Lecture # 23-28

Design of Couplings

Design of Couplings

Introduction

Couplings are used to connect two shafts for torque transmission in varied applications.

such as a motor and a generator

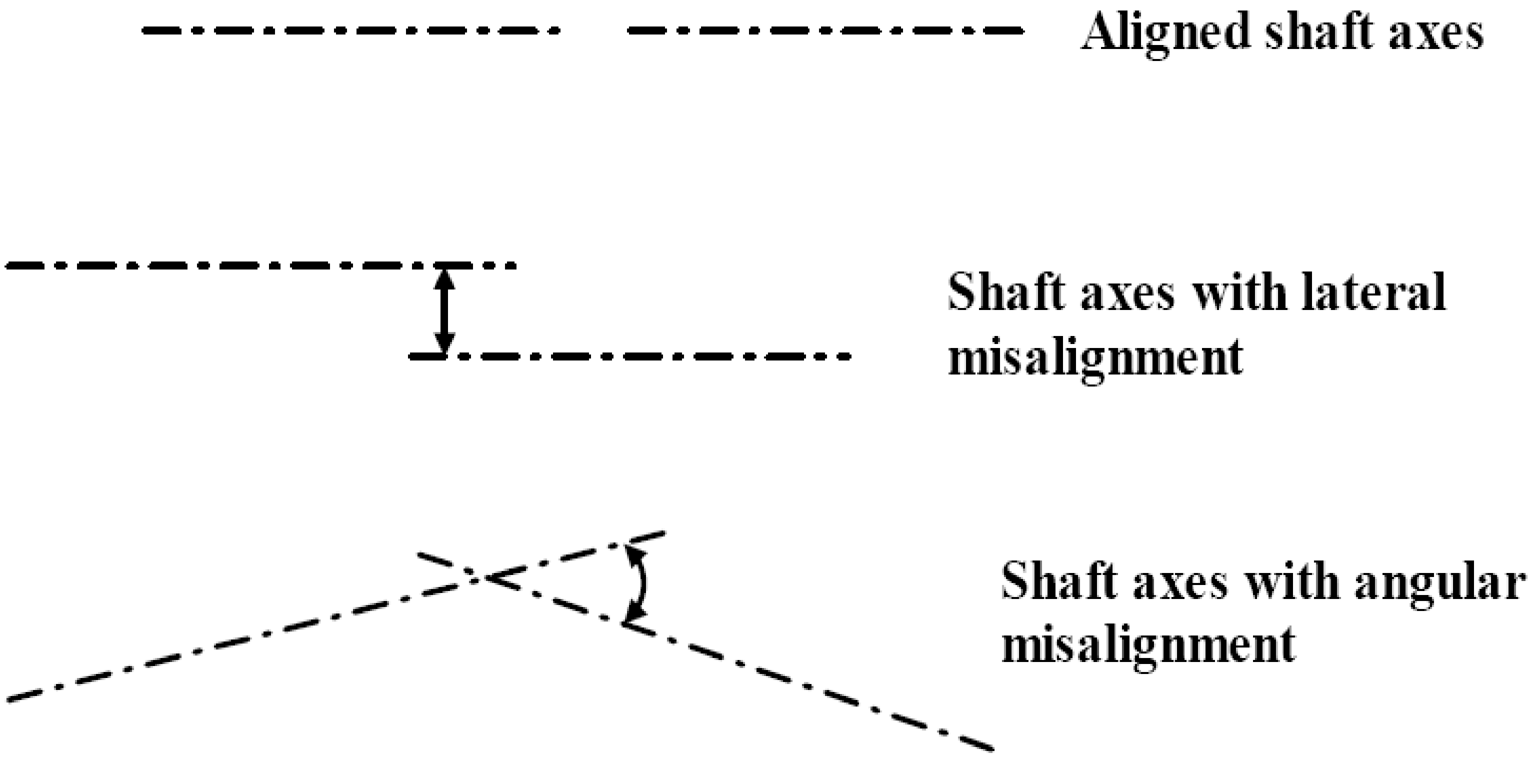
or to form a long line shaft by connecting shafts of standard lengths by couplings.

Coupling may be rigid or flexibile to compensate for any misalignment of shaft axes.

They may also reduce shock loading and vibration.

Design of Couplings

Types of Misalignment in shaft Axes



Design of Couplings

Types of couplings:

Rigid couplings

Rigid couplings are used for shafts having no misalignment

Since these couplings cannot absorb any misalignment, the shafts to be connected by a rigid coupling must have good lateral and angular alignment.

Flexible couplings

flexible couplings can absorb some amount of misalignment in the shafts to be connected.

