56 to 150	151 to 230	231 to 390	Above 390
No. of bolts	4	6	8	10	12

Marine type flange coupling

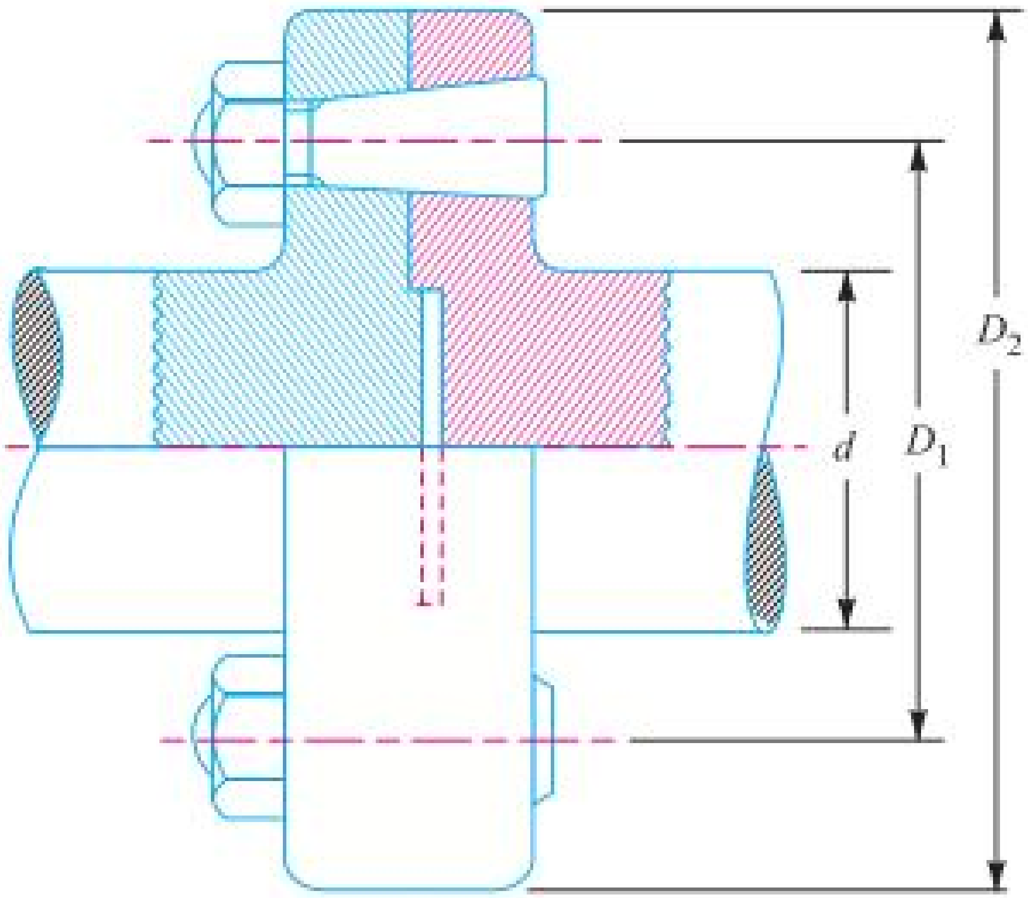


Fig. 13.14. Marine type flange coupling.

