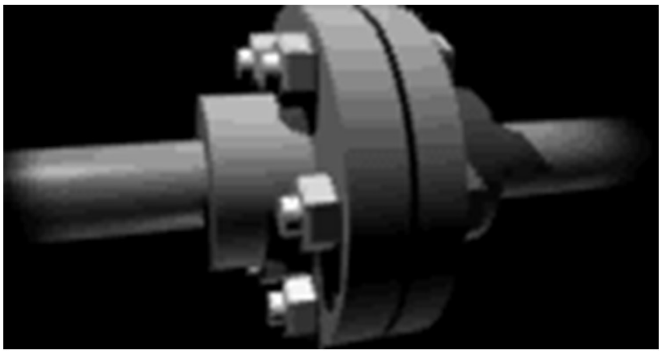
Coupling

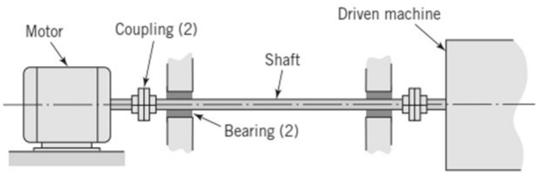


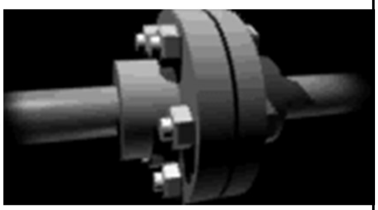
Shaft Coupling

Coupling - is a **mechanical device that joins two rotating shafts together so as to transmit a torque.**

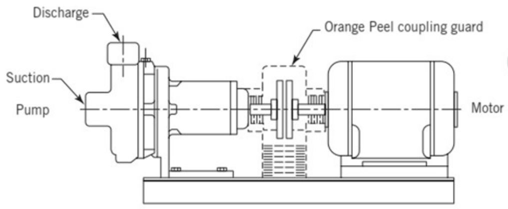
Necessity of Couplings

- To connect shaft of a driving machine to a separately manufactured driven unit as in the case of a turbine-generator set, motor-gearbox, motor-compressor etc..
- To overcome the inconvenience in transporting very long shafts.
- To make provision for easy repairs of the units like motor-gearbox, motor-compressor etc.
- To make provision for mechanical flexibility
- To make provision for lateral or angular misalignment of the shafts
- To decrease the transmission of shock loads

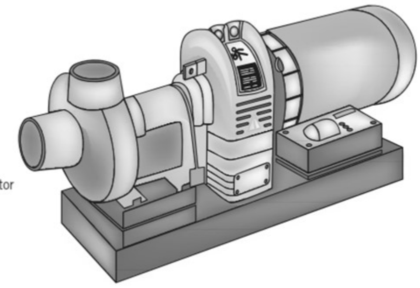




Shaft Coupling



(a) Side view


(b) Pump assembly

Coupling vs. Clutch

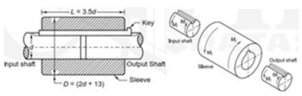
Coupling	Clutch
Semi-permanent connection between driver & driven shaft using bolts & keys	Temporary connection between driver & driven shaft
Disengagement of shafts can be possible only when shafts are at rest by unscrewing bolts or slackening the keys	In clutch, the shafts are engaged & disengaged while in motion

Shaft Coupling

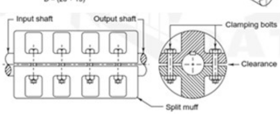
Type of Shaft Coupling

Rigid Coupling

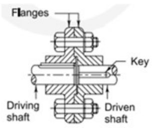
Muff or Sleeve coupling



Split Muff or Clamp coupling

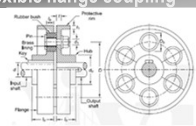


Rigid flange coupling

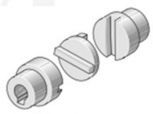


Flexible or Compliant Coupling

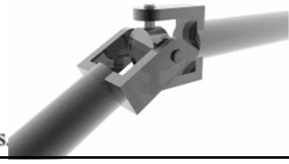
Flexible flange coupling



Oldham coupling


(a) Basic Oldham type

Universal Joint coupling

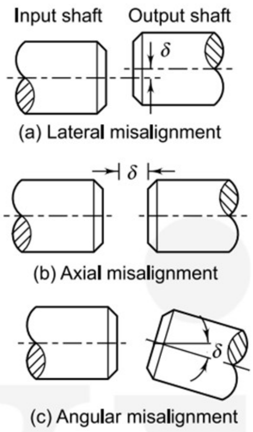


IS 6196–1971: Dimensions of fitted half coupling.
IS 2693–1964: Specifications for cast iron flexible couplings.

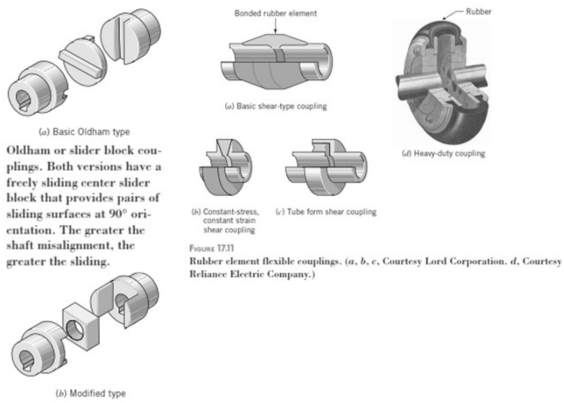
Shaft Coupling

A wide variety of commercial shaft couplings are available, ranging from simple keyed, rigid couplings to elaborate designs that utilize gears, elastomers, or fluids (in fluid coupling) to transmit the torque from one shaft to another in the presence of various types of misalignment.

Various types of misalignment



Flexible or Compliant Coupling



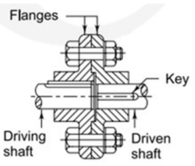
Rigid Coupling vs. Flexible Coupling

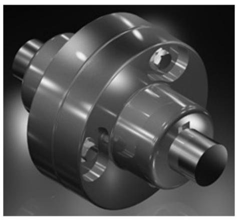
Rigid Coupling	Flexible Coupling
A rigid coupling cannot tolerate misalignment between the axes of the shafts. It can be used only when there is precise alignment between two shafts.	The flexible coupling, due to provision of flexible elements like bush or disk, can tolerate 0.5° of angular misalignment and 5 mm of axial displacement between the shafts.
Rigid coupling can be used only where the motion is free from shocks and vibrations.	The flexible elements provided in the flexible coupling absorb shocks and vibrations.

Rigid Flange Coupling

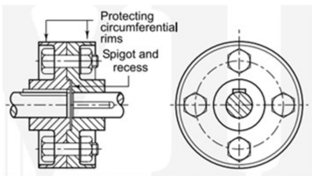
Type of Rigid Flange Coupling

Unprotected type





Protected type



Rigid Flange Coupling

Consisting of

- Two Flanges
- Two Keys
- Four or Six nos. of Bolts & Nuts

Rigid Flange Coupling

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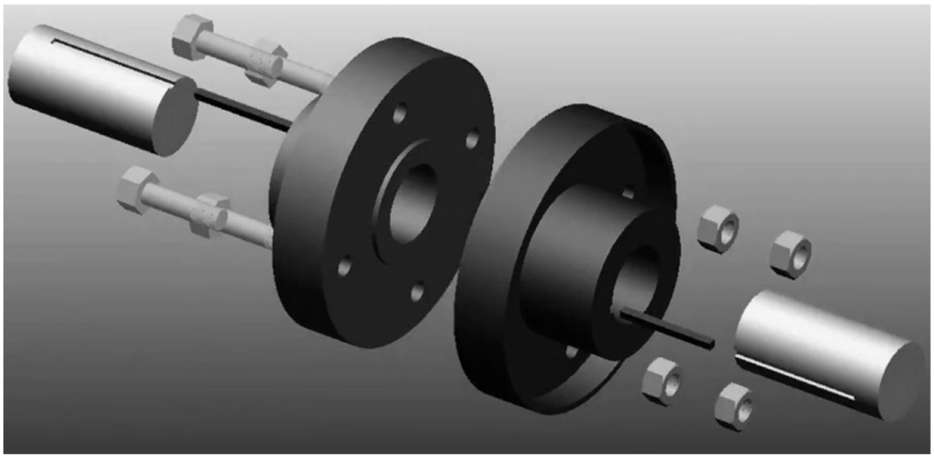
- Four or Six nos. of Bolts & Nuts