Design of Couplings

Rigid Couplings - Sleeve or Muff-coupling

It is the simplest type of rigid coupling.

It is made of cast iron.

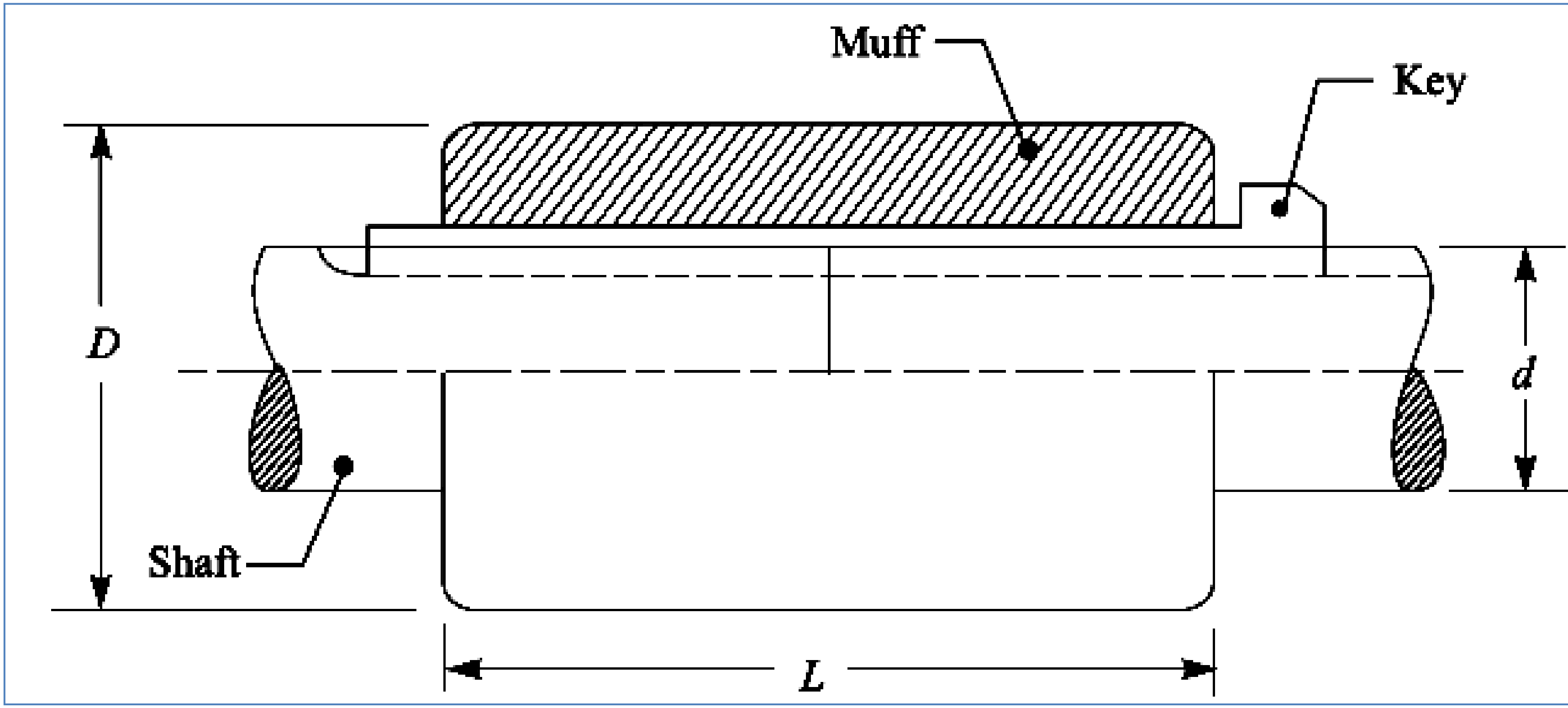
It consists of a hollow cylinder whose inner diameter is the same as that of the shaft.

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.

Design of Couplings



Design of Couplings

1. Design for sleeve

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

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.

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

Design of Couplings

2. Design for key

From the table of standard cross section of key, the cross section of key is selected based on the diameter of shaft.

Then the length of the key is determined from the following relations

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

Considering Shearing Failure

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

Considering Compression Failure

The higher length is adapted, but it should not be less than the hub length.

Design of Couplings

Clamp or Compression Coupling or split muff coupling

The halves of the muff are made of cast iron.

Both the halves are held together by means of mild steel studs or bolts and nuts.

