UNIT II
SHAFTS AND COUPLINGS
CHAPTER 4

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 4.1 Flange Coupling.

[Source: "A Textbook of Machine Design by R.S. Khurmi J.K. Gupta, Page: 485]

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. 4.2, 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.

The usual proportions for an unprotected type cast iron flange couplings, as shown in Fig. 4.2, are as follows:

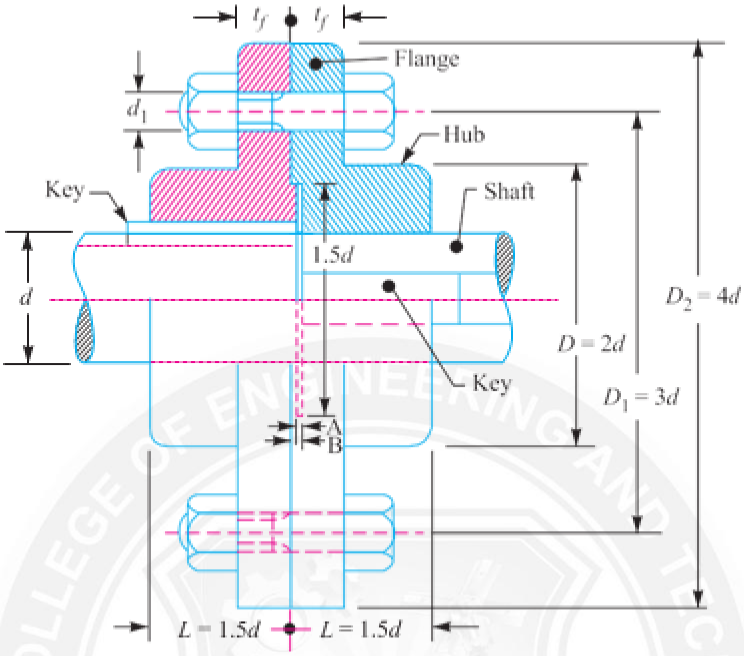

Fig. 4.2. Unprotected type flange coupling.

[Source: "A Textbook of Machine Design by R.S. Khurmi J.K. Gupta, Page: 485]

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

Outside diameter of hub, $D = 2\ d$

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. 4.3, the protruding bolts and nuts are protected by flanges on the two halves of the coupling, in order to avoid danger to the workman.

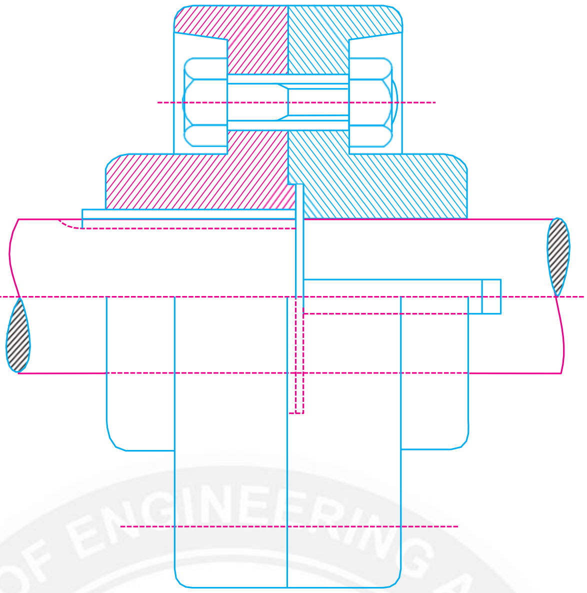

Fig 4.3 Protective type flange coupling.

[Source: "A Textbook of Machine Design by R.S. Khurmi J.K. Gupta, Page: 486]

The thickness of the protective circumferential flange (tp) 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. 4.4. 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 choosen from the following table.

