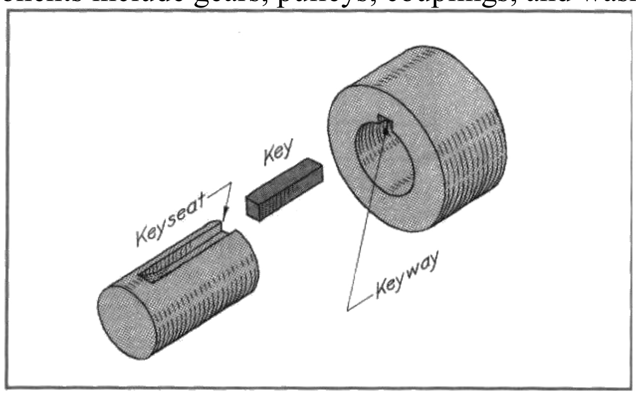
MOD II - KEYS

In mechanical engineering, a key is a machine element used to connect a rotating machine element to a shaft. The key prevents relative rotation between the two parts and may enable torque transmission. For a key to function, the shaft and rotating machine element must have a keyway and a keyseat, which is a slot and pocket in which the key fits. The whole system is called a keyed joint. A keyed joint may allow relative axial movement between the parts. Commonly keyed components include gears, pulleys, couplings, and washers.



Types of Keys

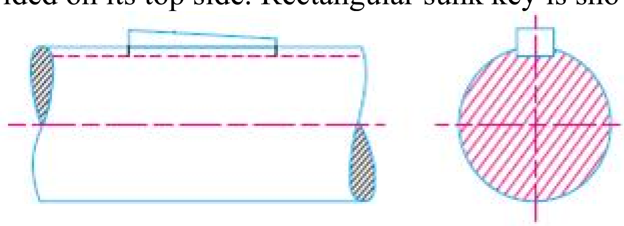
Common types of keys are:

1. Sunk keys 2. Saddle keys 3. Tangent keys 4. Round keys 5. Splines

1. **Sunk Keys**

A sunk key is a key in which half of the thickness of key fits into the keyway in the shaft and half in the keyway of the hub. The sunk keys are of the following types:

Rectangular sunk key: It is the simplest type of key and has a rectangular cross-section. A taper of about 1 in 100 is provided on its top side. Rectangular sunk key is shown in Figure.

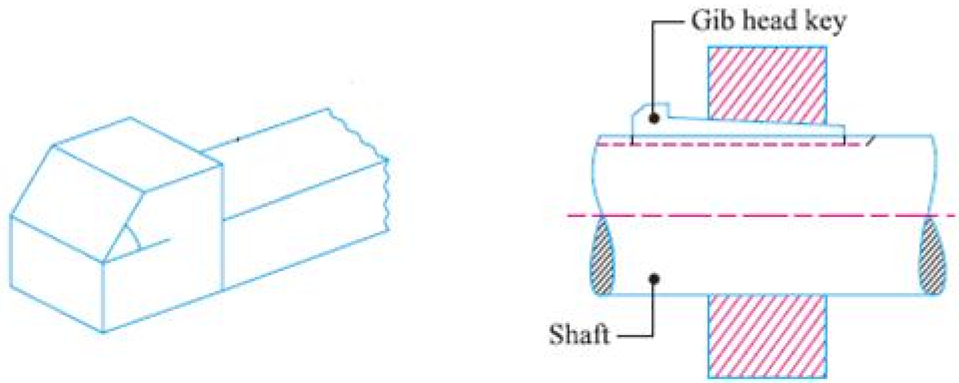


Rectangular Sunk Key

Square sunk key: Rectangular sunk key having equal width and thickness is called square sunk key. $w = t = d/4$

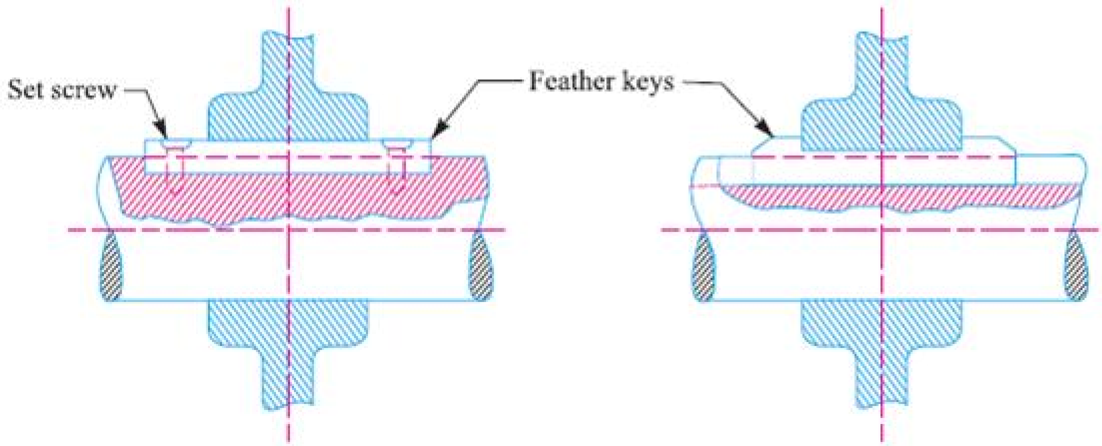
Parallel sunk key: If no taper is provided on the rectangular or square sunk key, it is called parallel sunk key i.e. it is uniform in width and thickness throughout. It is used where the pulley, gear or other mating piece is required to slide along the shaft.