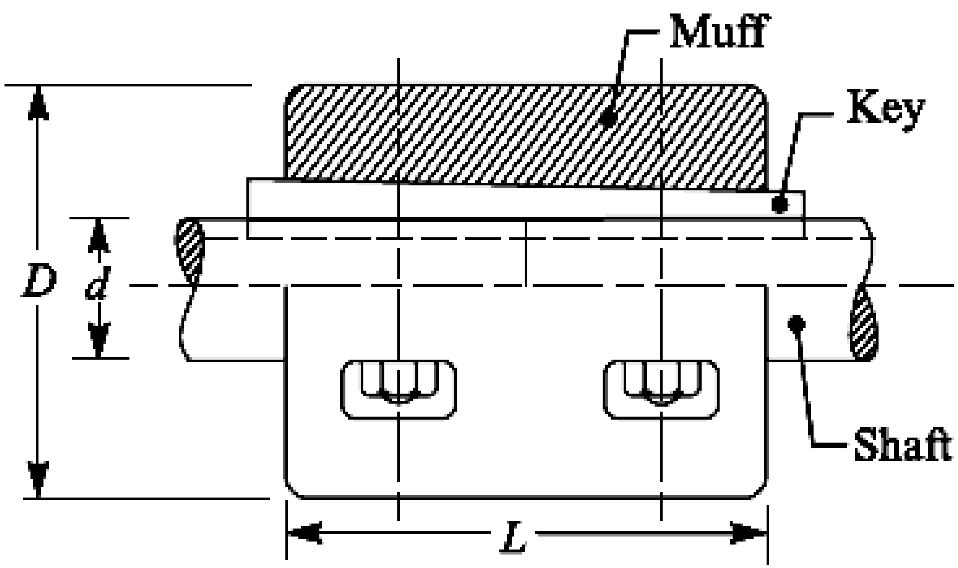
The number of bolts may be two, four or six.

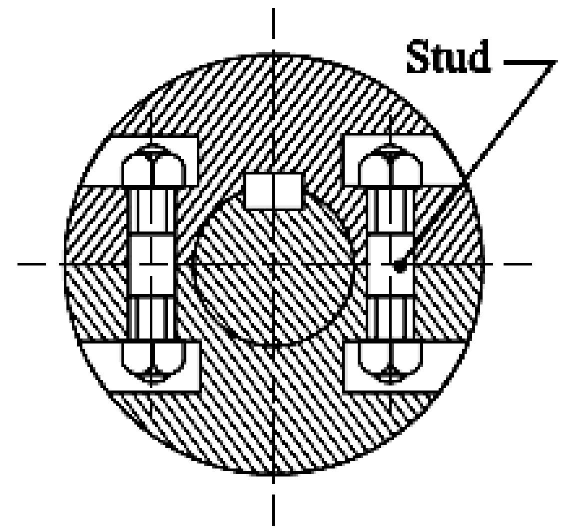
The nuts are recessed into the bodies of the muff castings.

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.

Design of Couplings





Design of Couplings

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.

Design of Couplings

Force exerted by each bolt $F = \frac{\pi}{4}(d_b)^2 \sigma_t$

$\therefore$ Force exerted by the bolts on each side of the shaft

$$F_1 = \frac{\pi}{4}(d_b)^2 \sigma_t \times \frac{n}{2}$$

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

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

Design of Couplings

∴ Frictional force between each shaft and muff,

$$F_f = \mu \times pressure \times \frac{1}{2} \times \pi d \times L$$

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

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

Design of Couplings

and the torque that can be transmitted by the coupling,

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

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

Design of Couplings

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.

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.

Design of Couplings

The flange couplings are of the following three types :

