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$$= \mu \times \frac{\pi}{4} (d_b)^2 \sigma_t \times \frac{n}{2} \times \pi = \mu \times \frac{\pi^2}{8} (d_b)^2 \sigma_t \times n$$

and the torque that can be transmitted by the coupling,

$$T = F \times \frac{d}{2} = \mu \times \frac{\pi^2}{8} (d_b)^2 \sigma_t \times n \times \frac{d}{2} = \frac{\pi^2}{16} \times \mu (d_b)^2 \sigma_t \times n \times d$$

From this relation, the root diameter of the bolt (d_b) may be evaluated.

Note: The value of μ may be taken as 0.3.

Example 13.5. Design a clamp coupling to transmit 30 kW at 100 r.p.m. 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.

Solution. Given : $P = 30 \text{ kW} = 30 \times 10^3 \text{ W}$; $N = 100 \text{ r.p.m.}$; $\tau = 40 \text{ MPa} = 40 \text{ N/mm}^2$; $n = 6$; $\sigma_t = 70 \text{ MPa} = 70 \text{ N/mm}^2$; $\mu = 0.3$

1. Design for shaft

Let d = Diameter of shaft.

We know that the torque transmitted by the shaft,

$$T = \frac{P \times 60}{2 \pi N} = \frac{30 \times 10^3 \times 60}{2 \pi \times 100} = 2865 \text{ N-m} = 2865 \times 10^3 \text{ N-mm}$$

We also know that the torque transmitted by the shaft (T),

$$2865 \times 10^3 = \frac{\pi}{16} \times \tau \times d^3 = \frac{\pi}{16} \times 40 \times d^3 = 7.86 d^3$$

$$\therefore d^3 = 2865 \times 10^3 / 7.86 = 365 \times 10^3 \text{ or } d = 71.4 \text{ say } 75 \text{ mm Ans.}$$

2. Design for muff

We know that diameter of muff,

$$D = 2d + 13 \text{ mm} = 2 \times 75 + 13 = 163 \text{ say } 165 \text{ mm Ans.}$$

and total length of the muff,

$$L = 3.5 d = 3.5 \times 75 = 262.5 \text{ mm Ans.}$$

3. Design for key

The width and thickness of the key for a shaft diameter of 75 mm (from Table 13.1) are as follows :

Width of key, $w = 22 \text{ mm Ans.}$

Thickness of key, $t = 14 \text{ mm Ans.}$

and length of key = Total length of muff = 262.5 mm **Ans.**

4. Design for bolts

Let d_b = Root or core diameter of bolt.

We know that the torque transmitted (T),

$$2865 \times 10^3 = \frac{\pi^2}{16} \times \mu (d_b)^2 \sigma_t \times n \times d = \frac{\pi^2}{16} \times 0.3 (d_b)^2 70 \times 6 \times 75 = 5830 (d_b)^2$$

$$\therefore (d_b)^2 = 2865 \times 10^3 / 5830 = 492 \text{ or } d_b = 22.2 \text{ mm}$$

From Table 11.1, we find that the standard core diameter of the bolt for coarse series is 23.32 mm and the nominal diameter of the bolt is 27 mm (M 27). **Ans.**

13.16 Flange Coupling

A flange coupling usually applies to a coupling having two separate cast iron flanges. Each flange is mounted on the shaft end and keyed to it. The faces are turned up at right angle to the axis of the shaft. One of the flange has a projected portion and the other flange has a corresponding recess.

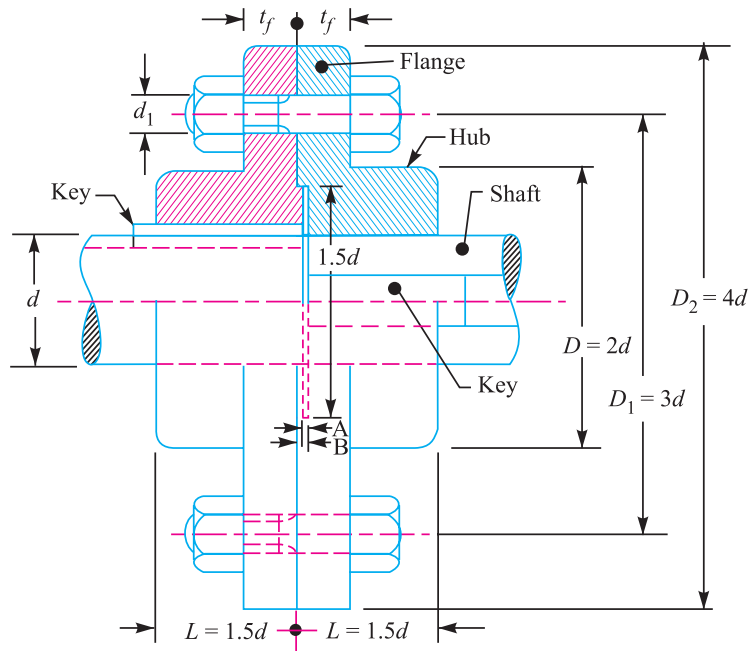


Fig. 13.12. Unprotected type flange coupling.