Table 4.1. 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

[Source: "A Textbook of Machine Design by R.S. Khurmi J.K. Gupta, Page: 486]

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

Thickness of flange = d / 3

Taper of bolt = 1 in 20 to 1 in 40

Pitch circle diameter of bolts, D_1 = 1.6 d

Outside diameter of flange, $D_2 = 2.2\ d$

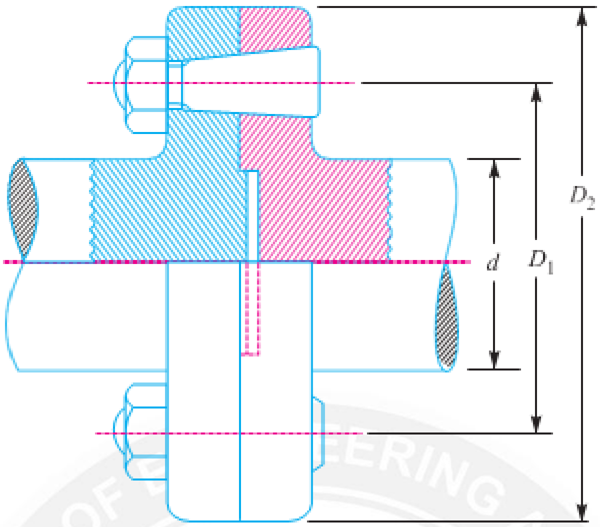

Fig 4.4 Marine type flange coupling.

[Source: "A Textbook of Machine Design by R.S. Khurmi J.K. Gupta, Page: 487]

Design of Flange Coupling

Consider a flange coupling as shown in Fig. 4.2 and Fig. 4.3.

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 τ_k = Allowable shear stress for shaft, bolt and key material respectively

τ_c = Allowable shear stress for the flange material i.e. cast iron,

σ_{cb}, and σ_{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.

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

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. 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 = Circumference of hub × Thickness of flange × Shear stress of flange × Radius of hub

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

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

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 (D1) is taken as 3 d.

We know that

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

$\therefore$ 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 (d1) 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

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

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

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

Problem 4.1

Design a rigid flange coupling to transmit a torque of 250 N-m between two coaxial shafts. The shaft is made of alloy steel, flanges out of cast iron and bolts out of steel. Four bolts are used to couple the flanges. The shafts are keyed to the flange hub. The permissible stresses are

Given Below:

Shear stress on shaft =100 MPa

Bearing or crushing stress on shaft =250 MPa

Shear stress on keys =100 MPa

Bearing stress on keys =250 MPa

Shearing stress on cast iron =200 MPa

Shear stress on bolts =100 MPa

After designing the various elements, make a neat sketch of the assembly indicating the important dimensions. The stresses developed in the various members may be checked if thumb rules are used for fixing the dimensions.

Given Data:

$T = 250$ N-m $= 250 \times 10^3$ N-mm

$n = 4$

$\tau_s = 100$ MPa $= 100$ N/mm^2

$\sigma_{cs} = 250$ MPa $= 250$ N/mm^2

$\tau_k = 100$ MPa $= 100$ N/mm^2

$\sigma_{ck} = 250$ MPa $= 250$ N/mm^2

$\tau_c = 200$ MPa $= 200$ N/mm^2

$\tau_b = 100$ MPa $= 100$ N/mm^2

The cast iron flange coupling of the protective type 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),

$$250 \times 10^3 = \frac{\pi}{16} \times \tau_s \times d^3$$

$$d^3 = 250 \times 10^3 / 19.64 = 12729 \text{ or}$$

$$d = 23.35 \text{ say}$$

$$d = 25 \text{ mm.}$$

We know that the outer diameter of the hub,

$$D = 2\,d$$

$$D = 2 \times 25$$

$$D = 50 \text{ mm}$$

and length of hub,

$$L = 1.5\,d$$

$$L = 1.5 \times 25$$

$$L = 37.5 \text{ mm}$$

Let us now check the induced shear stress in the hub by considering it as a hollow shaft.