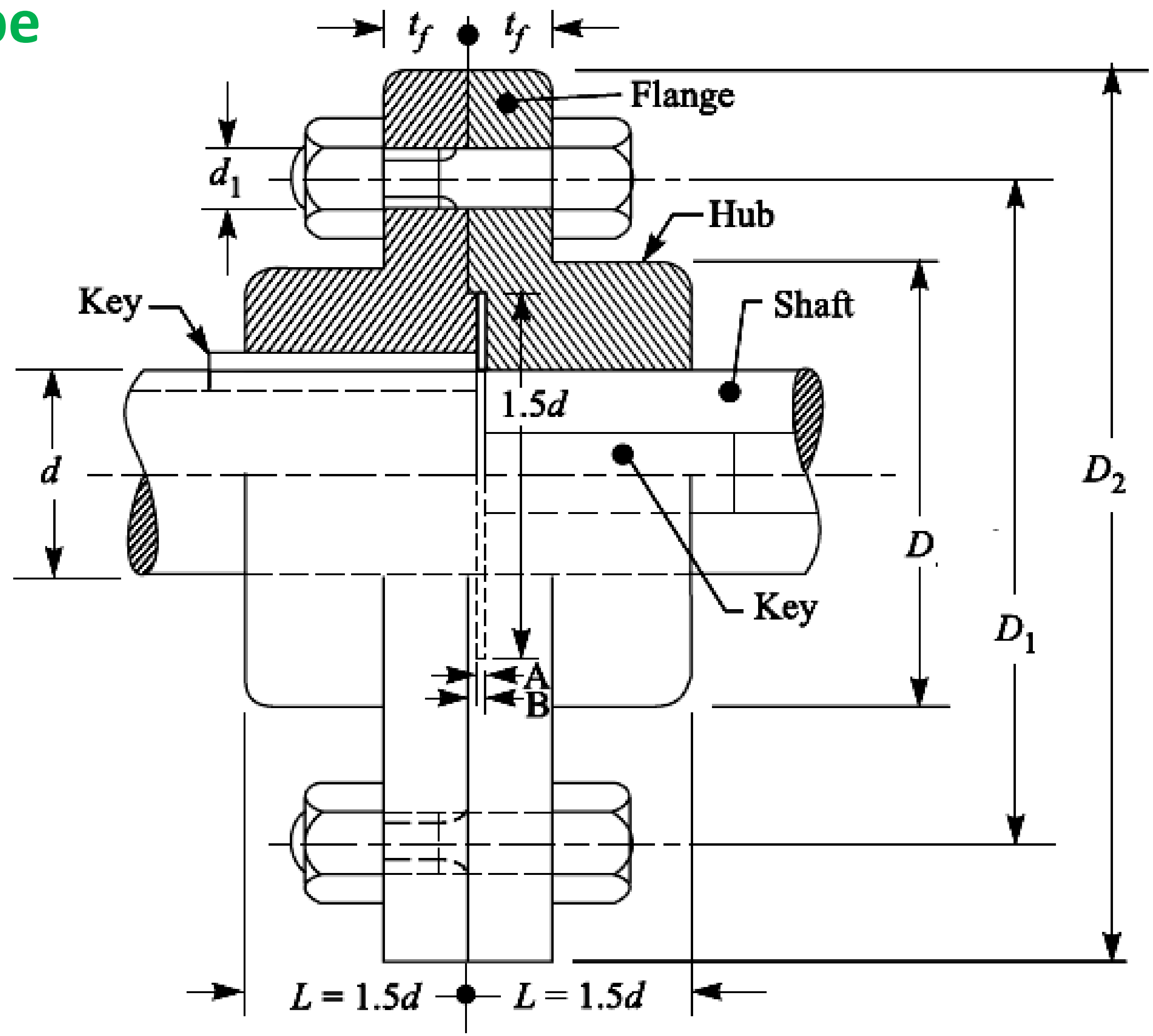
1. Unprotected type flange coupling.