This helps to bring the shafts into line and to maintain alignment. The two flanges are coupled together by means of bolts and nuts. The flange coupling is adopted to heavy loads and hence it is used on large shafting. The flange couplings are of the following three types :

1. Unprotected type flange coupling. In an unprotected type flange coupling, as shown in Fig. 13.12, each shaft is keyed to the boss of a flange with a counter sunk key and the flanges are coupled together by means of bolts. Generally, three, four or six bolts are used. The keys are staggered at right angle along the circumference of the shafts in order to divide the weakening effect caused by keyways.



Flange Couplings.

The usual proportions for an unprotected type cast iron flange couplings, as shown in Fig. 13.12, are as follows :

If d is the diameter of the shaft or inner diameter of the hub, then

Outside diameter of hub,

$$D = 2d$$

- Length of hub, $L = 1.5 d$
 Pitch circle diameter of bolts,
 $D_1 = 3d$
 Outside diameter of flange,
 $D_2 = D_1 + (D_1 - D) = 2 D_1 - D = 4 d$
 Thickness of flange, $t_f = 0.5 d$
 Number of bolts
 = 3, for d upto 40 mm
 = 4, for d upto 100 mm
 = 6, for d upto 180 mm

2. Protected type flange coupling. In a protected type flange coupling, as shown in Fig. 13.13, the protruding bolts and nuts are protected by flanges on the two halves of the coupling, in order to avoid danger to the workman.

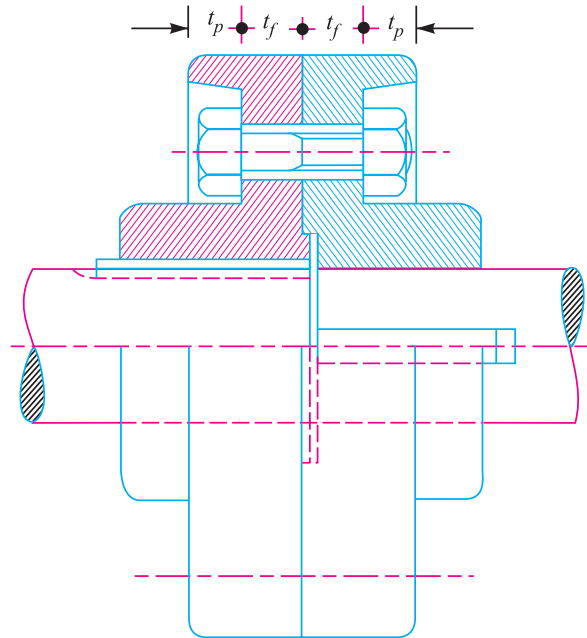


Fig. 13.13. Protective type flange coupling.

The thickness of the protective circumferential flange (t_p) is taken as $0.25 d$. The other proportions of the coupling are same as for unprotected type flange coupling.

3. Marine type flange coupling. In a marine type flange coupling, the flanges are forged integral with the shafts as shown in Fig. 13.14. The flanges are held together by means of tapered headless bolts, numbering from four to twelve depending upon the diameter of shaft.

The number of bolts may be chosen from the following table.

Table 13.2. Number of bolts for marine type flange coupling.
 (According to IS : 3653 - 1966 (Reaffirmed 1990))

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

The other proportions for the marine type flange coupling are taken as follows :

- Thickness of flange $= d / 3$
- Taper of bolt $= 1 \text{ in } 20 \text{ to } 1 \text{ in } 40$
- Pitch circle diameter of bolts, $D_1 = 1.6 d$
- Outside diameter of flange, $D_2 = 2.2 d$

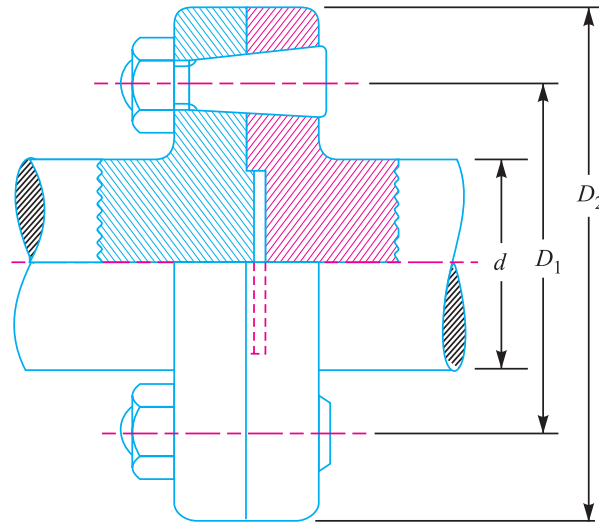


Fig. 13.14. Marine type flange coupling.