Rigid Flange Coupling

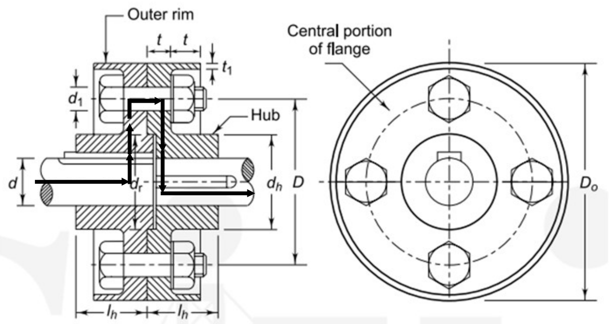
Advantages of Rigid Flange Couplings

- **Rigid flange coupling has high torque transmitting capacity.**
- **It is easy to assemble and dismantle.**
- **It has simple construction. It is easy to design and manufacture.**

Disadvantages of Rigid Flange Couplings

- **Rigid flange coupling cannot tolerate misalignment between the axes of two shafts.**
- **It can be used only where the motion is free from shocks and vibrations.**

Design of Rigid Flange Coupling



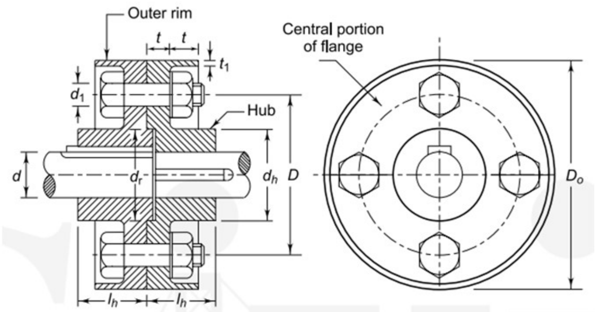
Three distinct regions of flange of protected type rigid flange couplings

- **Hub portion with keyway**
- **Central web portion with multiple holes for bolts**
- **Peripheral outer rim for protection**

Force or Power flow

Driving shaft ⇨ Key ⇨ Flange ⇨ Bolt ⇨ Flange ⇨ Key ⇨ Driven shaft

Design of Rigid Flange Coupling



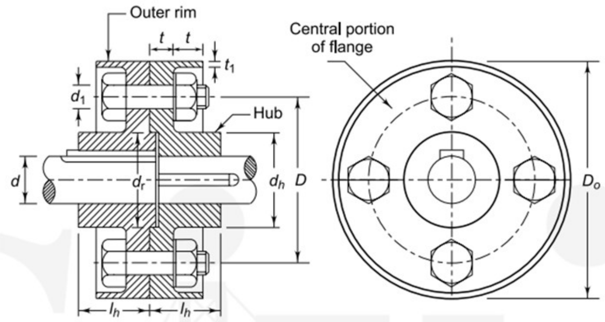
The no. of bolts (N) is decided based on shaft diameter (d)

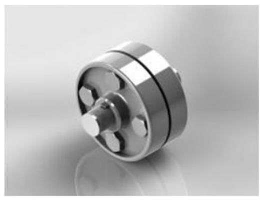
Shaft dia. (mm)	N
d<40	3
40≤d<100	4
100≤d	6

Empirical Relations:
$N \geq 0.02d+3$; (d in mm)

Notations		Empirical Relationship
d	Diameter of the shaft	
d_h	Outside diameter of hub	d_h=1.8d to 2d
d_r	Diameter of spigot & recess	d_r=1.5d
D	Bolt circle Diameter or PCD of bolts or dia. of pitch circle of the bolts	D=2.5d to 3d
t	Thickness of the flange or web thickness	t=0.5d
t_1	Thickness of outer rim	t_1=0.25d
l_h	Length of the hub or effective length of the key	l_h=1.5d to 2d
D_0	Outer diameter of flange	$D_0=\Sigma$

Design of Rigid Flange Coupling





Three distinct regions of flange of protected type rigid flange couplings

- Hub portion with keyway
- Central web portion with multiple holes for bolts
- Peripheral outer rim for protection

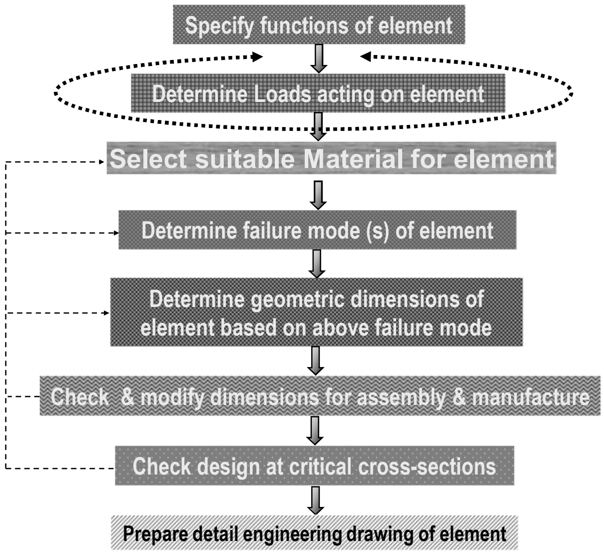
Force or Power flow

Driving shaft ⇨ Key ⇨ Flange ⇨ Bolt ⇨ Flange ⇨ Key ⇨ Driven shaft

Design consideration

- The torque capacity of the key
- The strength of the relatively thin web portion with multiple holes for bolts
- The strength of the bolts

Basic Procedure of Design of Machine Elements



Materials & Manufacturing

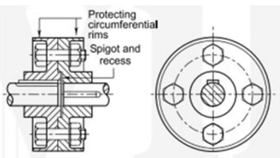
Components	Materials	Manufacturing
Shaft	Plain C steel, Alloy steel	Rolling & Machining
Flange	Grey Cast Iron	**Casting** as shape is complex
Key	Plain C steel, Alloy steel	Machining
Bolts	Plain C steel, Alloy steel	Machining, Metal forming

Design Criteria

- One of the major decisions confronting the designer is the selection of appropriate "Design Criteria" or "Failure-prevention". This is largely influenced by the **Mode of Failure** of the machine elements or structural elements.
- Designer should find the nature of action in the member that may cause it to fail.
- Some quantity such as stress, deflection etc. which characterizes the action that may cause its failure
- The action that initiates failure frequently is referred to as the Mode of Failure

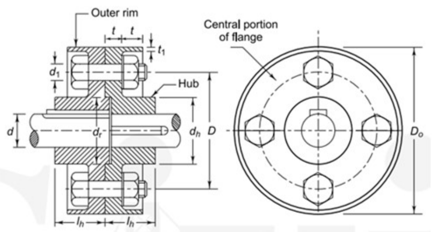
Common Modes of Failures

- Yielding → Shearing, Crushing, Bending
- Fracture
- Excessive elastic deflection
- Buckling
- Wear
- Corrosion etc…



Design Criteria

A flange coupling may fail or rather be unable to transmit the full magnitude of the shaft torque from the following causes



1. **The bolts may fail by** (a) Shearing (b) Crushing
2. **The keys may fail by** (a) Shearing (b) Crushing
3. **The flange may twist off at the hub**
4. **The flange may shear off at the junction of hub & web portion**
5. **The flange may be failed by repeated bending of flanges due to deflection of the shaft**

Design Analysis of Rigid Flange Coupling

Load Analysis

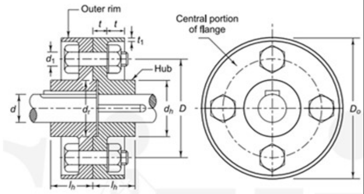
The load analysis of rigid flange coupling can be done by two different approaches, depending upon the clearance between the bolt & the hole.

