UNIT II

SHAFTS AND COUPLINGS

CHAPTER 3

Shaft Coupling

Shafts are usually available up to 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. Shaft couplings are used in machinery for several purposes, the most common of which are the following:

1. To provide for the connection of shafts of units that are manufactured separately such as a motor and generator and to provide for disconnection for repairs or alternations.
2. To provide for misalignment of the shafts or to introduce mechanical flexibility.
3. To reduce the transmission of shock loads from one shaft to another.
4. To introduce protection against overloads.
5. It should have no projecting parts.

Requirements of a Good Shaft Coupling

A good shaft coupling should have the following requirements:

1. It should be easy to connect or disconnect.
2. It should transmit the full power from one shaft to the other shaft without losses.
3. It should hold the shafts in perfect alignment.
4. It should reduce the transmission of shock loads from one shaft to another shaft.
5. It should have no projecting parts.

Types of Shafts Couplings

Shaft couplings are divided into two main groups as follows:

1. Rigid coupling. It is used to connect two shafts which are perfectly aligned. Following types of rigid coupling are
important from the subject point of view:

(a) Sleeve or muff coupling.

(b) Clamp or split-muff or compression coupling, and

(c) Flange coupling.

2. Flexible coupling. It is used to connect two shafts having both lateral and angular misalignments. Following types of flexible coupling are important from the subject point of view:

(a) Bushed pin type coupling,

(b) Universal coupling, and

(c) Oldham coupling.

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, as shown in Fig. 3.1 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. The usual proportions of a cast iron sleeve coupling are as follows:

Outer diameter of the sleeve, D = 2d + 13 mm

and length of the sleeve, L = 3.5 d

where d is the diameter of the shaft.

In designing a sleeve or muff-coupling, the following procedure may be adopted.

1. Design for sleeve

The sleeve is designed by considering it as a hollow shaft.

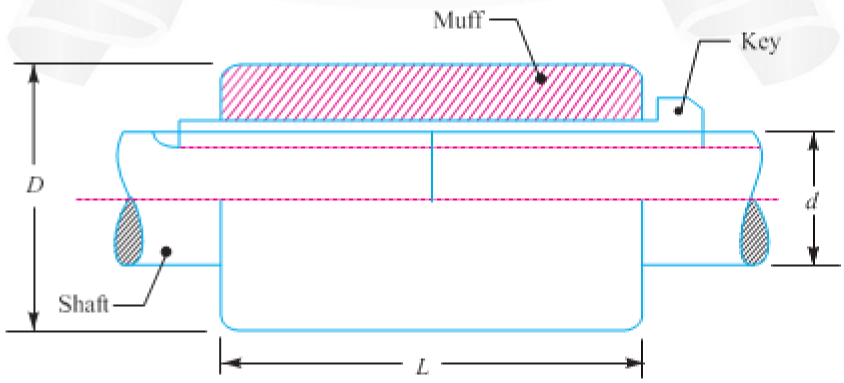

Fig 3.1 Sleeve or muff coupling.

[Source: "A Textbook of Machine Design by R.S. Khurmi J.K. Gupta, Page: 480]

Let T = Torque to be transmitted by the coupling, and

τ_c = Permissible shear stress for the material of the sleeve which is cast iron. The safe value of shear stress for cast iron may be taken as 14 MPa.

We know that torque transmitted by a hollow section,

$$T = \frac{\pi}{16} \times \tau_c \left(\frac{D^2 - d^2}{D}\right)$$

$$T = \frac{\pi}{16} \times \tau_c \times D^3 (1 - k^4) \qquad \ldots (k = d/D)$$

From this expression, the induced shear stress in the sleeve may be checked.

2. Design for key

The key for the coupling may be designed. The width and thickness of the coupling key is obtained from the proportions. The length of the coupling key is at least equal to the length of the sleeve (i.e. 3.5 d). The coupling key is usually made into two parts so that the length of the key in each shaft,

$$l = \frac{L}{2} = \frac{3.5d}{2}$$

After fixing the length of key in each shaft, the induced shearing and crushing stresses may be checked. We know that torque transmitted,

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

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

The depth of the keyway in each of the shafts to be connected should be exactly the same and the diameters should also be same. If these conditions are not satisfied, then the key will be bedded on one shaft while in the other it will be loose. In order to prevent this, the key is made in two parts which may be driven from the same end for each shaft or they may be driven from opposite ends.