2. Protected type flange coupling.

3. Marine type flange coupling.

Design of Couplings

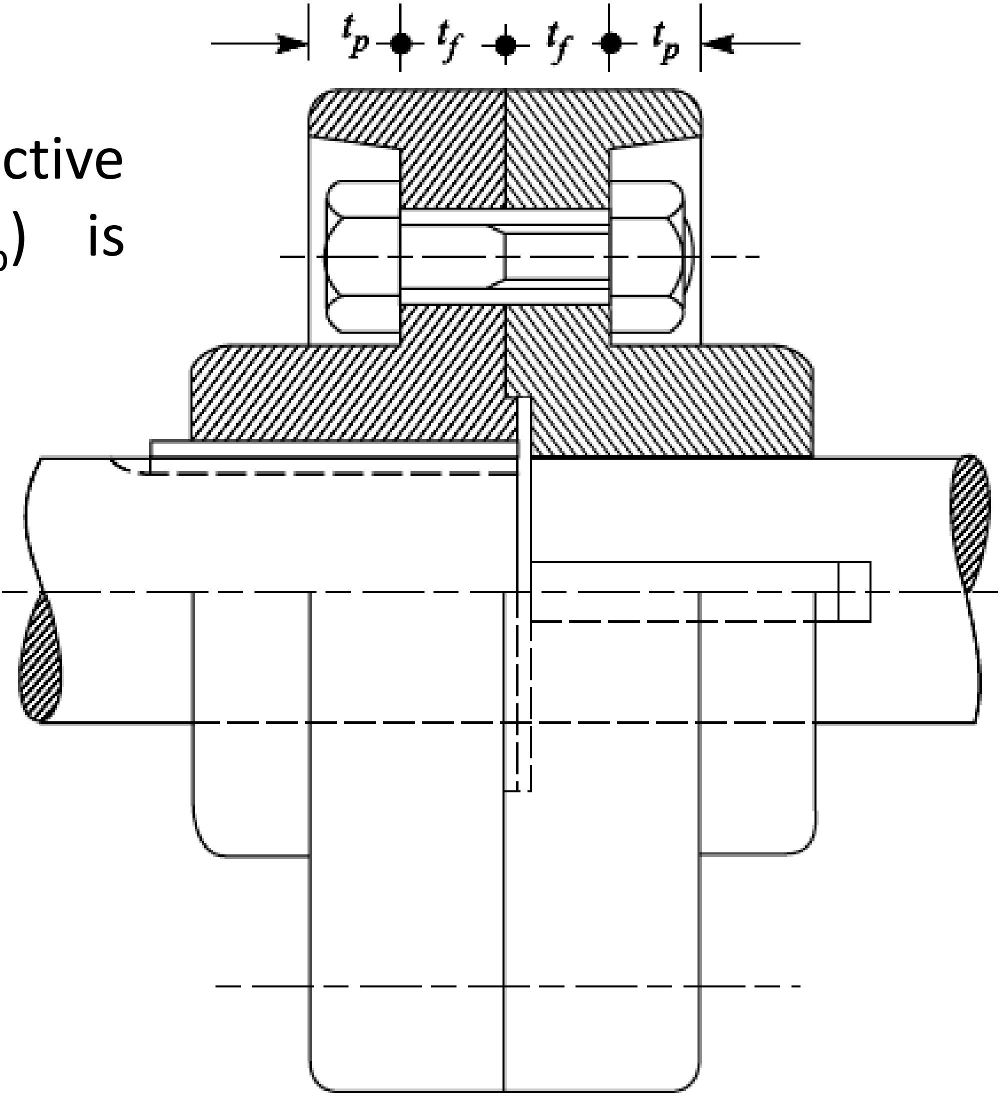
1. Unprotected type flange coupling.



Design of Couplings

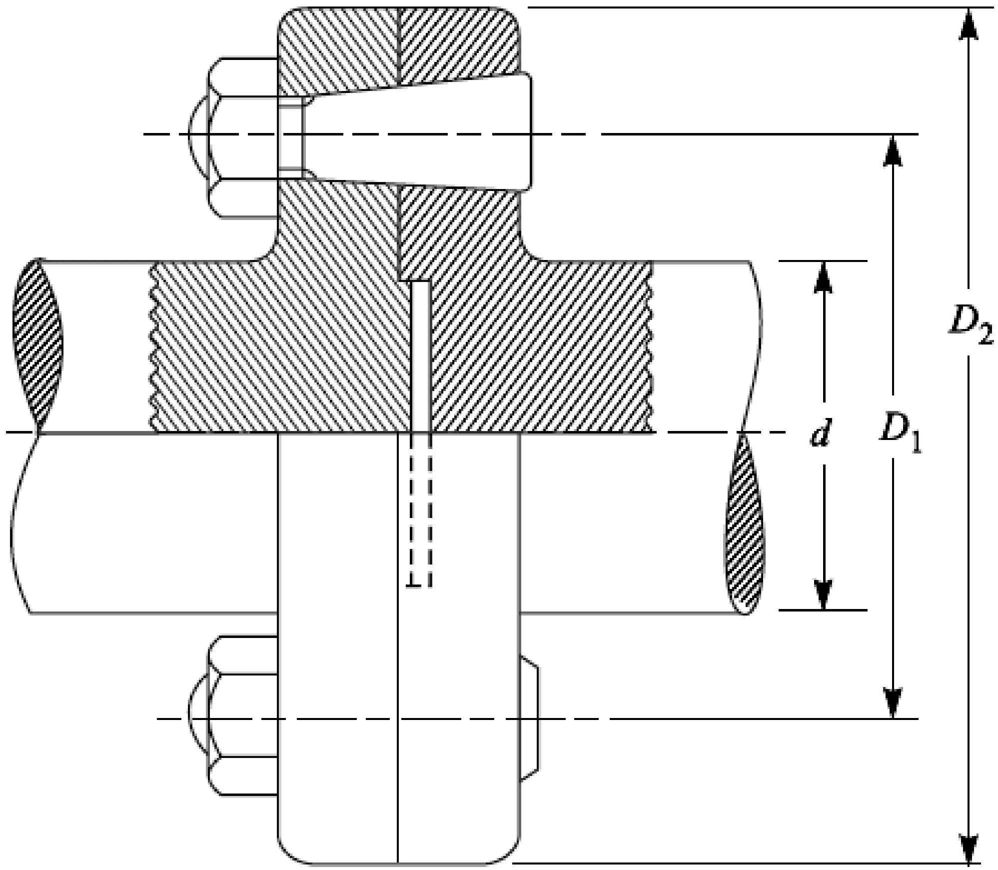
2. Protected type flange

The thickness of the protective circumferential flange (t_p) is taken as 0.25 d.