Approach 1: Bolts are fitted in reamed & ground holes

- **There is no clearance & the bolts are tight. Therefore, power is transmitted by means of shear resistance of the bolts**

Approach 2: Bolts are fitted in large clearance holes

- **There is large clearance & the bolts are tightened with a pre-load or pre-tension. Therefore, power is transmitted by means of friction between the two flanges.**

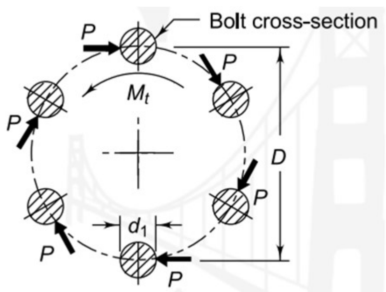


Design Analysis of Rigid Flange Coupling

Load Analysis | Approach 1: Bolts are fitted in reamed & ground holes

- **Power is transmitted by means of shear resistance of the bolts**

P=resisting force acting on each bolt (N)
D=diameter of bolt circle (mm)
N= number of bolts
M_t= Torque transmitted by the coupling (N-mm)



External torque=Resisting torque

$$M_t = P\frac{D}{2}N$$

$$P = \frac{2M_t}{DN}$$

Stress Analysis

Bolts are subjected to direct shear stress due to the force P

τ=Direct shear stress in the bolt (N/mm^2)
d_1=shank diameter of the bolt (mm)

$$\tau = \frac{P}{\frac{\pi}{4}d_1^2} \Rightarrow \tau = \frac{8M_t}{\pi D N d_1^2} \le [\tau]_b$$

Design Analysis of Rigid Flange Coupling

Stress Analysis

Hub portion

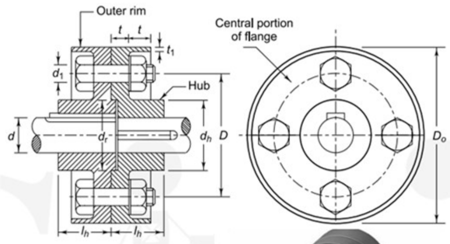
- The torsional shear stress in the hub can be calculated by considering it as a hollow shaft subjected to torsional moment M_t.

$$\tau = \frac{M_t r}{J} \Rightarrow \tau = \frac{16 M_t d_h}{\pi (d_h^4 - d^4)} \leq [\tau]$$

Web portion

Minimum thickness of web (t) is based on two considerations:

- **Shear of the web**
- **Bearing or crushing of web & bolt**



Shear of the web

- **The flange at the junction of hub & web is under shear.**

Area under shear= $\pi d_h t$

Resisting torque (M_t)=Shear force×(d_h/2) ⇨ Shear force=$2M_t/d_h$

Shear stress $\tau = \frac{2M_t}{\pi d_h^2 t} \leq [\tau]$

Shear stress (τ)=Shear force/shear resisting area

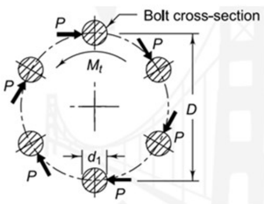
Design Analysis of Rigid Flange Coupling

Web portion

Bearing or crushing of the web & bolt shank

- **The torque capacity based on bearing**

Bearing or crushing area of each bolt = $d_1 t$



External torque=Resisting torque

$$M_t = P_c \frac{D}{2} N$$

$$P_c = \frac{2M_t}{DN}$$

Bearing or crushing stress (σ_c)=P_c/crushing area

$$\sigma_c = \frac{P_c}{d_1 t} \Rightarrow \sigma_c = \frac{2M_t}{DNd_1 t} \begin{array}{l} \leq [\sigma_c] \\ \leq [\sigma_c]_b \end{array}$$

$[\sigma_c]$ = Allowable crushing stress of flange material
$[\sigma_c]_b$= Allowable crushing stress of bolt material

Service Factor

- In practical applications, the torque developed by the source of power varies during the workcycle. Similarly, the torque required by the driven machine also varies

- In design, the maximum force due to maximum torque is the criteria.
- This is accounted by means of a Service Factor

$$\text{Service Factor (Cs)} = \frac{\text{Maximum Torque}}{\text{Rated Torque}}$$

Maximum Torque=Service Factor (Cs) × Rated Torque

Design Torque = Maximum Torque

Service factor depends on working characteristics like light shock, medium shock, heavy shock etc.

For electric motor:

$$\text{Service Factor (Cs)} = \frac{\text{Starting Torque}}{\text{Rated Torque}}$$

Design of Rigid Flange Coupling

Main Steps in Design Analysis of Rigid flange coupling

Step 1 - Either shaft diameter (d) is given or estimate shaft diameter (d).

Step 2 - Selection of Materials & Assume suitable Factor of Safety (FoS)

Step 3 - Calculate the dimensions of flanges by empirical relations IS 2293:1963

Step 4 - Decide the number of bolts

Step 5 - Determine the diameter of the bolts

Step 6 - Determine the dimensions of the keys

- **Step 6.1** - Select **width×height** of the key based on shaft diameter from IS 2293:1963 (Data Book)
- **Step 6.2** - Calculate force acting on key.
- **Step 6.3** - Calculate effective length of the key (L) based on two design criteria (shear failure & crushing failure) & recommend larger of the above two dimensions.

Selection of Material & Factor of Safety

Components	Materials	Mechanical Properties	Factor of safety	Remarks
Shaft	Plain C steel (40C8)	S_{yt}=380 N/mm^2	3	
Flange	Grey Cast Iron (FG 200)	S_{ut}=200N/mm^2	8	Why high?
Key	Plain C steel (30C8)	S_{yt}=400 N/mm^2	2	Why low?
Bolt	Plain C steel (40C8)	S_{yt}=380 N/mm^2	2.5	

Ex#1

It is required to design a rigid type of flange coupling to connect two shafts. The input shaft transmits 37.5 kW power at 180 rpm to the output shaft through the coupling. The service factor for the application is 1.5 (i.e., the design torque is 1.5 times of the rated torque). Select suitable materials for various parts of the coupling, design the coupling and specify the dimensions of its components.

Step 1 - Either shaft diameter (d) is given or estimate shaft diameter (d).

Step 2 - Selection of Materials & Assume suitable Factor of Safety (FoS)

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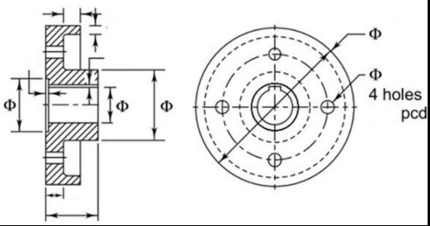

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Solution Given data

Power= 37.5 kW=37500 W; RPM (n)=180

Service factor=1.5; i.e., Design torque (M_t)=1.5× Rated torque (M_r)