Problem 3.1

Design and make a neat dimensioned sketch of a muff coupling which is used to connect two steel shafts transmitting 40 kW at 350 r.p.m. The material for the shafts and key is plain carbon steel for which allowable shear and crushing stresses may be taken as 40

MPa and 80 MPa respectively. The material for the muff is cast iron for which the allowable shear stress may be assumed as 15 MPa.

Given Data:

$P = 40$ kW $= 40 \times 10^3$ W;

$N = 350$ r.p.m.

$\tau_s = 40$ MPa $= 40$ N/mm^2

$\sigma_{cs} = 80$ MPa $=80$ N/mm^2

$\tau_c = 15$ MPa $= 15$ N/mm^2

1.Design for shaft

Let d = Diameter of the shaft.

We know that the torque transmitted by the shaft, key and muff,

$$T = \frac{P \times 60}{2\pi N} = \frac{40 \times 10^3 \times 60}{2\pi \times 350}$$

$T = 1100$ N-m

$T = 1100 \times 10^3$ N-mm

We also know that the torque transmitted (T),

$$1100 \times 10^3 = \frac{\pi}{16} \times \tau_s \times d^3$$

$$1100 \times 10^3 = \frac{\pi}{16} \times 40 \times d^3$$

$$1100 \times 10^3 = 7.86\, d^3$$

$$d^3 = 1100 \times 10^3 / 7.86$$

$$d^3 = 140 \times 10^3$$

$d = 52$ mm say

$\therefore d = 55$ mm.

2. Design for sleeve

We know that outer diameter of the muff,

$D = 2d + 13$ mm

$D = 2 \times 55 + 13$

$D = 123$ say 125 mm.

and length of the muff,

$L = 3.5\, d$

$L = 3.5 \times 55$

$L = 192.5$ say 195 mm.

Let us now check the induced shear stress in the muff. Let τ_c be the induced shear stress in the muff which is made of cast iron. Since the muff is considered to be a hollow shaft, therefore the torque transmitted (T),

$$1100 \times 10^3 = \frac{\pi}{16} \times \tau_c \left(\frac{D^2 - d^2}{D}\right)$$

$$1100 \times 10^3 = \frac{\pi}{16} \times \tau_c \left(\frac{125^2 - 55^2}{125}\right)$$

$$1100 \times 10^3 = \tau_c \times 370 \times 10^3$$

$$\tau_c = 1100 \times 10^3 / 370 \times 10^3$$

$$\tau_c = 2.97 \text{ N/mm}^2$$

Since the induced shear stress in the muff (cast iron) is less than the permissible shear stress of 15 N/mm^2, therefore the design of muff is safe.

3. Design for key

From Table,

we find that for a shaft of 55 mm diameter,

Width of key, w = 18 mm Ans.

Since the crushing stress for the key material is twice the shearing stress, therefore a square key may be used.

∴ Thickness of key, t = w = 18 mm.

We know that length of key in each shaft,

$$l = L / 2$$

$$l = 195 / 2$$

$$l = 97.5 \text{ mm.}$$

Let us now check the induced shear and crushing stresses in the key. First of all, let us consider shearing of the key. We know that torque transmitted (T),

$$1100 \times 10^3 = l \times w \times \tau_s \times \frac{d}{2}$$

$$1100 \times 10^3 = 97.5 \times 18 \times \tau_s \times \frac{55}{2}$$

$$1100 \times 10^3 = 48.2 \times 10^3 \tau_s$$

$$\tau_s = 1100 \times 10^3 / 48.2 \times 10^3$$

$$\therefore \tau_s = 22.8 \text{ N/mm}^2$$

Now considering crushing of the key. We know that torque transmitted (T),

$$1100 \times 10^3 = l \times \frac{t}{2} \times \sigma_c \times \frac{d}{2}$$

$$1100 \times 10^3 = 97.5 \times \frac{18}{2} \times \sigma_c \times \frac{55}{2}$$

$$1100 \times 10^3 = 24.1 \times 10^3\ \sigma_c$$

$$\sigma_c = 1100 \times 10^3 / 24.1 \times 10^3$$

$$\sigma_c = 45.6\ \text{N/mm}^2$$

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

Clamp or Compression Coupling

It is also known as split muff coupling. In this case, the muff or sleeve is made into two halves and are bolted together as shown in Fig. 3.2. The halves of the muff are made of cast iron. The shaft ends are made to a butt each other and a single key is fitted directly in the keyways of both the shafts. One-half of the muff is fixed from below and the other half is placed from 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 or six. The nuts are recessed into the bodies of the muff castings. This coupling may be used for heavy duty and moderate speeds. The advantage of this coupling is that the position of the shafts need not be changed for assembling or disassembling of the coupling. The usual proportions of the muff for the clamp or compression coupling are