Design of Couplings

3. 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

Design of Couplings

Design of Flange Coupling

Consider a flange coupling as shown in Figure above.

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.

Design of Couplings

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.

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

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

Design of Couplings

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

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

The thickness of flange is usually taken as half the diameter of shaft.

Design of Couplings

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.

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

[illegible]

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

Design of Couplings

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

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

Design of Couplings

Flexible Coupling

Following are the different types of flexible couplings :

1. Bushed pin flexible coupling,
2. Oldham's coupling, and
3. Universal coupling.

Design of Couplings

Flexible Couplings - Bushed pin flexible coupling

A bushed-pin flexible coupling is a modification of the rigid type of flange coupling.

The coupling bolts are known as pins.

The rubber or leather bushes are used over the pins.

The two halves of the coupling are dissimilar in construction.

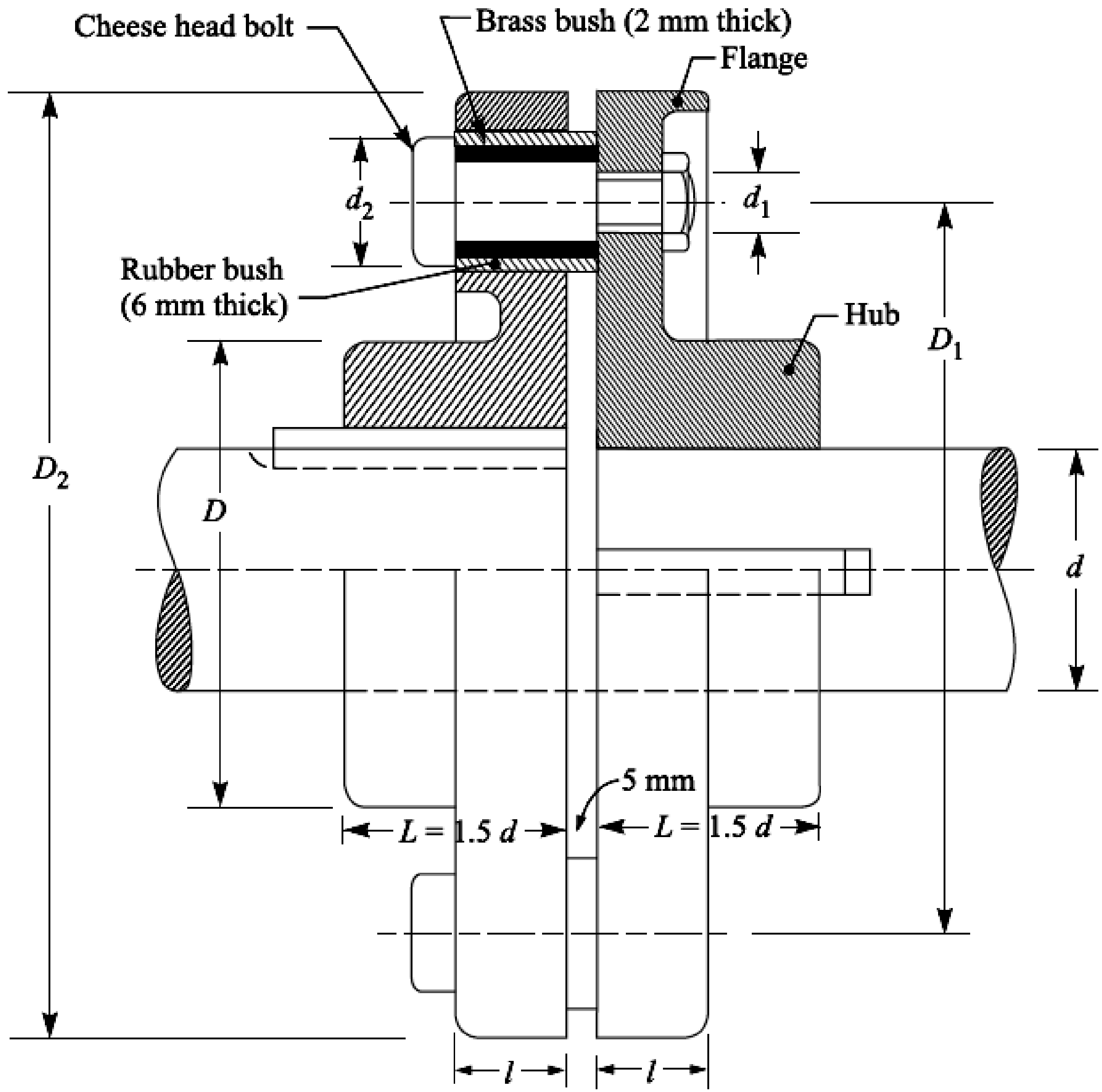
A clearance of 5 mm is left between the face of the two halves of the coupling.