Gib-head key: It is a rectangular sunk key with a head at one end known as gib head, which is provided to facilitate the removal of key. Gib Head key is shown in Figure.



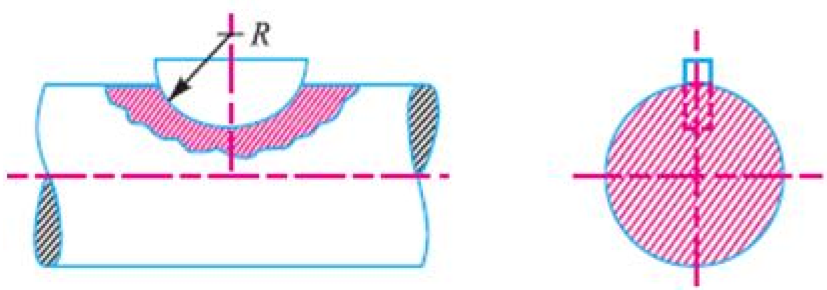
Gib Head Key

Feather key: Feather key is a parallel key made as an integral part of the shaft with the help of machining or using set-screws. It permits axial movement and has a sliding fit in the key way of the moving piece. Feather keys are shown in Figure.



Feather Key

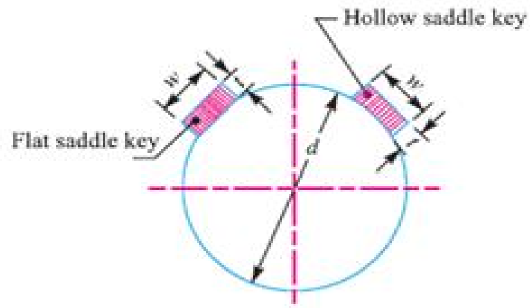
Woodruff key: Woodruff key is a sunk key in the form of a semicircular disc of uniform thickness. Lower portion of the key fits into the circular keyway of the shaft. It can be used with tapered shafts as it can tilt and align itself on the shaft. But the extra depth of keyway in the shaft increases stress concentration and reduces strength of the shaft. Woodruff key is shown in Figure.



Woodruff Key

2. Saddle Keys

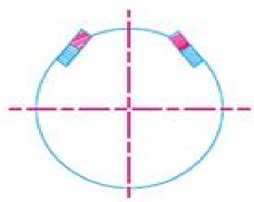
Slot for this type of is provided only in the hub as shown in Figure. Torque is transmitted by friction only and cannot therefore transmit high torque and is used only for light applications. The saddle keys are of two types: Flat Saddle Key and Hollow Saddle Key. In flat saddle key, the bottom surface touching the shaft is flat and it sits on the flat surface machined on the shaft. Hollow saddle key has a concave surface at the bottom to match the circular surface of the shaft. Chances of slip in case of the flat saddle key are relatively lesser and can transmit more power than the hollow saddle key.



Saddle Key

3. Tangent Keys

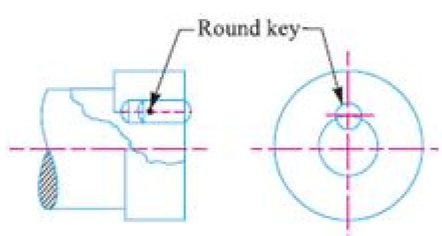
Tangent keys are shown in Figure. These are used to transmit high torque. They may be used as a single key or a pair at right angles. Single tangent key can transmit torque only in one direction.



Tangent Key

4. Round Keys

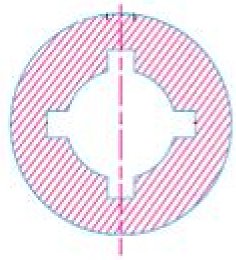
The round keys have a circular cross-section and fit into holes drilled partly in the shaft and partly in the hub. Slot is drilled after the assembly so the shafts can be properly aligned. These are used for low torque transmission. Round keys are shown in Figure.



