

# Course: Machine Design-I: MEC-212

## Unit-2 Levers

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## LEVERS

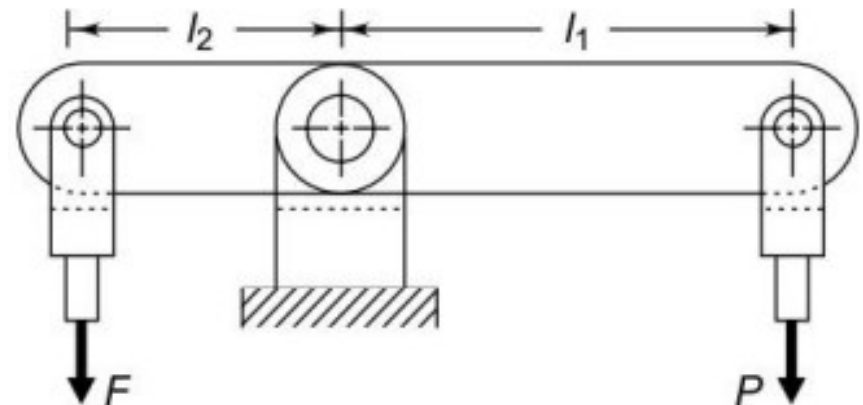
- A lever is defined as a mechanical device in the form of a rigid bar pivoted about the **fulcrum** to multiply or transfer the force.

Taking moment of forces about the fulcrum,

$$F \times l_2 = P \times l_1$$

or

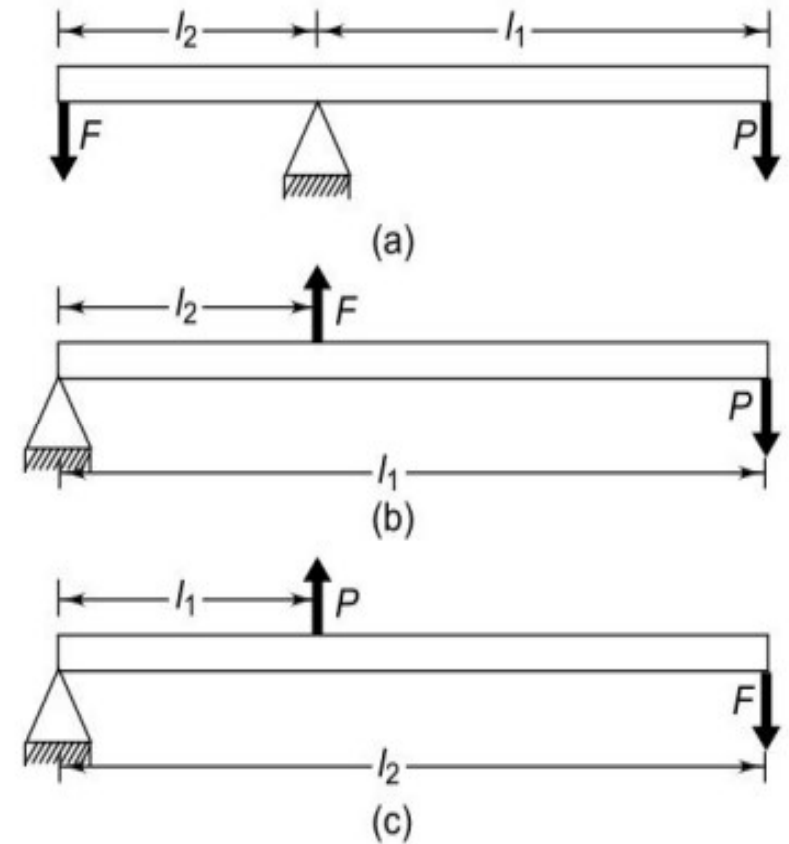
$$\frac{F}{P} = \frac{l_1}{l_2}$$



- The ratio of **Load (F)** to **Effort (P)** is called the **Mechanical Advantage (MA)** of the lever.
- The ratio of the **Effort arm ( $l_1$ )** to the **Load arm ( $l_2$ )** is called **Leverage**.

## TYPES OF LEVERS

- **First Type:** Fulcrum is located between the load and the effort. Effort arm is kept more than the load arm to get MA. Used in applications like the rocker arm for the overhead valves of internal combustion engine, bell crank levers in railway signal mechanisms and levers of hand pumps.
- **Second Type:** Load is located between the fulcrum and the effort. Effort arm is always more than the load arm and the MA is more than 1. Used in lever-loaded safety valves mounted on the boilers.
- **Third Type:** Effort is located between the load and the fulcrum. Load arm is always greater than the effort arm and the MA is less than 1. Not recommended in engineering applications.