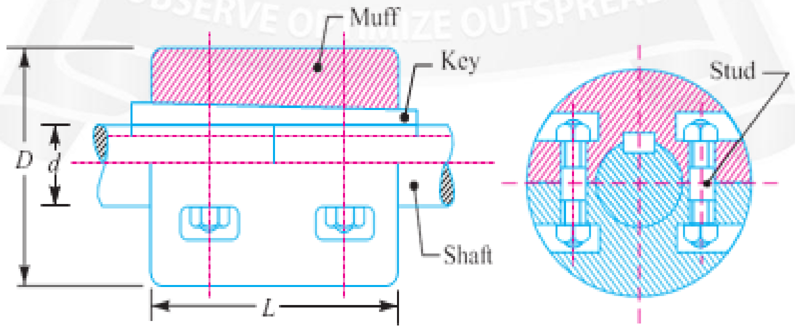

Fig 3.2 Clamp or compression coupling.

[Source: "A Textbook of Machine Design by R.S. Khurmi J.K. Gupta, Page: 483]

Diameter of the muff or sleeve, D = 2d + 13 mm

Length of the muff or sleeve, L = 3.5 d

where d = Diameter of the shaft.

In the clamp or compression coupling, the power is transmitted from one shaft to the other by means of key and the friction between the muff and shaft. In designing this type of coupling, the following procedure may be adopted.

1. Design of muff and key

The muff and key are designed in the similar way as discussed in muff coupling.

2. Design of clamping bolts

Let T = Torque transmitted by the shaft,

d = Diameter of shaft,

d_b = Root or effective diameter of bolt,

n = Number of bolts,

σ_t = Permissible tensile stress for bolt material,

μ = Coefficient of friction between the muff and shaft, and

L = Length of muff.

We know that the force exerted by each bolt

$$= \frac{\pi}{4} (d_b)^2 \sigma_t$$

∴ Force exerted by the bolts on each side of the shaft

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

Let p be the pressure on the shaft and the muff surface due to the force, then for uniform pressure distribution over the surface,

$$p = \frac{\text{Force}}{\text{Projected Area}} = \frac{\frac{\pi}{4}(d_b)^2 \sigma_t \times \frac{n}{2}}{\frac{1}{2} \times L \times d}$$

∴ Frictional force between each shaft and muff,

$$F = \mu \times \text{pressure} \times \text{area}$$

$$F = \mu \times p \times \frac{1}{2} \times \pi d \times L$$

$$F = \mu \times \frac{\frac{\pi}{4}(d_b)^2 \sigma_t \times \frac{n}{2}}{\frac{1}{2} \times L \times d} \times \frac{1}{2} \times \pi d \times L$$

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

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

and the torque that can be transmitted by the coupling,

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

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

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

From this relation, the root diameter of the bolt (d_b) may be evaluated. The value of μ may be taken as 0.3.

Problem 3.2

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.

Given Data:

$P = 30 \text{ kW} = 30 \times 10^3 \text{ W}$

$N = 100$ 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,

$$T = \frac{P \times 60}{2\pi N} = \frac{30 \times 10^3 \times 60}{2\pi \times 100}$$

$$T = 2865 \text{ N-m}$$

$$T = 2865 \times 10^3 \text{ N-mm}$$

We also know that the torque transmitted (T),

$$2865 \times 10^3 = \frac{\pi}{16} \times \tau_s \times d^3$$

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

$$2865 \times 10^3 = 7.86\ d^3$$

$$d^3 = 2865 \times 10^3 / 7.86$$

$$d^3 = 365 \times 10^3$$

$$d = 71.4 \text{ mm say}$$

$$\therefore d = 75 \text{ mm.}$$

2. Design for muff

We know that diameter of muff,

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

and total length of the muff,

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

3. Design for key

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

Width of key, w = 22 mm Ans.

Thickness of key, t = 14 mm Ans.

and length of key = Total length of muff = 262.5 mm

4. Design for bolts

Let d_b = Root or core diameter of bolt.

We know that the torque transmitted (T),

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

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

$$2865 \times 10^3 = 5830\ (d_b)^2$$

$(d_b)^2 = 2865 \times 10^3 / 5830$

$(d_b)^2 = 492$

$d_b = 22.2$ mm

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).