There is no rigid connection between them and

the drive takes place through the medium of the compressible rubber or leather bushes.

Design of Couplings

Bushed pin flexible coupling

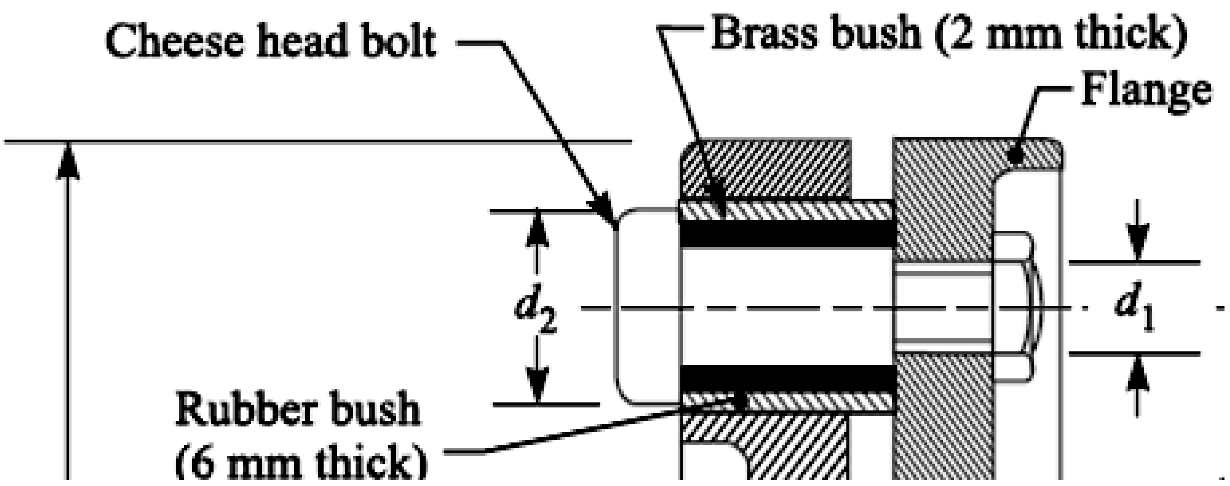


Design of Couplings

In designing the bushed-pin flexible coupling, the proportions of the rigid type flange coupling are modified.

The main modification is to reduce the bearing pressure on the rubber or leather bushes and it should not exceed 0.5 N/mm^2.

In order to keep the low bearing pressure, the pitch circle diameter and the pin size is increased.



Design of Couplings

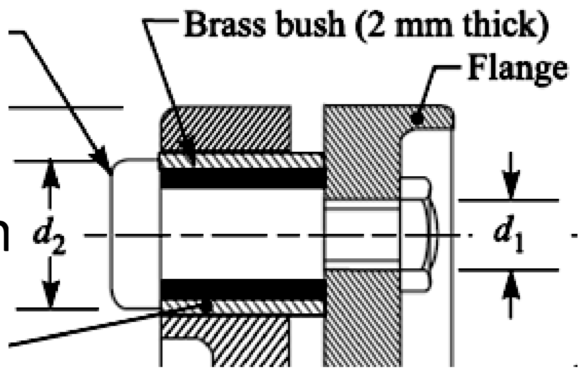
Let l = Length of bush in the flange,

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

$\therefore$ Total bearing load on the bush or pins $= W \times n$

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

d_2 = bolt diameter + 2 x thickness of brass bush +2 x thickness of rubber bush

$$d_2 = d_1 + 2t_{br} + 2t_r$$

Design of Couplings

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.