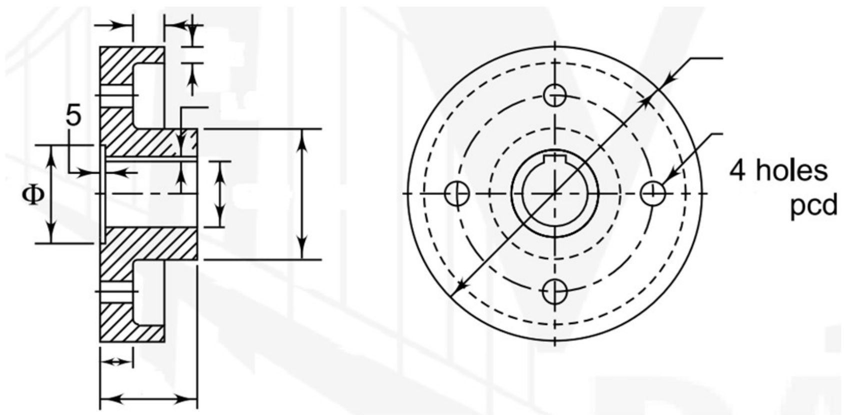
Power= $2\pi n M_r/60$

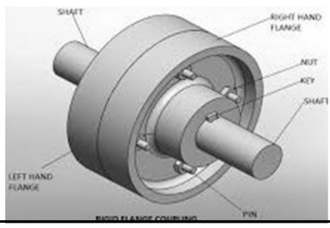
M_r=(60×37500)/(2π ×180) N-m=1989.44 N-m

M_t=1.5×1989.44 N-m=2984.1552 N-m=2984155.2 N-mm

Material selection

Components	Materials	Mechanical Properties	Factor of safety	Allowable stresses
Shaft	Plain C steel (40C8)	S_{yt}=380 N/mm^2	3	[τ]=0.75[380/(2×3)] MPa =164 MPa
Flange	Grey Cast Iron (FG 200)	S_{ut}=200N/mm^2	8	[τ]=200/(2×8) MPa =12.5 MPa
Key	Plain C steel (30C8)	S_{yt}=400 N/mm^2	2	[σ]=400/2 MPa
Bolt	Plain C steel (40C8)	S_{yt}=380 N/mm^2	2.5	[τ]=380/(2×2.5) MPa =76 MPa





Rigid Flange Coupling

Step 1 - Either shaft diameter (d) is given or estimate shaft diameter (d).

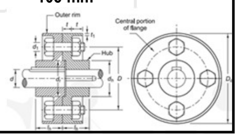
$$\tau = \frac{16M_t}{\pi d^3} \le [\tau] \Rightarrow d \ge 68.4 \text{ mm}$$

Recommended: d = 70 mm

Step 2 - Calculate the dimensions of Flanges by empirical relations (as per IS)

Notations		*Empirical Relationship*	*Dimensions*
d	Diameter of the shaft		70 mm
d_h	Outside diameter of hub	d_h=1.8d to 2d	126 to 140 mm
D	Pin circle Diameter	D=2.5d to 3d	175 to 210 mm
D_0	Outer diameter of flange	D_0=	
t	Thickness of the flange or web thickness of flange at driven shaft	t=0.5d	35 mm
t_1	Thickness of outer rim	t_1=0.25d	18 mm
lh	Length of the hub or effective length of the key	l_h=1.5d to 2d	105 to 140 mm
d_r	Diameter of spigot & recess	d_r=1.5d	105 mm

d_h=126 mm   D=175 mm l_h=105 mm

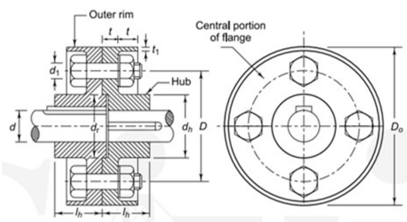


Check through Stress Analysis

Hub portion

- **The torsional shear stress in the hub can be calculated by considering it as a hollow shaft subjected to torsional moment M_t.**

$$\tau = \frac{M_t r}{J} \Rightarrow \tau = \frac{16 M_t d_h}{\pi(d_h^4 - d^4)} \le [\tau]$$



Web portion

Minimum thickness of web (t) is based on two considerations:
- **Shear of the web**
- **Bearing or crushing of web & bolt**

Shear of the web

- **The flange at the junction of hub & web is under shear.**

Area under shear= $\pi d_h t$ Shear stress (τ)=Shear force/shear resisting area

Resisting torque (M_t)=Shear force×(d_h/2) $\Rightarrow$ Shear force=$2M_t/d_h$

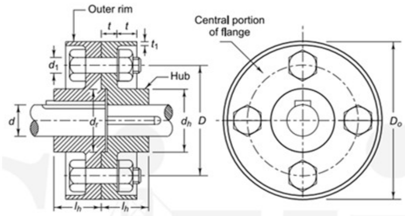
Shear stress $\tau = \frac{2M_t}{\pi d_h^2 t} \le [\tau]$

Check through Stress Analysis

Hub portion

- **The torsional shear stress in the hub can be calculated by considering it as a hollow shaft subjected to torsional moment M_t.**

$$\tau = \frac{M_t r}{J} \Rightarrow \tau = \frac{16 M_t d_h}{\pi (d_h^4 - d^4)} \leq [\tau]$$



$$\tau = \frac{16 \times 2984155.2 \times 126}{\pi (126^4 - 70^4)}$$

$$= 8.39 \text{ N/mm}^2 < [\tau]$$

where $[\tau] = 12.5 \text{ N/mm}^2$

Dimensions of Flanges

Material: Grey CI FG 200

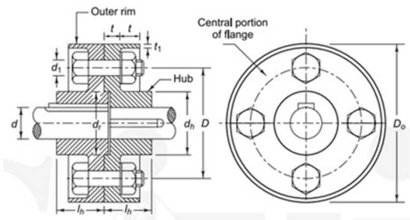
$S_{ut} = 200 \text{ N/mm}^2$, $FOS = 8$

$[\sigma] = \frac{S_{ut}}{FOS} = \frac{200}{8} \text{ N/mm}^2$

$[\sigma_c] = 1.3[\sigma] = 1.3 \times 25 \text{ N/mm}^2 = 32.5 \text{ N/mm}^2$

$[\tau] = 0.5[\sigma] = 12.5 \text{ N/mm}^2$

Check through Stress Analysis



Empirical Relations $t = 0.5d = 0.5 \times 70 = 35$ mm

Choose $t = 35$ mm

$t_1 = 0.25d = 18$ mm

Web portion

Shear of the web

- **The flange at the junction of hub & web is under shear.**

Area under shear= $\pi d_h t$ Shear stress (τ)=Shear force/shear resisting area

Resisting torque (M_t)=Shear force×(d_h/2) $\Rightarrow$ Shear force=$2M_t/d_h$

Shear stress $\tau = \frac{2M_t}{\pi d_h^2 t} \leq [\tau] \Rightarrow \frac{2 \times 2984155.2}{\pi \cdot (126)^2 \times 35} = 3.42 \text{ N/mm}^2 < [\tau]$

Rigid Flange Coupling

Notations		Empirical Relationship	Dimensions
d	Diameter of the shaft		70 mm
d_h	Outside diameter of hub	d_h=1.8d to 2d	126 to 140 mm
D	Pin circle Diameter	D=2.5d to 3d	175 to 210 mm
D_0	Outer diameter of flange	D_0=	
t	Thickness of the flange or web thickness of flange at driven shaft	t=0.5d	35 mm
t_1	Thickness of outer rim	t_1=0.25d	18 mm
lh	Length of the hub or effective length of the key	Lh=1.5d to 2d	105 to 140 mm

t = ?
t = 9.57 mm
or 35 mm

$D = 2.5d \text{ to } 3d = 175 \text{ mm to } 210 \text{ mm}$

D=175 mm

The no. of bolts (N) is decided based on shaft diameter (d)

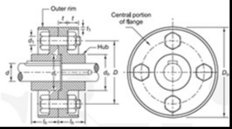
Shaft dia. (mm)	N
d<40	3
40≤d<100	4
100≤d	6

Empirical Relations:
N≥0.02d+3; (d in mm)

Decide the number of bolts

The no. of bolts (N) = 4

Bolts are fitted in reamed & ground holes



Diameter of bolts

The bolts may fail by

(a) Shearing
(b) Crushing

Shear failure of Bolts

Material : 40C8 ; $S_{yt} = 380 \text{ N/mm}^2$, FOS = 2.5 ; $[\tau] = \frac{1}{2}\frac{380}{2.5} \text{ N/mm}^2 = 76 \text{ N/mm}^2$