13.17 Design of Flange Coupling

Consider a flange coupling as shown in Fig. 13.12 and Fig. 13.13.

- Let $d =$ Diameter of shaft or inner diameter of hub,
- $D =$ Outer diameter of hub,
- $d_1 =$ Nominal or outside diameter of bolt,
- $D_1 =$ Diameter of bolt circle,
- $n =$ Number of bolts,
- $t_f =$ Thickness of flange,
- τ_s, τ_b and $\tau_k =$ Allowable shear stress for shaft, bolt and key material respectively
- $\tau_c =$ Allowable shear stress for the flange material *i.e.* cast iron,
- σ_{cb} and $\sigma_{ck} =$ Allowable crushing stress for bolt and key material respectively.

The flange coupling is designed as discussed below :

1. Design for hub

The hub is designed by considering it as a hollow shaft, transmitting the same torque (T) as that of a solid shaft.

$$\therefore T = \frac{\pi}{16} \times \tau_c \left(\frac{D^4 - d^4}{D} \right)$$

The outer diameter of hub is usually taken as twice the diameter of shaft. Therefore from the above relation, the induced shearing stress in the hub may be checked.

The length of hub (L) is taken as $1.5 d$.

2. Design for key

The key is designed with usual proportions and then checked for shearing and crushing stresses.

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The material of key is usually the same as that of shaft. The length of key is taken equal to the length of hub.

3. Design for flange

The flange at the junction of the hub is under shear while transmitting the torque. Therefore, the torque transmitted,

$$T = \text{Circumference of hub} \times \text{Thickness of flange} \times \text{Shear stress of flange} \times \text{Radius of hub}$$

$$= \pi D \times t_f \times \tau_c \times \frac{D}{2} = \frac{\pi D^2}{2} \times \tau_c \times t_f$$

The thickness of flange is usually taken as half the diameter of shaft. Therefore from the above relation, the induced shearing stress in the flange may be checked.

4. Design for bolts

The bolts are subjected to shear stress due to the torque transmitted. The number of bolts (n) depends upon the diameter of shaft and the pitch circle diameter of bolts (D_1) is taken as $3d$. We know that

$$\text{Load on each bolt} = \frac{\pi}{4} (d_1)^2 \tau_b$$

∴ Total load on all the bolts

$$= \frac{\pi}{4} (d_1)^2 \tau_b \times n$$

and torque transmitted,
$$T = \frac{\pi}{4} (d_1)^2 \tau_b \times n \times \frac{D_1}{2}$$

From this equation, the diameter of bolt (d_1) may be obtained. Now the diameter of bolt may be checked in crushing.

We know that area resisting crushing of all the bolts

$$= n \times d_1 \times t_f$$

and crushing strength of all the bolts

$$= (n \times d_1 \times t_f) \sigma_{cb}$$

∴ Torque,
$$T = (n \times d_1 \times t_f \times \sigma_{cb}) \frac{D_1}{2}$$

From this equation, the induced crushing stress in the bolts may be checked.

Example 13.6. Design a cast iron protective type flange coupling to transmit 15 kW at 900 r.p.m. from an electric motor to a compressor. The service factor may be assumed as 1.35. The following permissible stresses may be used :

Shear stress for shaft, bolt and key material = 40 MPa

Crushing stress for bolt and key = 80 MPa

Shear stress for cast iron = 8 MPa

Draw a neat sketch of the coupling.

Solution. Given : $P = 15 \text{ kW} = 15 \times 10^3 \text{ W}$; $N = 900 \text{ r.p.m.}$; Service factor = 1.35 ; $\tau_s = \tau_b = \tau_k = 40 \text{ MPa} = 40 \text{ N/mm}^2$; $\sigma_{cb} = \sigma_{ck} = 80 \text{ MPa} = 80 \text{ N/mm}^2$; $\tau_c = 8 \text{ MPa} = 8 \text{ N/mm}^2$

The protective type flange coupling is designed as discussed below :

1. Design for hub

First of all, let us find the diameter of the shaft (d). We know that the torque transmitted by the shaft,

$$T = \frac{P \times 60}{2 \pi N} = \frac{15 \times 10^3 \times 60}{2 \pi \times 900} = 159.13 \text{ N-m}$$