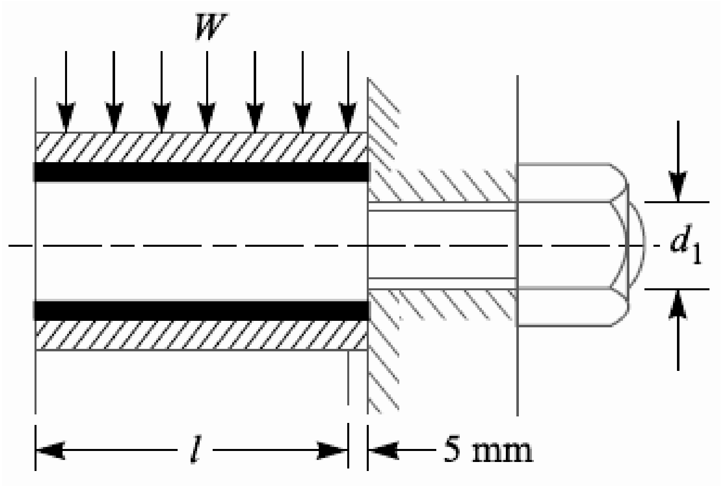
Design of Couplings

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

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

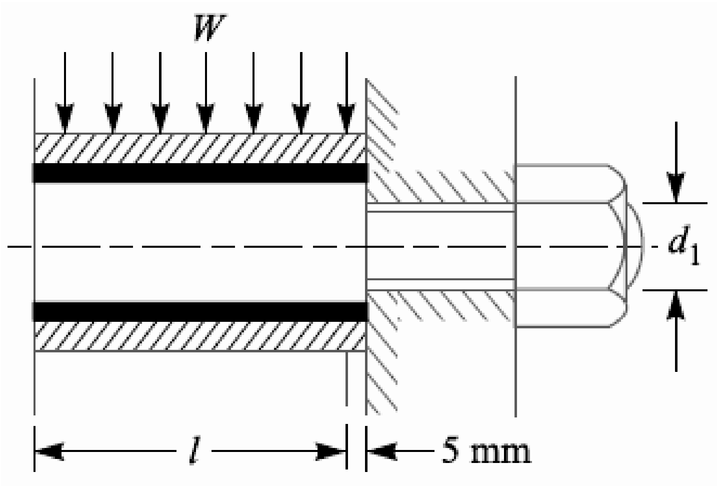
Since the pin and the rubber or leather bush is not rigidly held in the left hand flange,

therefore the tangential load (W) at the enlarged portion will exert a bending action on the pin as shown in Fig.



Design of Couplings

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,

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

Then Bending Stress is given as

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

Design of Couplings

Since the pin is subjected to bending and shear stresses, therefore the design must be checked

either for the maximum principal stress or maximum shear stress by the following relations

$$\text{Maximum Principal Stress}, \sigma_{max} = \frac{1}{2}\left[\sigma + \sqrt{\sigma^2 + 4\tau^2}\right]$$

and the maximum shear Stress on the pin, $\tau_{max} = \frac{1}{2}\sqrt{\sigma^2 + 4\tau^2}$

Design of Couplings

Example 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.

Design of Couplings

Example 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.

Design of Couplings

Example 3 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.

Design of Couplings

Example 4 Design and draw a protective type of cast iron flange coupling for a steel shaft transmitting 15 kW at 200 r.p.m. and having an allowable shear stress of 40 MPa. The working stress in the bolts should not exceed 30 MPa. Assume that the same material is used for shaft and key and that the crushing stress is twice the value of its shear stress. The maximum torque is 25% greater than the full load torque. The shear stress for cast iron is 14 MPa.

Design of Couplings

Example 5 The shaft and the flange of a marine engine are to be designed for flange coupling, in which the flange is forged on the end of the shaft. The following particulars are to be considered in the design :

Power of the engine = 3 MW

Speed of the engine = 100 r.p.m.

Permissible shear stress in bolts and shaft = 60 MPa

Number of bolts used = 8

Pitch circle diameter of bolts = 1.6 × Diameter of shaft

Find : 1. diameter of shaft ; 2. diameter of bolts ; 3. thickness of flange ; and 4. diameter of flange.

Design of Couplings

Example 6

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.

Design of Couplings

Example 7

Design a bushed-pin type of flexible coupling to connect a pump shaft to a motor shaft transmitting 32 kW at 960 r.p.m. 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.

Draw neat sketch of the coupling.

References

ABDULLA SHARIF, Design of Machine Elements, Dhanpat Rai Publications (P) Ltd, New Delhi, 1995.

V. B. Bhandari, Design of Machine Elements, Third Ed., The McGraw-Hills Companies, New Delhi

R. S. KHURMI and J.K.GUPTA, A Text Book of Machine Design, S.Chand and company ltd., New Delhi, 2000.

http://www.nptel.iitm.ac.in