Shear Stress $\tau = \dfrac{P}{\frac{\pi}{4}d_1^2} = \dfrac{8M_t}{\pi D N d_1^2} \leq [\tau]$

$$d_1 \geq \sqrt{\frac{8M_t}{\pi D N [\tau]}}$$

$$\geq \sqrt{\frac{8 \times 2984155.2}{\pi \times 175 \times 4 \times 76}}$$

$$\geq 11.95 \text{ mm}$$

$$d_1 = 12 \text{ mm}$$

d_1=shank diameter of the bolt (mm)

Diameter of bolts

The bolts may fail by

(a) Shearing
(b) Crushing

Crushing failure of Shank of the Bolts & Web

$$\sigma_c = \frac{2M_t}{DNd_1t}$$

$$= \frac{2 \times 2984155.2}{175 \times 4 \times 12 \times 35}$$

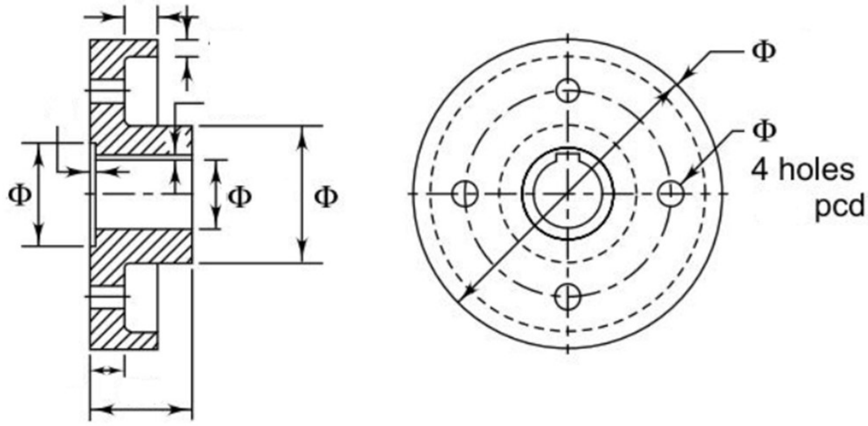
$$= 20.3\ N/mm^2 < [\sigma_c]$$

$$< [\sigma_c]_b$$

Crushing bet^n Shank of the bolt & Web.

$[\sigma_c]_{flange} = 32.5\ N/mm^2$

$[\sigma_c]_{bolt} = 1.3 \times \frac{380}{2.5} = 197.6\ N/mm^2$



Keys

Rectangular Sunk Key

- Sunk key with rectangular cross-section, is also called Flat Key

d=diameter of the shaft = diameter of the hole in the hub
b= width of key
h=height or thickness of key
l=length of key

Usual proportions of dimensions of key

$$b = \frac{d}{4} \quad h = \frac{2}{3}b = \frac{d}{6} \quad l \geq 1.5d$$

Square Sunk Key

- Width & thickness are equal

Usual proportions of dimensions of key

$$b = h = \frac{d}{4} \quad l \geq 1.5d$$

N.B: Flat key has more stability as compared with square key

Dimensions of Square & Rectangular Sunk Keys (in mm) [*IS : 2293*]

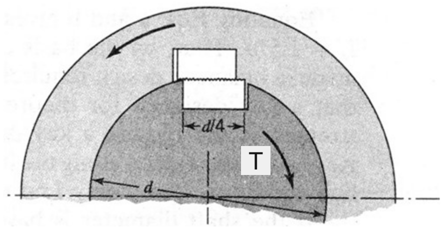
Shaft diameter		Key size	Keyway depth	
Above	Upto & including	Width × Height	*In shaft*	*In hub*
6	8	2 × 2	1.2	1
8	10	3 × 3	1.8	1.4
10	12	4 × 4	2.5	1.8
12	17	5 × 5	3	2.3
17	22	6 × 6	3.5	2.8
22	30	8 × 7	4	3.3
30	38	10 × 8	5	3.3
38	44	12 × 8	5	3.3
44	50	14 × 9	5.5	3.8
50	58	16 × 10	6	4.3
58	65	18 × 11	7	4.4
65	75	20 × 12	7.5	4.9
75	85	22 × 14	8.5	5.9

Design Analysis

Due to the power or torque transmitted by the shaft, the key may fail due to shearing or crushing.

Design of sunk key is based on two criteria:

- Failure due to shear.
- Failure due to crushing.



Design Analysis

Failure due to Shear

- Shear failure will occur in plane AB.

Area resisting shearing: $A_s = b \times L$

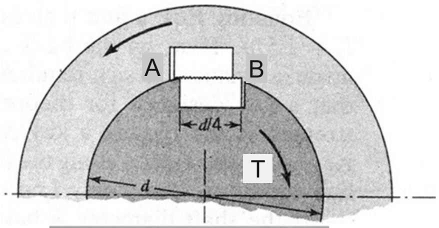
Shear stress induced in plane AB = τ

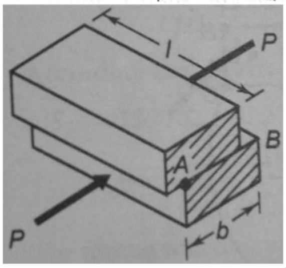
$$\tau = \frac{P}{A_s} = \frac{P}{b \times L}$$

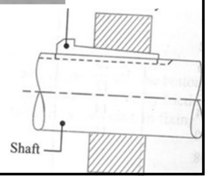
$$\tau = \frac{2T}{d.b.L} \le [\tau]_{key}$$

$$L \ge \frac{2T}{d.b.[\tau]_{key}}$$

L= Effective length of the Key







Design Analysis

Failure due to Crushing

- Crushing failure will occur on surface AC or DB.

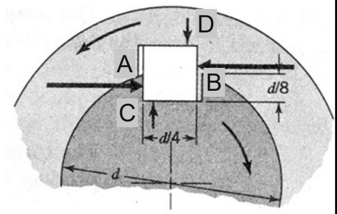
Area resisting crushing: $A_c = L \times h/2$

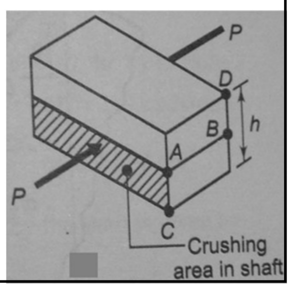
Crushing stress induced = σ_c

$$\sigma_c = \frac{P}{A_c} = \frac{P}{L \times \frac{h}{2}}$$

$$\sigma_c = \frac{4T}{d.h.L} \le \text{min. of } ([\sigma_c]_{key}, [\sigma_c]_{shaft}, [\sigma_c]_{hub})$$

$$L \ge \frac{4T}{d.h.[\sigma_c]_{min}}$$

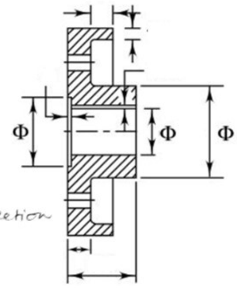




Dimension of the Key

Length of the hub l_h=1.5d to 2d

l_h=105 mm



For shaft diameter = 70mm, the Standard Cross-Section of flat key is 20×12 as per IS:2293

i.e Width of key (b) = 20mm

Height of key (h) = 12 mm

Let us consider length of key = length of hub (l_h)

l = 105 mm

Check:

Shear Stress $\tau = \frac{2M_t}{dbl}$

$= \frac{2 \times 2984155.2}{70 \times 20 \times 105}$

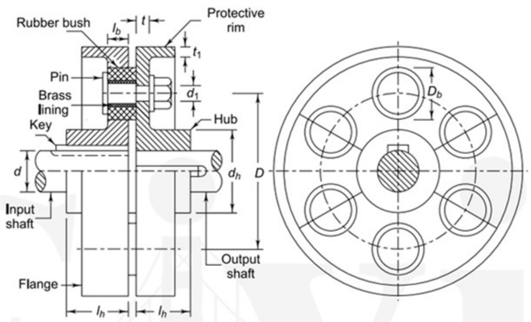
$= 40.6$ N/mm² $< [\tau]_{key}$

Crushing Stress $\sigma_c = \frac{4M_t}{dhl}$

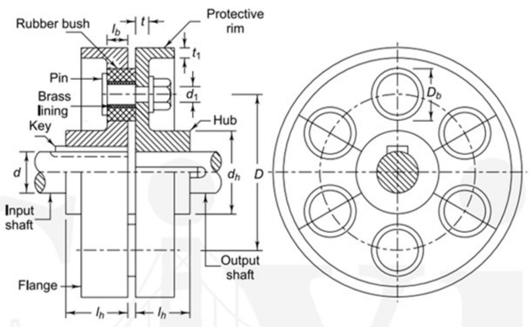
$= \frac{2 \times 2984155.2}{70 \times 12 \times 105}$

$= 67.66$ N/mm² $< [\sigma_c]_{key}$

Flexible Flange Coupling



Flexible Flange Coupling



Pin-bushed type Flexible Flange Coupling

Consisting of
- Two Flanges
- Two Keys
- Rubber bush with brass lining
- Four or Six nos. of pin with end thread & Nuts

Pin-bushed type Flexible Flange Coupling

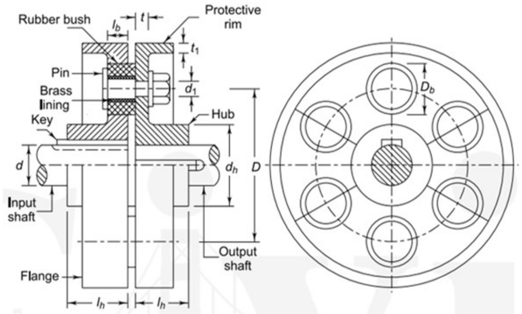
Advantages

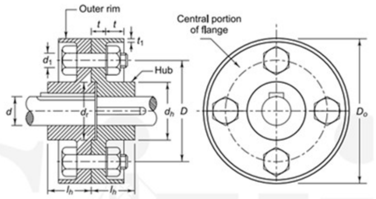
- **It can tolerate 0.5 mm of lateral or axial misalignment and 1.5° of angular misalignment.**
- **It prevents transmission of shock from one shaft to the other and absorbs vibrations.**
- **It can be used for transmitting high torques.**

Disadvantages

- **It requires more radial space.**
- **The cost is more than rigid coupling.**

Pin-bushed type Flexible Flange Coupling





Three distinct regions of flange of pin-bushed type flexiblecouplings

- **Hub portion with keyway**
- **Central portion with multiple large holes for pin with bush (for left flange)**
  (Central portion with multiple small holes for pin (for right flange)
- **Peripheral outer rim for protection**

Power flow

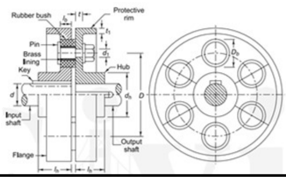
Driving shaft ⇨ Key ⇨ Flange ⇨ Bush ⇨ Pin ⇨ Flange ⇨ Key ⇨ Driven shaft

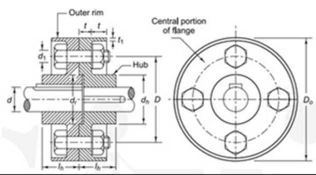
Pin-bushed type Flexible Flange Coupling

Important Features

(a) There is a gap or clearance between the driving and driven flanges of flexible bush coupling. This gap is essential for taking care of axial & angular misalignment between the two shafts. There is no such clearance between the flanges of rigid coupling. Therefore, rigid coupling cannot tolerate any angular misalignment.

(b) In case of rigid coupling, the torque is transmitted by means of bolts. These bolts are made of steel and resisting shear or tensile stresses are high. Therefore, the diameter of the bolts or the pitch circle diameter of bolts is comparatively less than that of pin-bush type flexible flange coupling. On the other hand, the torque is transmitted by means of a force passing through a rubber bush in case of flexible coupling. The permissible pressure between the rubber bush and cast iron flange is only 0.5-1.5 N/mm^2 . Therefore, the diameter of the pin, nos. of pin, pitch circle diameter of pins is comparatively large than that of rigid flange coupling. It should be noted that for connecting shafts of a particular size, pin-bush type flexible flange coupling either has greater number of bolts (or pins) than rigid coupling or has larger bolt circle diameter than rigid coupling. This reduces the force acting on the bolts (pins) and lowers bearing pressure on the rubber bush.



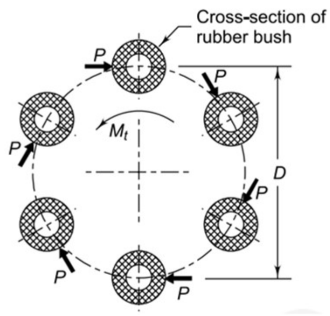


Pin-bushed type Flexible Flange Coupling

Load Analysis

- **Power is transmitted by means of shear resistance of the pins**

P=resisting force acting on each pin or rubber bush (N)
D=diameter of pin circle (mm)
N= number of pins or bushes
M_t= Torque transmitted by the coupling (N-mm)

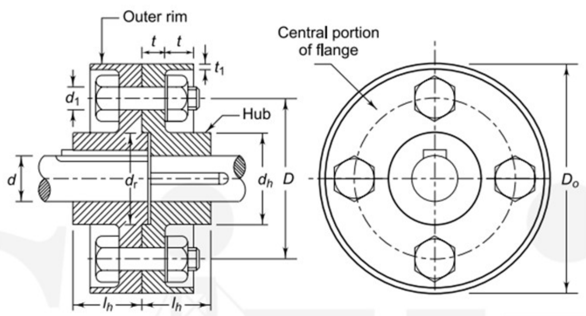


At pin External torque=Resisting torque

$$M_t = P\frac{D}{2}N$$

$$P = \frac{2M_t}{DN}$$

Design of Rigid Flange Coupling



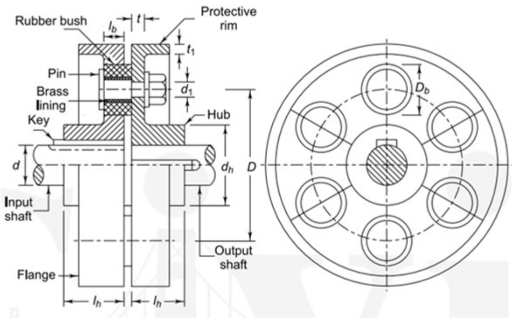
The no. of bolts (N) is decided based on shaft diameter (d)

Shaft dia. (mm)	N
d<40	3
40≤d<100	4
100≤d	6

Empirical Relations:
N≥0.02d+3; (d in mm)

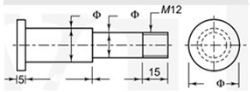
Notations		Empirical Relationship
d	Diameter of the shaft	
d_h	Outside diameter of hub	d_h=1.8d to 2d
d_r	Diameter of spigot & recess	d_r=1.5d
D	Bolt circle Diameter or PCD of bolts or dia. of pitch circle of the bolts	D=2.5d to 3d
t	Thickness of the flange or web thickness	t=0.5d
t_1	Thickness of outer rim	t_1=0.25d
l_h	Length of the hub or effective length of the key	l_h=1.5d to 2d
D_0	Outer diameter of flange	D_0=Σ

Pin-bushed type Flexible Flange Coupling



The no. of pins (N) is decided based on shaft diameter (d)