We know that the torque transmitted (T),

$$250 \times 10^3 = \frac{\pi}{16} \times \tau_c \left(\frac{D^4 - d^4}{D}\right)$$

$$250 \times 10^3 = \frac{\pi}{16} \times \tau_c \left(\frac{50^4 - 25^4}{50}\right)$$

$$250 \times 10^3 = 23013\ \tau c$$

$$\therefore \tau_c = 250 \times 10^3/23013$$

$$\tau_c = 10.86\ \text{N/mm}^2$$

$$\therefore \tau_c = 10.86\ \text{MPa}$$

` Since the induced shear stress for the hub material (i.e. cast iron) is less than 200 MPa, therefore the design for hub is safe.

2. Design for key

From Table 13.1, we find that the proportions of key for a 25 mm diameter shaft are:

Width of key, w = 10 mm Ans.

and thickness of key, t = 8 mm Ans.

The length of key (l) is taken equal to the length of hub,

l = L = 37.5 mm.

Let us now check the induced shear and crushing stresses in the key. Considering the key in shearing. We know that the torque transmitted (T),

$$250 \times 10^3 = l \times w \times \tau_k \times \frac{d}{2}$$

$$250 \times 10^3 = 37.5 \times 10 \times \tau_k \times \frac{25}{2}$$

$$250 \times 10^3 = 4688\ \tau_k$$

$$\tau_k = 250 \times 10^3 / 4688$$

$$\tau_k = 53.3\ \text{N/mm}^2$$

$$\tau_k = 53.3\ \text{MPa}$$

Considering the key in crushing. We know that the torque transmitted (T),

$$250 \times 10^3 = l \times \frac{t}{2} \times \sigma_{ck} \times \frac{d}{2}$$

$$250 \times 10^3 = 37.5 \times \frac{8}{2} \times \sigma_{ck} \times \frac{25}{2}$$

$$250 \times 10^3 = 1875\ \sigma_{ck}$$

$$\sigma_{ck} = 250 \times 10^3 / 1875$$

$$\sigma_{ck} = 133.3\ N/mm^2$$

$$\sigma_{ck} = 133.3\ MPa$$

Since the induced shear and crushing stresses in the key are less than the given stresses, therefore, the design of key is safe.

3. Design for flange

The thickness of the flange (t_f) is taken as 0.5 d.

$$\therefore t_f = 0.5\ d$$

$$\therefore t_f = 0.5 \times 25$$

$$\therefore t_f = 12.5\ mm.$$

Let us now check the induced shear stress in the flange by considering the flange at the junction of the hub in shear. We know that the torque transmitted (T),

$$250 \times 10^3 = \frac{\pi D^2}{2} \times t_f \times \tau_c$$

$$250 \times 10^3 = \frac{\pi 50^2}{2} \times 12.5 \times \tau_c$$

$$250 \times 10^3 = 49094\ \tau_c$$

$$\tau_c = 250 \times 10^3 / 49094$$

$$\tau_c = 5.1\ N/mm^2$$

$$\tau_c = 5.1\ MPa$$

Since the induced shear stress in the flange of cast iron is less than 200 MPa, therefore design of flange is safe.

4. Design for bolts

Let d_1 = Nominal diameter of bolts.

We know that the pitch circle diameter of bolts,

$\therefore D_1 = 3\ d = 3 \times 25$

$\therefore D_1 = 75$ mm.

The bolts are subjected to shear stress due to the torque transmitted. We know that torque transmitted (T),

$250 \times 10^3 = \frac{\pi}{4}(d_1)^2 \tau_b \times n \times \frac{D_1}{2}$

$250 \times 10^3 = \frac{\pi}{4}(d_1)^2 \times 100 \times 4 \times \frac{75}{2}$

$250 \times 10^3 = 11780(d_1)^2$

$(d1)^2 = 250 \times 10^3 / 11\ 780$

$(d_1)^2 = 21.22$ or

$\therefore d_1 = 4.6$ mm

Assuming coarse threads, the nearest standard size of the bolt is M 6. Ans. Other proportions of the flange are taken as follows:

Outer diameter of the flange,

$D_2 = 4\ d = 4 \times 25$

$D_2 = 100$ mm.

Thickness of the protective circumferential flange,

$t_p = 0.25\ d$

$t_p = 0.25 \times 25$

$t_p = 6.25$ mm