Formula for marine type flange coupling

Thickness of flange = d/3

Taper of bolt = 1 in 20 in 1 in 40

Pitch circle diameter of bolts d_p = 1.6d

Outside diameter of flange D_o = 2d (or) 2.2d

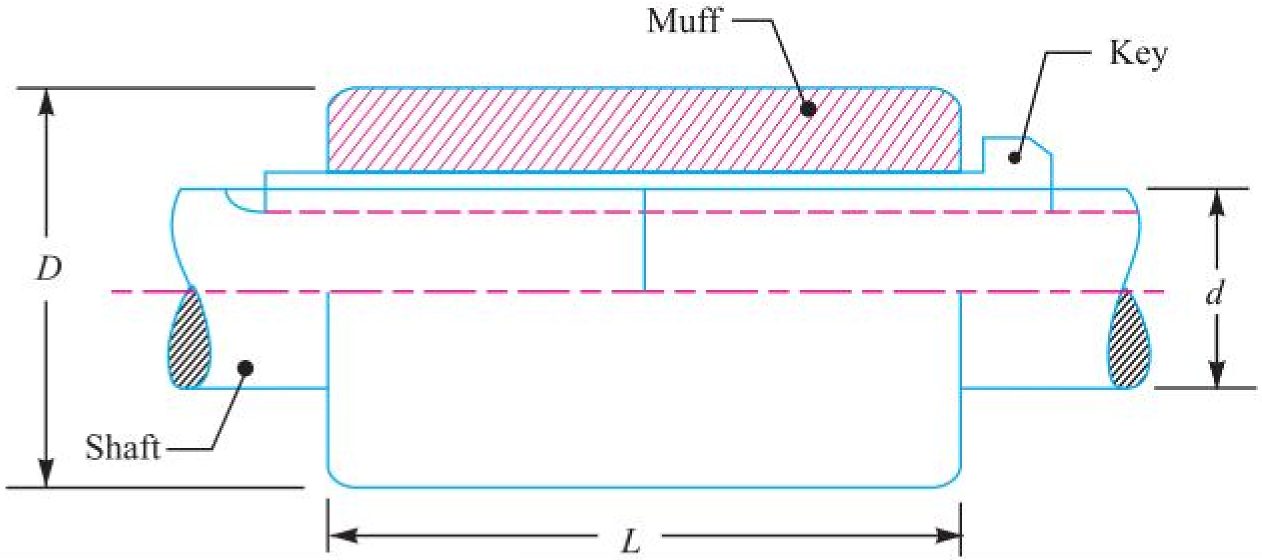
Problem

A marine type coupling is used to transmit 65 kW at 100 rpm. The permissible shear stress for shafts and bolts is 33 MPa and permissible crushing stress for bolts is 35 MPa. Design the coupling, assuming number of bolt used as 8.

Sleeve (or) Muff coupling

- It is the simplest type of rigid coupling, made of cast iron.
- It consists of a hollow cylinder whose inner diameter is the same as that of the shaft.
- It is fitted over the ends of the two shafts by means of a gib head key.
- The power is transmitted from one shaft to the other shaft by means of a key and a sleeve.
- It is therefore, necessary that all the elements must be strong enough to transmit the torque.

Sleeve (or) Muff coupling



Sleeve or muff coupling.

Problems

Design a muff (or) sleeve coupling for a shaft to transmit 35 kW at 350 rpm. The safe shear stress for the steel shaft is 50 N/mm^2 and for the cast Iron muff is 15 N/mm^2. The allowable shear and crushing stresses for the key material are 42 N/mm^2 and 120 N/mm^2 respectively.

Formula

$D = 2d+13$ mm

$L = 3.5d$

$l = L/2$

Continue…

STEPS:

Step – 1

Design of shaft diameter

Step – 2

- Design of sleeve (or) muff
- Checking

Step – 3

- Design of key
- Checking

Clamp (or) Compression (or) Split muff coupling

- In this case, the muff (or) sleeve is made into two halves and are bolted together.
- The halves of the muff are made of Cast Iron
- One half of the muff is fixed from below and the other half is placed above.
- Both the halves are held together by means of mild steel studs (or) bolts and nuts.
- The number of bolts may be two, four, six.
- This coupling may be used for heavy duty and moderate speeds.

Continue…

Formula

D = 2d+13 mm

L = 3.5d

l = L

STEPS:

Step – 1

Design of shaft diameter

Step – 2

- Design of sleeve (or) muff
- Checking

Step – 3

- Design of key
- Checking

Step – 4

Design for bolts

Problems

Design a clamp coupling to transmit 30 kW at 100 rpm. The allowable shear stress for the shaft and key is 40 MPa and the number of bolts connecting the two halves are six. The permissible tensile stress for the bolts is 70 MPa. The coefficient of friction between the muff and the shaft surface may be taken as 0.3

Flexible Coupling

- A flexible coupling is used to connect two shafts which have lateral (or) angular misalignment.

- It is also used to reduce the effect of shock and impact load.