Shaft dia. (mm)	N
d<20	3
20≤d<50	4
50≤d<100	6



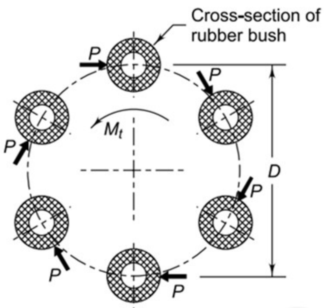
Notations		Empirical Relationship
d	Diameter of the shaft	
d_h	Outside diameter of hub	$d_h=2d$
D	Bolt circle Diameter or PCD of bolts or dia. of pitch circle of the bolts	$D=3d$ to $4d$
D_0	Outer diameter of flange	$D_0=$
t	Thickness of the flange or web thickness of flange at driven shaft	$t=0.5d$
t_1	Thickness of outer rim	$t_1=0.25d$
d_b	Diameter of pin at bush or inner diameter of bush	
d_p	Diameter of pin head	$1.2d_b$ to $1.4d_b$
l_{ph}	Step length of pin head	$0.3d_b$ to $0.5d_b$

Pin-bushed type Flexible Flange Coupling

Load Analysis

- Power is transmitted by means of shear resistance of the pins

P=resisting force acting on each pin or rubber bush (N)
D=diameter of pin circle (mm)
N= number of pins or bushes
M_t= Torque transmitted by the coupling (N-mm)



At pin External torque=Resisting torque

$$M_t = P\frac{D}{2}N$$

$$P = \frac{2M_t}{DN}$$

Shear Stress Analysis in pin

Pins are subjected to direct shear stress due to the force P

$$\tau = \frac{P}{\frac{\pi}{4}d_1^2} \Rightarrow \tau = \frac{8M_t}{\pi D N d_1^2} \le [\tau]_b$$

$d_1 \geq$

τ=Direct shear stress in the bolt (N/mm²)
d_1=diameter of the pin (mm)

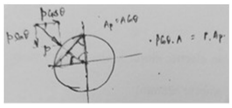
Pin-bushed type Flexible Flange Coupling

Load Analysis

At bush - **Power is transmitted by means of permissible intensity of pressure between rubber bush & the flange.**

D_b=outer diameter of the bush (mm)
l_b= effective length of the bush in contact with the input flange (mm)
$[p_m]$= Allowable pressure on the rubber bush (N/mm^2)

Force at bush (P)=Projected area × intensity of pressure



Bush outer surface
$P=(D_b\, l_b)\times p_{mo}$

Bush inner surface
$P=(d_b\, l_b)\times p_{mi}$

$M_t = P\frac{D}{2}N$

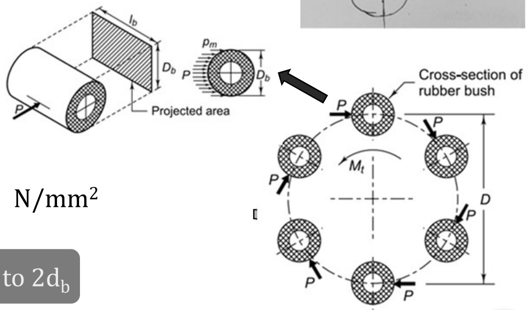
$P_{mi} > p_{mo}$

Then $p_{mi}= P/(d_b\, l_b) \le [p_m]$

where $l_b=k_1\times d_b$ & $[p_m]$=0.5 to 1.5 N/mm^2

k_1 = 1.3 to 2

D_b = 1.6d_b to 2d_b

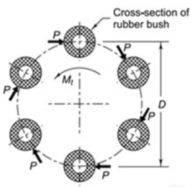


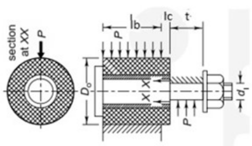
Pin-bushed type Flexible Flange Coupling

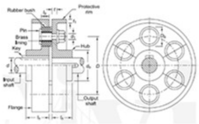
Bending Load Analysis

- **It is assumed that the force P is uniformly distributed over the effective length of the bush (l_b)**

D=diameter of pin circle (mm); N= number of pins or bushes
M_t= Torque transmitted by the coupling (N-mm)
l_b= effective length of the bush in contact with the input flange (mm)
l_c= gap or clearance between two flanges (mm)







At pin External torque=Resisting torque

$M_t = P\frac{D}{2}N$

$P = \frac{2M_t}{DN}$

Bending Stress Analysis in pin

$M_b=P(l_c+l_b/2)$

$\sigma_b = \frac{M_b y}{I}$ ⇨ $\sigma_b = \frac{32M_b}{\pi d_1^3} \le [\sigma]_b$

$d_1 \ge$

σ_b=Stress due to bending of pin(N/mm^2)
d_1=Min. diameter of the pin (mm)

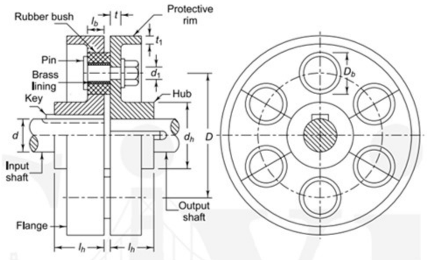
Pin-bushed type Flexible Flange Coupling

Check through Stress Analysis

Hub portion

- **The torsional shear stress in the hub can be calculated by considering it as a hollow shaft subjected to torsional moment M_t.**

$\tau = \frac{M_t r}{J}$ ⇨ $\tau = \frac{16 M_t d_h}{\pi(d_h^4 - d^4)}$ **≤ [τ]** $d_h \geq$



Web portion

Minimum thickness of web (t) is based on two considerations:

- **Shear of the web**
- **Bearing or crushing of web & bolt**

Shear of the web

- **The flange at the junction of hub & web is under shear.**

Area under shear= $\pi d_h t$ Shear stress (τ)=Shear force/shear resisting area

Resisting torque (M_t)=Shear force×(d_h/2) ⇨ Shear force=$2M_t/d_h$

Shear stress $\tau = \frac{2M_t}{\pi d_h^2 t}$ **≤ [τ]** $t \geq$

Pin-bushed type Flexible Flange Coupling

Ex. # 2

It is required to design a pin-bushed-type flexible coupling to connect the output shaft of an electric motor to the shaft of a centrifugal pump. The motor delivers 20 kW power at 720 rpm. The starting torque of the motor can be assumed to be 150% of the rated torque. Design the coupling and specify the dimensions of its components.

Solution Given data

Power= 20 kW=20000 W; RPM (n)=720
Service factor (C_s)=1.5; i.e., Design torque (M_t)=1.5× Rated torque (M_r)
Power= $2\pi n M_r/60$
M_r=(60×20000)/(2π ×720) N-m=265.26 N-m
M_t=1.5×265.26 N-m=397.8874 N-m=397887.4 N-mm

Material selection

Components	Materials	Mechanical Properties	Factor of safety	Allowable stresses
Shaft	Plain C steel (40C8)	S_{yt}=380 N/mm²	3	[τ]=0.75[380/(2×3)] MPa
Flange	Grey Cast Iron (FG 200)	S_{ut}=200N/mm²	8	[τ]=200/(2×6) MPa
Key	Plain C steel (30C8)	S_{yt}=400 N/mm²	2	[σ]=380/2 MPa
Pin	Plain C steel (30C8)	S_{yt}=400 N/mm²	2.5	

Pin-bushed type Flexible Flange Coupling

Step 1 - Either shaft diameter (d) is given or estimate shaft diameter (d).

Step 2 - Calculate the dimensions of flanges by empirical relations (as per IS)

Step 3 - Decide the number of pins

Step 4 - Determine the dimensions of bushes & min. diameter of the pins

Step 5 - Determine the dimensions of the keys

Step 5.1 - Select **width×height** of the key based on shaft diameter from IS 2293:1963 (Data Book)

Step 5.2 - Calculate force acting on key.