Round Key

5. Splines

A number of keys made as an integral part of the shaft are called splines. Keyways are provided in the hub. These are used for high torque transmission e.g. in automobile transmission. Splines also permit the axial movement. Splines are shown in Figure.



Splines

Effect of Keyways

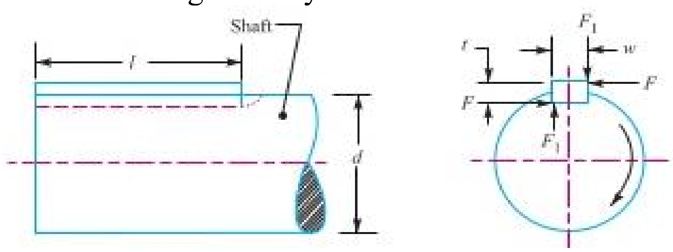
The keyway cut into the shaft reduces the load carrying capacity of the shaft. This is due to the stress concentration near the corners of the keyway and reduction in the cross-sectional area of the shaft. It other words, the torsional strength of the shaft is reduced.

DESIGN OF SUNK KEY

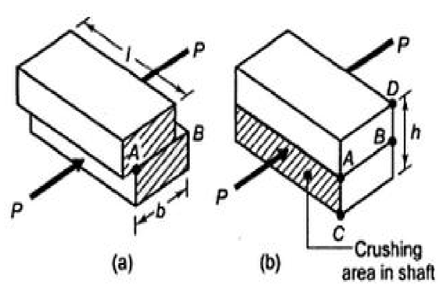
Forces acting on a Sunk Key

- Forcea F_1 due to the fit of the key in its keyway, compressive in nature.
- Forces F due to the torque transmitted by the shaft which produce shearing and crushing.

The forces acting on a key for clockwise transmission of torque is shown in figure.



Failure of Key



a. Shear Failure b. Crushing Failure

Let

T = Torque transmitted by the shaft,

F = Tangential force acting at the circumference of the shaft,

d = Diameter of shaft,

l = Length of key,
w = Width of key.
t = Thickness of key, and
τ and σ_c = Shear and crushing stresses for the material of key.
w = d/4
t = (2/3) × w = d/6
for a square key, w = t = d/4
A little consideration will show that due to the power transmitted by the shaft, the key may fail due to shearing or crushing.

Considering shearing of the key, the tangential shearing force acting at the circumference of the shaft,
F = Area resisting shearing × Shear stress = $l \times w \times \tau$
Therefore Torque transmitted by the shaft,
$$\boldsymbol{T = F \times (d/2) = l \times w \times \tau \times (d/2)} \quad \text{...(i)}$$

Considering crushing of the key, the tangential crushing force acting at the circumference of the shaft,
F = Area resisting crushing × Crushing stress = $l \times (t/2) \times \sigma_c$
Therefore Torque transmitted by the shaft,
$$\boldsymbol{T = F \times (d/2) = l \times (t/2) \times \sigma_c \times (d/2)} \quad \text{...(ii)}$$

Problems:

1. *Design the rectangular key for a shaft of 50mm diameter. The shearing and crushing stresses for the key material are 42 MPa and 70 MPa. (Also, w=16mm, t=10mm)*
2. A square key is used to key a gear to a 35mm diameter shaft. The hub length of gear is 60mm. both shaft and key are to be made of same material, with allowable shear stress of 55Mpa. What are the minimum dimensions for the sides of square key if 395Nm of torque is to be transmitted?
3. A 40mm diameter shaft is subjected to a tangential force of 20KN. Determine the size of key. Allowable shear stress in key is 60MPa.
4. Design the rectangular key for a shaft of 45mm diameter. T = 80MPa and σ_c = 240MPa.

MOD II - SHAFT COUPLING

Shaft couplings are used to join shafts of same or different diameters for reasons such as:
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.

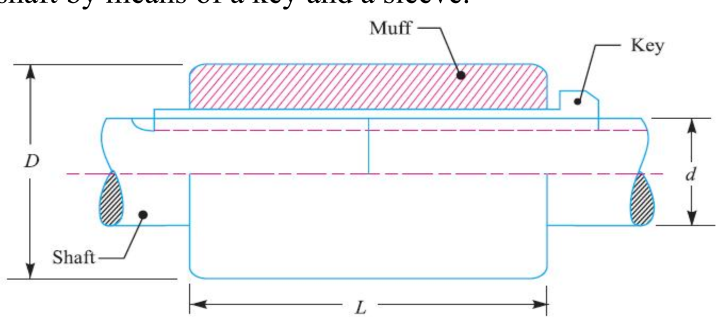
Requirements of a Good Shaft Coupling
A good shaft coupling should have the following requirements:
1. It should be easy to connect or disconnect.
2. It should transmit the full power from one shaft to the other shaft without losses.
3. It should hold the shafts in perfect alignment.
4. It should reduce the transmission of shock loads from one shaft to another shaft.
5. It should have no projecting parts.