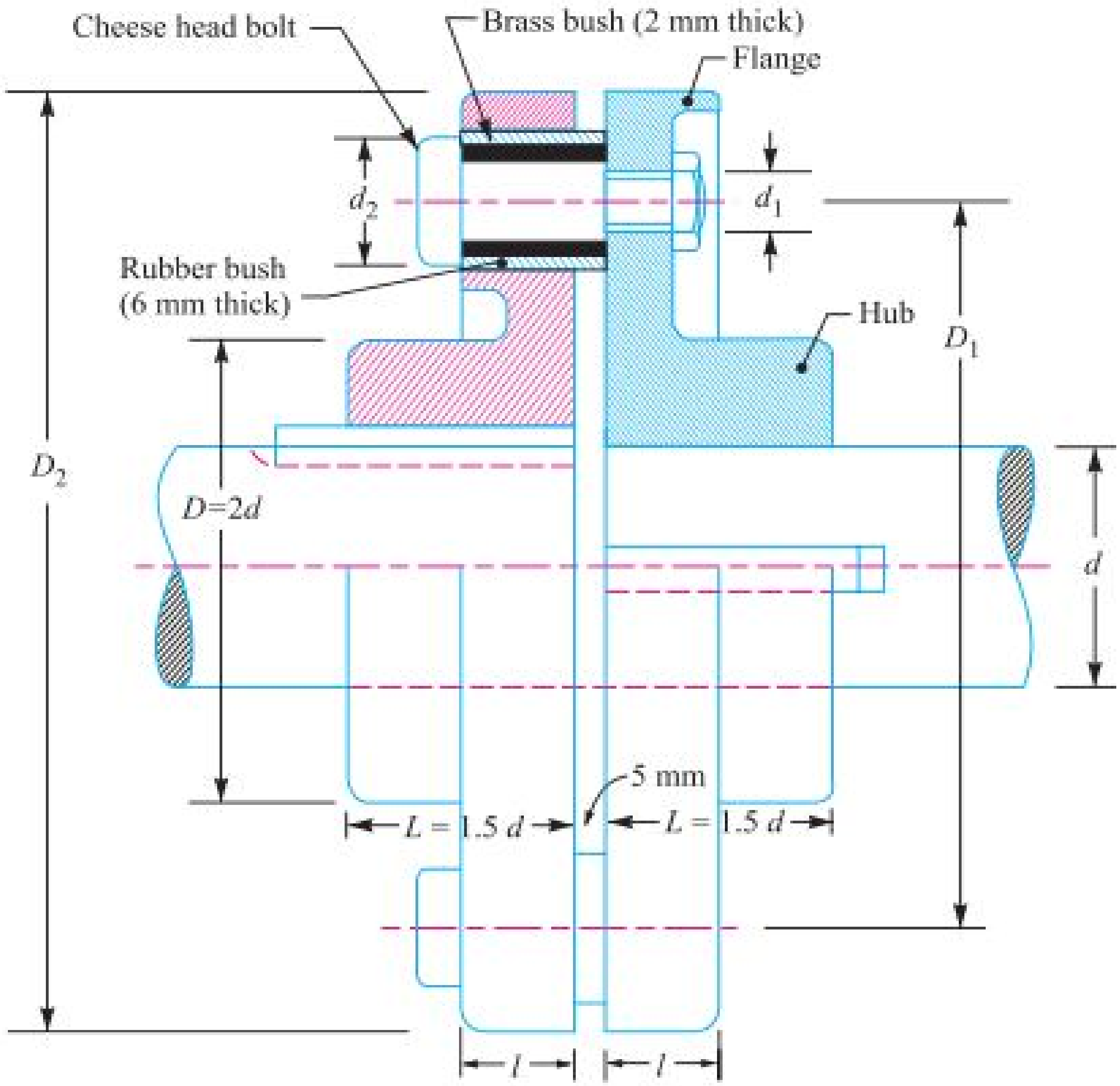
Flexible Coupling

(a) Bellows coupling , (b) Elastomeric coupling, (c) Flanged coupling , (d) Flexible coupling

Bushed Pin Type Flexible Coupling

- It is one type of flexible coupling. It is commonly used where the driving and driven members are mounted on a mono block.
- The construction of a flexible coupling is similar to that of a rigid coupling except that a rubber bushes are used over the pins as shown in fig.
- The coupling bolts are known as pins.
- The rubber (or) leather bushes are used over the pins.

Bushed Pin type flexible Coupling



Continue…

Let l = Length of bush in the flange,

d_2 = Diameter of bush,

p_b = Bearing pressure on the bush or pin,

n = Number of pins, and

D_1 = Diameter of pitch circle of the pins.

We know that bearing load acting on each pin,

$$W = p_b \times d_2 \times l$$

∴ Total bearing load on the bush or pins

$$= W \times n = p_b \times d_2 \times l \times n$$

Torque transmitted by the coupling:

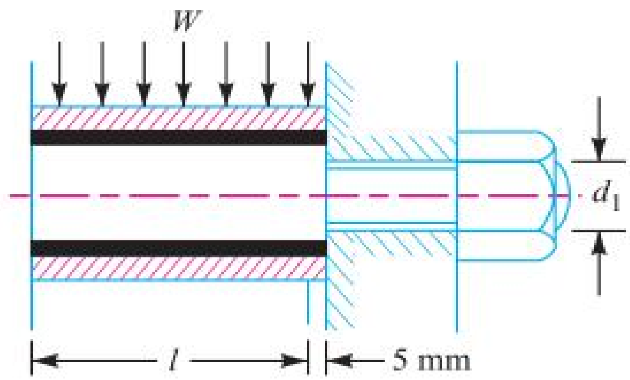
$$T = W \times n\left(\frac{D_1}{2}\right) = p_b \times d_2 \times l \times n\left(\frac{D_1}{2}\right)$$