Step 5.3 - Calculate effective length of the key (L) based on two design criteria (shear failure & crushing failure) & recommend larger of the above two dimensions.

Pin-bushed type Flexible Flange Coupling

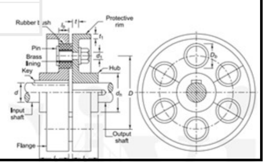
Step 1 - Either shaft diameter (d) is given or estimate shaft diameter (d).

$$\tau = \frac{16M_t}{\pi d^3} \leq [\tau] \Rightarrow d \geq 27.73 \text{ mm}$$

Recommended: d = 30 mm

Step 2 - Calculate the dimensions of flanges by empirical relations (as per IS)

Notations		Empirical Relationship	Dimensions
d	Diameter of the shaft		30 mm
d_h	Outside diameter of hub	d_h=2d	60 mm
D	Pin circle Diameter	D=4d	120 mm
D_0	Outer diameter of flange	D_0=	
t	Thickness of the flange or web thickness of flange at driven shaft	t=0.5d	15 mm
t_1	Thickness of outer rim	t_1=0.25d	7.5 mm
lh	Length of the hub or effective length of the key	Lh=1.5d	



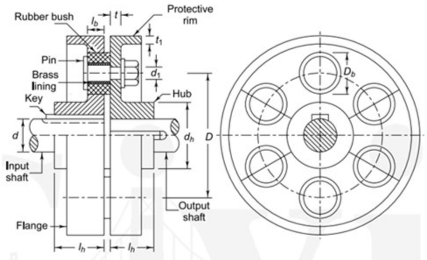
Pin-bushed type Flexible Coupling

Check through Stress Analysis

Hub portion

- **The torsional shear stress in the hub can be calculated by considering it as a hollow shaft subjected to torsional moment M_t.**

$$\tau = \frac{M_t r}{J} \Rightarrow \tau = \frac{16 M_t d_h}{\pi (d_h^4 - d^4)} \le [\tau]$$



Web portion

Minimum thickness of web (t) is based on two considerations:

- **Shear of the web**
- **Bearing or crushing of web & bolt**

Shear of the web

- **The flange at the junction of hub & web is under shear.**

Area under shear= $\pi d_h t$ Shear stress (τ)=Shear force/shear resisting area

Resisting torque (M_t)=Shear force×(d_h/2) ⇨ Shear force=$2M_t/d_h$

Shear stress $\tau = \frac{2M_t}{\pi d_h^2 t} \le [\tau]$

Pin-bushed type Flexible Coupling

Check through Stress Analysis

Hub portion

- **The torsional shear stress in the hub can be calculated by considering it as a hollow shaft subjected to torsional moment M_t.**

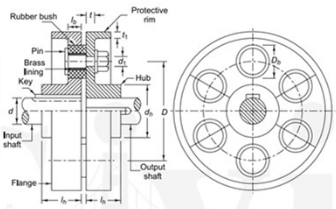
$$\tau = \frac{M_t r}{J} \Rightarrow \tau = \frac{16 M_t d_h}{\pi (d_h^4 - d^4)} \le [\tau]$$

$$J = \frac{\pi (d_h^4 - d^4)}{32} = \frac{\pi (60^4 - 30^4)}{32} = 1\,192\,823.46 \text{ mm}^4$$

$$r = \frac{d_h}{2} = \frac{60}{2} = 30 \text{ mm}$$

$$\tau = \frac{M_t r}{J} = \frac{(397\,887.36)(30)}{(1\,192\,823.46)} = 10.01 \text{ N/mm}^2$$

$$\tau < 16.67 \text{ N/mm}^2$$



Web portion

Shear of the web

- **The flange at the junction of hub & web is under shear.**

Area under shear= $\pi d_h t$ Shear stress (τ)=Shear force/shear resisting area

Resisting torque (M_t)=Shear force×(d_h/2) ⇨ Shear force=$2M_t/d_h$

Shear stress $\tau = \frac{2M_t}{\pi d_h^2 t} \le [\tau]$

$$\tau = \frac{2 M_t}{\pi d_h^2 t} = \frac{2(397\,887.36)}{\pi (60)^2 (15)} = 4.69 \text{ N/mm}^2$$

$$\tau < 16.67 \text{ N/mm}^2$$

The stresses in the flange are within limit.

Pin-bushed type Flexible Coupling

Step 3 Decide the number of pins

The number of pins is selected as 6

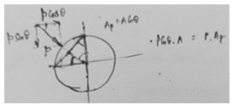
Step 4 Determine the dimensions of bushes & min. diameter of the pins

At bush - **Power is transmitted by means of permissible intensity of pressure between rubber bush & the flange.**

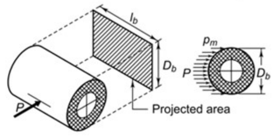
D_b=outer diameter of the bush (mm)
l_b= effective length of the bush in contact with the input flange (mm)
p_m= permissible intensity of pressure between the rubber bush & the flange (N/mm^2)

Force at bush (P)=Projected area × intensity of pressure

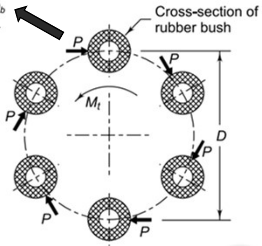
$P=(D_b\ l_b)\times p_{mo}$ $P=(d_b\ l_b)\times p_{mi}$



$M_t = P\frac{D}{2}N$



Then $M_t=0.5(D_b\ l_b)\times p_m DN$



If $l_b=D_b$ & $[p_m]$=1 N/mm^2

$M_t=0.5(D_b\ D_b DN)$ ⇨ $$D_b^2 = \frac{2M_t}{DN} = \frac{2(397\ 887.36)}{(120)(6)}$$

or D_b = 33.25 or 35 mm

$D_b = l_b$ = 35 mm

Pin-bushed type Flexible Coupling

Step 4 Determine the min. diameter of the pins & bushes

Shear Stress Analysis in pin

D=diameter of pin circle =120 mm
N= number of pins or bushes =6
M_t= Torque transmitted by the coupling =397887.4 N-mm
$[\tau]_b$=Direct shear stress in the bolt (N/mm^2)
d_1=diameter of the pin (mm)

Pins are subjected to direct shear stress due to the force P

$\tau = \frac{P}{\frac{\pi}{4}d_1^2}$ ⇨ $\tau = \frac{8M_t}{\pi D N d_1^2}$ **≤ $[\tau]_b$**

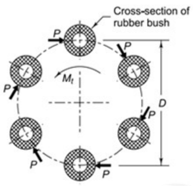
$d_1 \geq$ mm

Pin-bushed type Flexible Coupling

Bending Load Analysis

- **It is assumed that the force P is uniformly distributed over the effective length of the bush (l_b)**

D=diameter of pin circle (mm); N= number of pins or bushes
M_t= Torque transmitted by the coupling (N-mm)
l_b= effective length of the bush in contact with the input flange (mm)
l_c= gap or clearance between two flanges (mm)

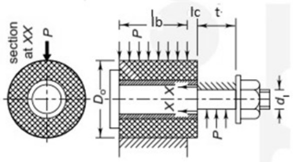


At pin External torque=Resisting torque

$$M_t = P\frac{D}{2}N$$

$$P = \frac{2M_t}{DN}$$

Bending Stress Analysis in pin



$\mathbf{M_b=P(l_c+l_b/2)}$ $l_b=D_b$ =35 mm; l_c=5 mm

$$\sigma_b = \frac{M_b y}{I} \Rightarrow \sigma_b = \frac{32M_b}{\pi d_1^3} \le [\sigma]_b$$

$d_1 \ge$ mm

σ_b=Stress due to bending of pin(N/mm^2)
d_1=Min. diameter of the pin (mm)

Pin-bushed type Flexible Coupling

Step 3 Decide the number of pins

The number of pins is selected as 6

Step 4 Determine the min. diameter of the pins & bushes