Types of Shafts Couplings

1. ***Rigid coupling***
   It is used to connect two shafts which are perfectly aligned.
   a) Sleeve or muff coupling
   b) *Clamp or split-muff or compression coupling*
   c) *Flange coupling*
2. ***Flexible coupling***
   It is used to connect two shafts having both lateral and angular misalignment.
   a) Bushed pin type coupling
   b) *Universal coupling*
   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. The power is transmitted from one shaft to the other shaft by means of a key and a sleeve.



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*

1. ***Design of Shaft***
   As per the design procedure for torsion.

2. ***Design of sleeve***
   The sleeve is designed by considering it as a hollow shaft.

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.
$T = (\pi/16) \times \tau_c \times [(D^4 - d^4)/D] = (\pi/16) \times \tau_c \times D^3(1-k^4)$
and $k = d/D$

3. ***Design of key***

- The coupling key is usually made into two parts so that the length of the key in each shaft
- Total length of the coupling key is atleast equal to the length of the sleeve (*i.e. 3.5 d).*

i.e., $l = L/2 = (3.5d)/2$
(We have already discussed the design of keys)
Considering shearing of the key,
Torque, $T = F \times (d/2) = l \times w \times \tau \times (d/2)$ ...(i)
Considering crushing of the key,
Torque, $T = F \times (d/2) = l \times (t/2) \times \sigma_c \times (d/2)$ ...(ii)

Problems:

1. A line shaft is to transmit 40KW at 150rpm. The shaft pieces are connected by muff coupling. Design the coupling assuming an overload of 20%. Shear stress for shaft and key is given as 40MPa. Crushing stress for key material = 90MPa, Shear stress for Muff material = 15MPa.
2. Design a muff coupling which is used to connect two steel shafts transmitting 40KW at 350rpm. Design shaft and muff from strength point of view and other dimensions by empirical formulae. Safe shear stress for muff and shaft are 15MPa and 30MPa. Assume maximum torque to be 25% more than mean torque.

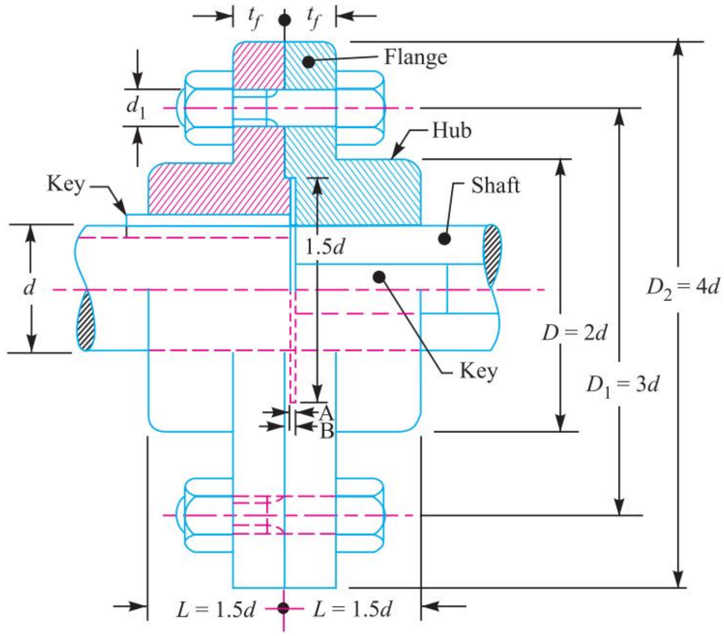
Flange Coupling

Flange coupling consists of two flanges keyed to the shafts. The flanges are connected together by means of bolts arranged on a circle concentric to shaft. Power is transmitted from driving shaft to flange on driving shaft through key, from flange on driving shaft to the flange on driven shaft through bolts and then to the driven shaft through key again.

Types :

- Unprotected type flange coupling
- Protected type flange coupling
- Marine type flange coupling

Design of Unprotected type Flange Coupling



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
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 = 4 d
Thickness of flange, t_f = 0.5 d

Number of bolts = 3, for d up to 40 mm
= 4, for d up to 100 mm
= 6, for d up to 180 mm

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

$$\mathbf{T = (\pi/16) \times \tau_c \times [(D^4-d^4)/D] = (\pi/16) \times \tau_c \times D^3(1-k^4)}$$

and k = d/D

2. Design for key

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

$= \pi D \times t_f \times \tau_c \times (D/2) = (\pi D^2/2) \times \tau_c \times t_f$

4. Design for bolts

Diameter of bolt = d_1

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

$\therefore$ Total load on all the bolts

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

and torque transmitted,

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