Direct shear stress due to pure torsion in the coupling halves:

$$\tau = \frac{W}{\frac{\pi}{4}(d_1)^2}$$

Assuming a uniform distribution of the load W along the bush, the maximum bending moment on the pin:

$$M = W\left(\frac{l}{2} + 5mm\right)$$



Bending stress:

$$\sigma = \frac{M}{Z} = \frac{W\left(\frac{l}{2} + 5mm\right)}{\frac{\pi}{32}(d_1)^3}$$

Maximum principal stress:

$$= \frac{1}{2}\left[\sigma + \sqrt{\sigma^2 + 4\tau^2}\right]$$

Maximum shear stress on the pin:

$$= \frac{1}{2}\left[\sqrt{\sigma^2 + 4\tau^2}\right]$$

(a) Taper bush (b) Locking-assembly (shaft or bush connectors)
(c) Friction joint bushing (d) Safety overload coupling.

Maximum principal stress

$$= \frac{1}{2}\left[\sigma + \sqrt{\sigma^2 + 4\tau^2}\right]$$

and the maximum shear stress on the pin

$$= \frac{1}{2}\sqrt{\sigma^2 + 4\tau^2}$$

The value of maximum principal stress varies from 28 to 42 MPa.

Problem

Design a bushed – pin type of flexible coupling to connect a pump shaft to a motor shaft transmitting 32 KW at 960 rpm. The overall torque is 20 percent more than mean torque. The material properties are as follows.

(a) The allowable shear and crushing stress for shaft and key material is 40 Mpa and 80 Mpa respectively.

(b) The allowable shear stress for cast Iron is 15 Mpa.

(c) The allowable bearing pressure for rubber bush is 0.8 N/mm^2

(d) The material of the pin is same as that of shaft and key and the torque transmitted by the coupling,

$$T = W \times n\left(\frac{D_1}{2}\right) = p_b \times d_2 \times l \times n\left(\frac{D_1}{2}\right)$$

The threaded portion of the pin in the right hand flange should be a tapping fit in the coupling hole to avoid bending stresses.

The threaded length of the pin should be as small as possible so that the direct shear stress can be taken by the unthreaded neck.

Direct shear stress due to pure torsion in the coupling halves,

$$\tau = \frac{W}{\frac{\pi}{4}(d_1)^2}$$

Since the pin and the rubber or leather bush is not rigidly held in the left hand flange, therefore the tangential load (W) at the enlarged portion will exert a bending action on the pin as shown in Fig. 13.16. The bush portion of the pin acts as a cantilever beam of length l. Assuming a uniform distribution of the load W along the bush, the maximum bending moment on the pin,

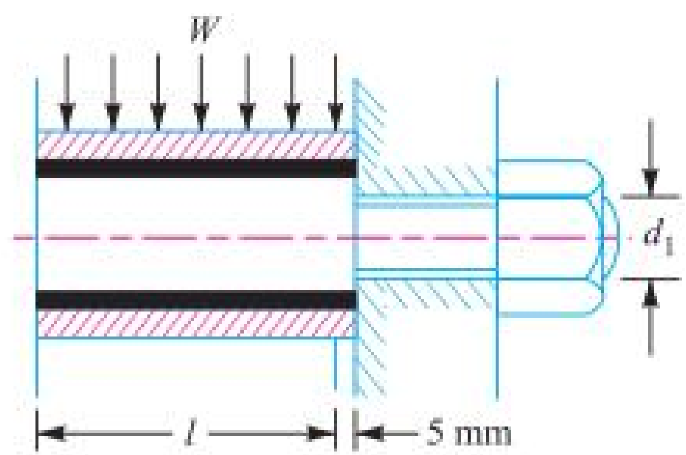


Fig. 13.16.

$$M = W\left(\frac{l}{2} + 5 \text{ mm}\right)$$

We know that bending stress,

$$\sigma = \frac{M}{Z} = \frac{W\left(\frac{l}{2} + 5 \text{ mm}\right)}{\frac{\pi}{32}(d_1)^3}$$

Design of shaft

SHAFT:

It is a rotating member, usually circular in cross-section used to transmit power.

TRANSMISSION SHAFT:

It transmit power from one place to another place.

Ex. Shaft coupled with turbine.

MACHINE SHAFT:

Integral part of the machine.

Ex. Crank shaft

SPINDLE:

Short shaft is called spindle.

Ex. Drilling machine spindle, Lathe spindle

AXLE:

It is appearance similar to shaft. It is load carrying member. It may be rotating (or) Non-rotating.

SHAFT MATERIAL:

- Mild steel
- Cast Iron
- Steel-Chromium alloy
- Steel-Vanadium alloy
- Copper alloy

Continue…

STRESS INDUCED IN SHAFT MATERIAL:

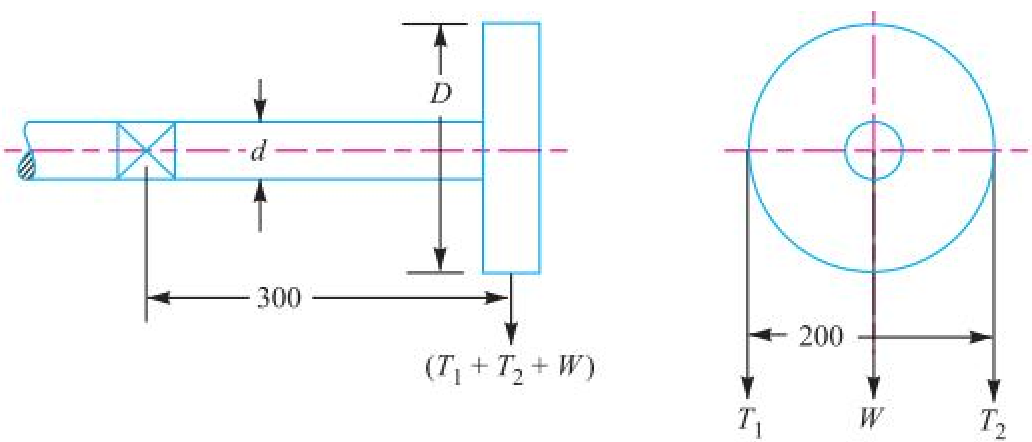
- Shear stress due to transmission of torque
- Bending stress due to weight of pulley (or) gear in the shaft.
- Combined shear stress and Bending stress.
- Combined shear stress, Bending stress and axial stress.

Problems

1. A line shaft rotating at 300 rpm is to transmit 20 kW. Determine the diameter of the shaft, if the permissible shear stress of the shaft is 42 Mpa. Neglect bending moment on the shaft.
2. A shaft is transmitting 97.5 kW at 180 rpm. It the allowable shear stress in the material is 60MPa, find the suitable diameter for the shaft. The shaft is not to twist more than 1^{o} in a length of 3m. Take C = 80GPa.

3. A solid circular shaft is subjected to a bending moment of 3000 N-m and a torque of 10000 N-m. The shaft is made of 45 C 8 steel having ultimate tensile stress of 700 MPa and a ultimate shear stress of 500 MPa. Assuming a factor of safety as 6, determine the diameter of the shaft.
4. A mild steel shaft transmits 20 kW at 200 rpm. It carries a central load of 1000 N and is simply supported between the bearing 2 m apart. Determine the size of the shaft, if the allowable shear stress is 42 MPa and maximum tensile (or) compressive stress is not to be exceed 56 MPa. What size of the shaft is required, if it is subjected to gradually applied loads?

5. Design a shaft to transmit power from an electric motor to a lathe head stock through a pulley by means of a belt drive. The pulley weighs 200 N and is located at 300 mm from the centre of the bearing. The diameter of the pulley is 200 mm and the maximum power transmitted is 1 kW at 120 rpm. The angle of lap of the belt is 180º and coefficient of friction between the belt and the pulley is 0.3. The shock and fatigue factors for bending and twisting are 1.5 and 2.0 respectively. The allowable shear stress in the shaft may be taken as 35 MPa.



All dimensions in mm.

6. A mild steel shaft transmit 100 kW at 300 rpm. The supported length of the shaft is 3 m. It carries two pulleys each weighting 1500 N mounted at a distance of 1m from the ends respectively. Determine the size of the shaft, if the allowable shear stress for the shaft material is 60 N/mm^2.

7. A mild steel shaft 900 mm between bearings support, a 600 mm pulley 300 mm to the right of the left band bearing and a belt drives the pulley directly below. Another pulley of 450 mm diameter is located 200 mm to the left of the right hand bearing and the belt is driven from a pulley horizontal to the right. The angle of contact for both the pulleys is 180º and the tension ratio is 2.2. The maximum tension in the belt on 600 mm diameter pulley is 2.25 kN. Determine the suitable diameter for the solid shaft, if the permissible tensile stress is 63 N/mm^2 and the permissible shear stress is 42 N/mm^2.

8. A shaft is supported on bearings A and B 800 mm between centers. A 20º straight tooth spur gear with 600 mm pitch diameter is locate 200 mm to the right of the left hand bearing A and a 700 mm diameter pulley is mounted 250 mm towards the left of bearing B. The gear is driven by a pinion with a downward tangential force while the pulley drives the horizontal belt having 180º angle of wrap. The pulley also serves as a flywheel and weight 2000 N. The maximum belt tension is 3:1. Determine the maximum bending moment and the necessary shaft diameter if the allowable shear stress of the material is 40 N/mm^2. The maximum belt tensile is 3000 N.

A steel solid shaft transmitting 15kW at 200 rpm is supported on two bearings 750 mm apart and has two gears keyed to it. The pinion having 30 teeth of 5 mm module is located 100 mm to the left of the right hand bearing delivers power horizontally to the right. The gear having 100 teeth of 5 mm module is located 150 mm to the right of the left hand bearing and receives power in a vertical direction from below. Using an allowable stress of 54 MPa in shear, determine the diameter of the shaft.

A horizontal nickel steel shaft rests on two bearings, A at the left and B at the right end and carries two gears C and D located at distances of 250 mm and 400 mm respectively from the centre line of the left and right bearings. The pitch diameter of the gear C is 600 mm and that of gear D is 200 mm. The distance between the centre line of the bearings is 240 mm.

DESIGN OF KEYS

KEY:

The key is a element which is inserted between the shaft and hub of rotating element like gear (or) pulley (or) sprocket.

- It prevent the relative motion of a shaft and the member connected to it.
- Keys are used as temporary fastenings and (or) subjected to crushing and shearing.
- A key way is a slot provided in shaft hub of pulley (or) gear (or) sprocket to accommodate to key.

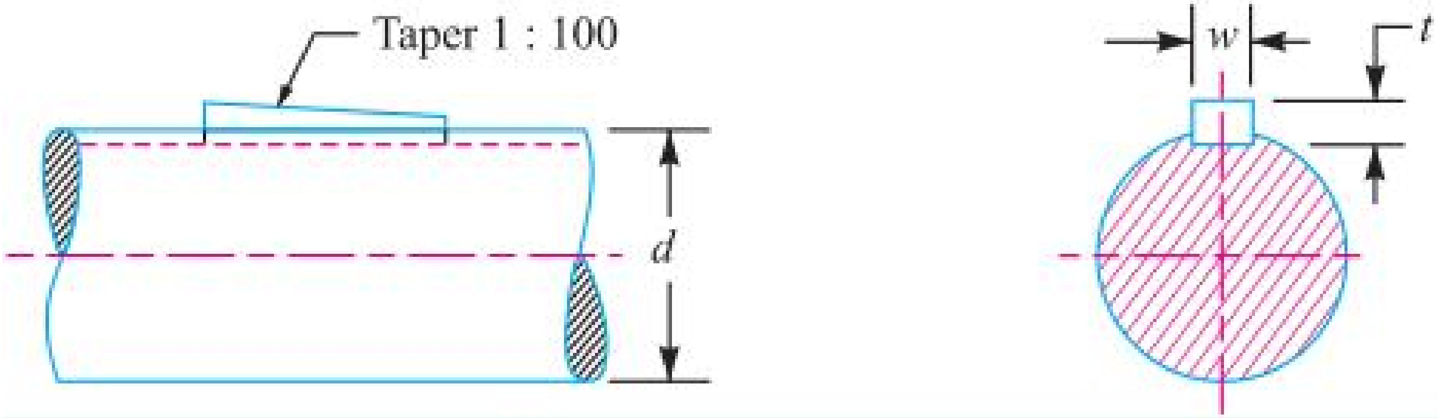
TYPES OF KEYS:

- Sunk key
- Saddle key
- Tangent key
- Round key
- Taper key
- splines

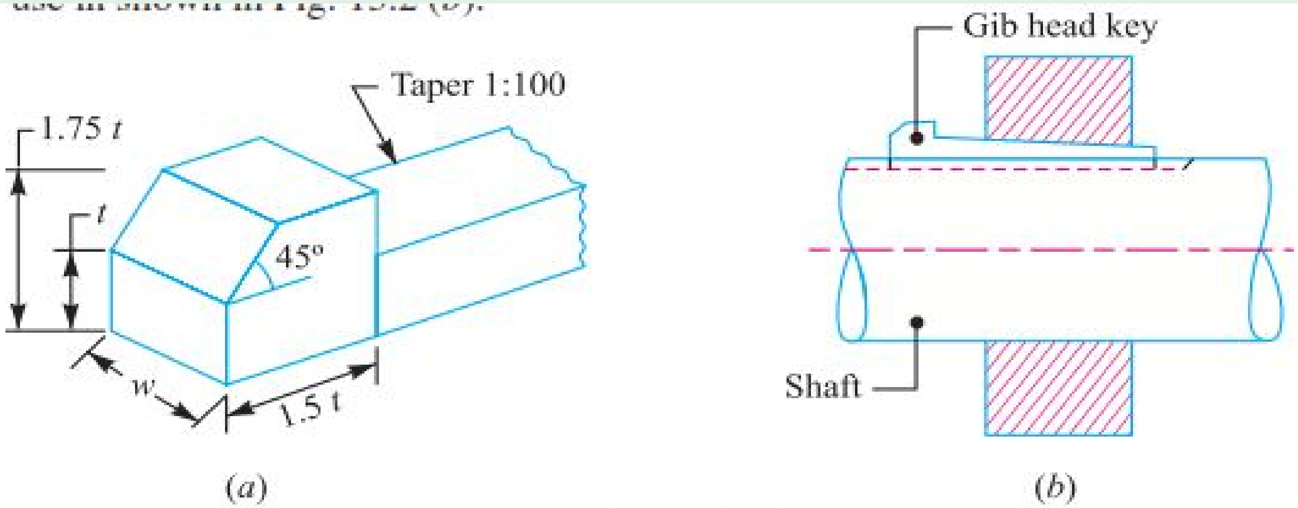
SUNK KEY:

One half portion is accommodated in the key way and that of the shaft and other half in the key way of hub.

TYPES OF KEYS



Rectangular sunk key.



Gib-head key.

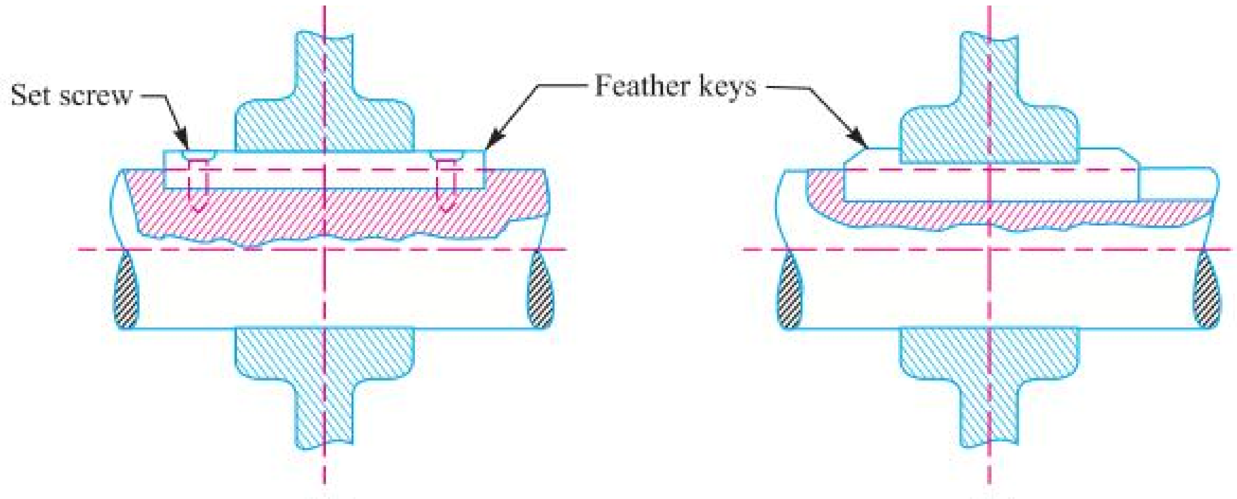


Fig. 13.3. Feather key.

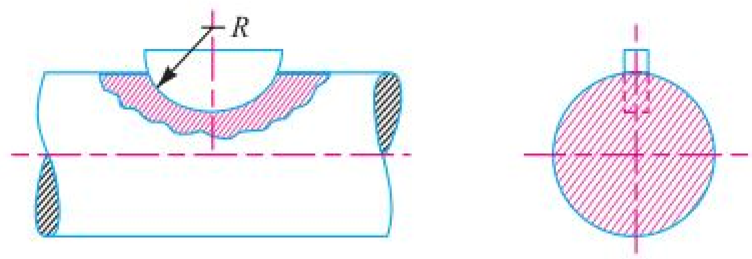
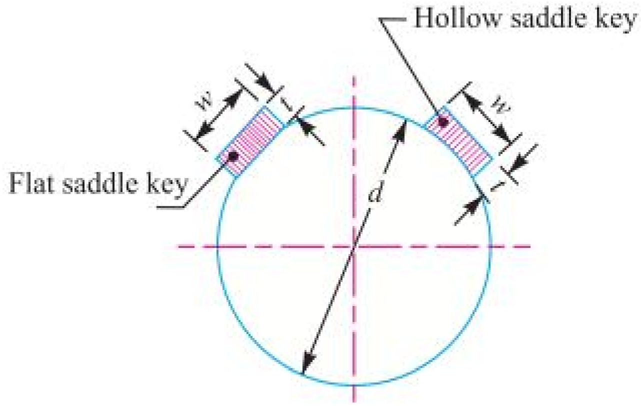


Fig. 13.4. Woodruff key.



$t = w / 3 = d / 12$

Fig. 13.5. Saddle key.

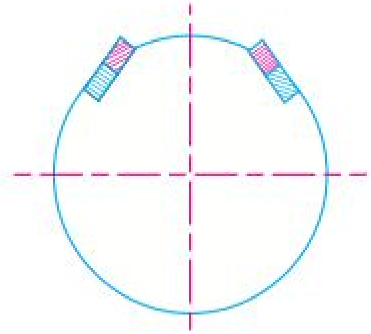


Fig. 13.6. Tangent key.

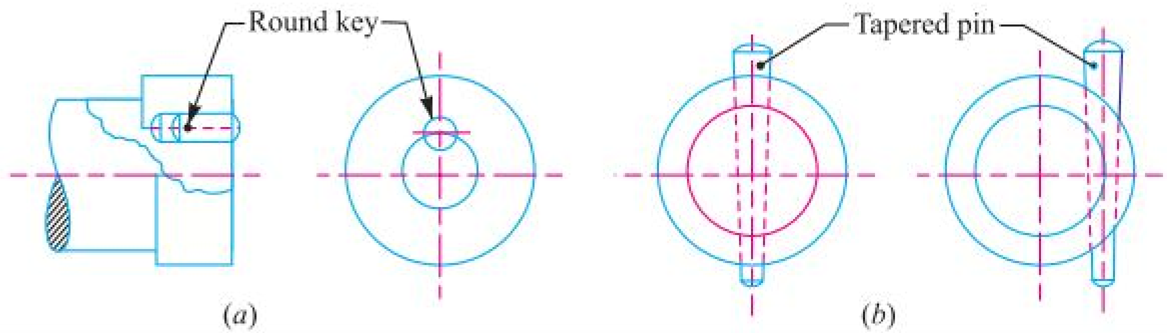
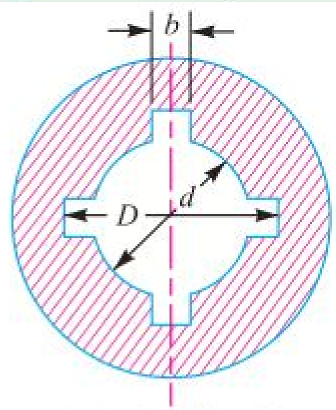


Fig. 13.7. Round keys.



$D = 1.25\ d$ and $b = 0.25\ D$

Fig. 13.8. Splines.

DESIGN OF SUNK KEY

$$F = \frac{2T}{d}$$

Shear stress (τ_k)

τ_k = Force / Shearing area

$$\tau_k = \frac{2T}{d \times l \times w} \quad \text{N/mm}^2$$

Crushing stress (σ_{ck})

σ_{ck} = Force / cutting area

$$\sigma_{ck} = \frac{4T}{d \times l \times t} \quad \text{N/mm}^2$$

Where

T – Torque transmitted – N-mm

F – Force applied – N

d – Diameter of shaft – mm

l – length of key – mm

w – width of key – mm

t – Thickness of key – mm

τ_k – Shear stress induced in key material, N/mm^2

(τ_k) – Allowable (or) Permissible shear stress for key material ,N/mm^2

σ_{ck} - Crushing stress induced in key material, N/mm^2

(σ_{ck}) – Allowable (or) Permissible crushing stress for key material, N/mm^2

Problem

A rectangular key 40 mm length is required to transmit 10 kW at 900 rpm. Determine the size of key, if the permissible shear stress and crushing stress are limited to 65 N/mm^2 and 110 N/mm^2 respectively. Assume that the shaft and key are made of same material. **(April/2010)**

END