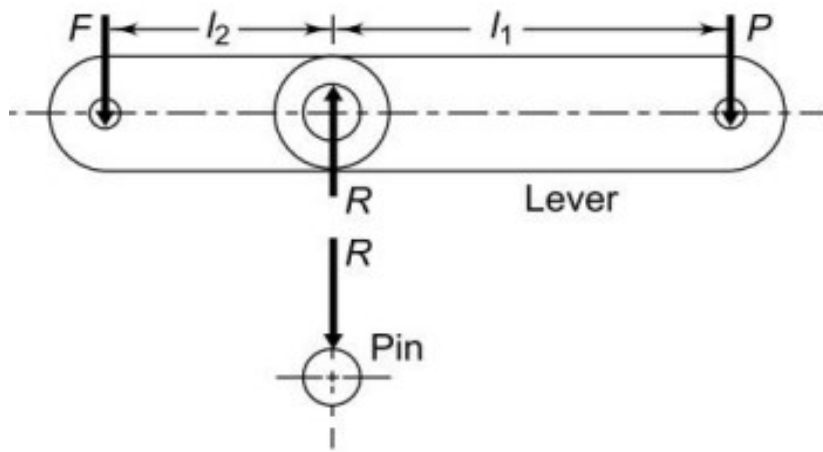


Types of Lever

# Design of Bell Crank Lever

1. Force Analysis
2. Design of Lever Arm
3. Design of Fulcrum Pin

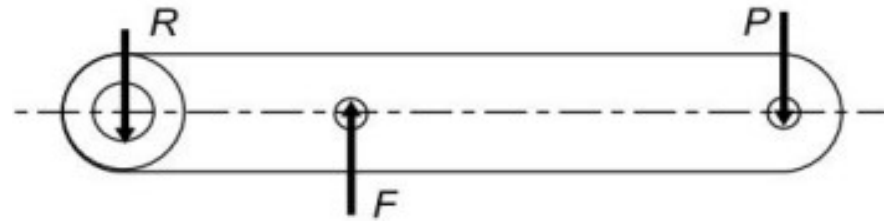
# Force Analysis



*Free body Diagram of Forces acting on First type of Lever*

$R$  is the reaction at the fulcrum pin.

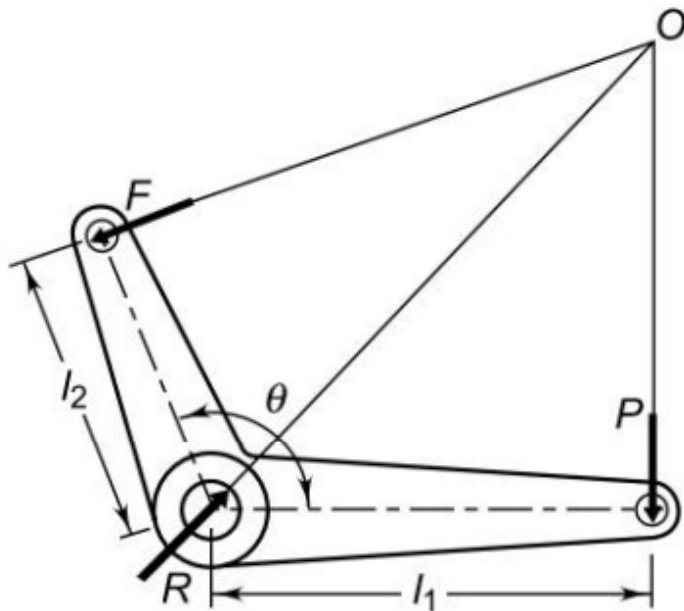
$$R = F + P$$



*Free body Diagram of Forces acting on Second type of Lever*

$$R = F - P$$

# Force Analysis



When the arms of the bell-crank lever are at right angles to one another,

$$\theta = 90^\circ \text{ and } \cos \theta = 0$$

Therefore,

$$R = \sqrt{F^2 + P^2}$$

$$R = \sqrt{F^2 + P^2 - 2FP \cos \theta}$$

## Design of Lever Arm

- The cross-section of the lever is subjected to bending moment. BM is maximum at section XX and it is given by

$$M_b = P (l_1 - d_1)$$

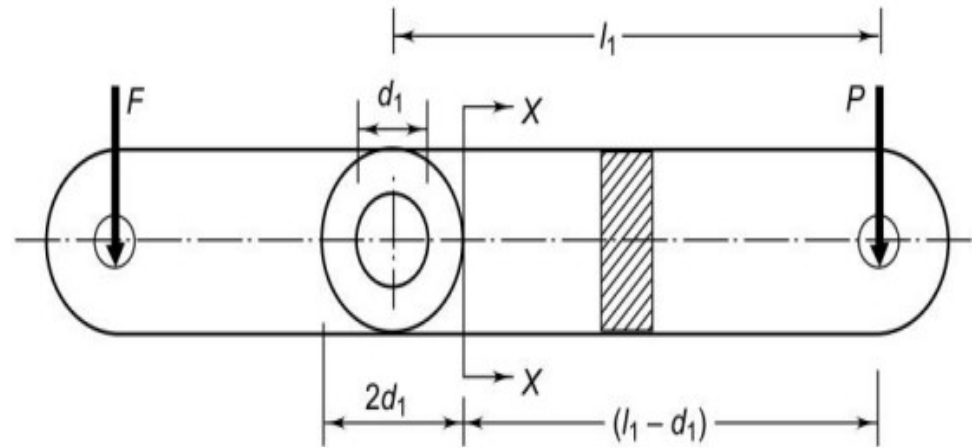
- The cross-section of the lever can be **rectangular, elliptical or I-section**

For a rectangular cross-section,

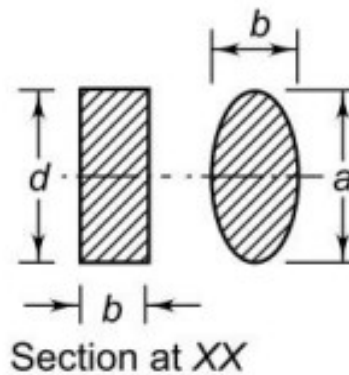
$$I = \frac{bd^3}{12} \quad \text{and} \quad y = \frac{d}{2}$$

For an elliptical cross-section,

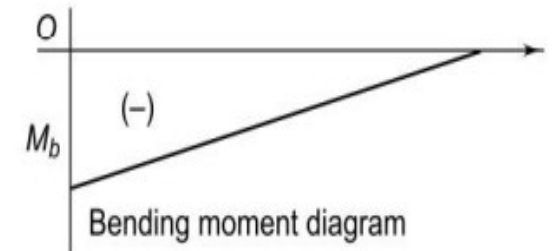
$$I = \frac{\pi ba^3}{64} \quad \text{and} \quad y = \frac{a}{2}$$



(a)



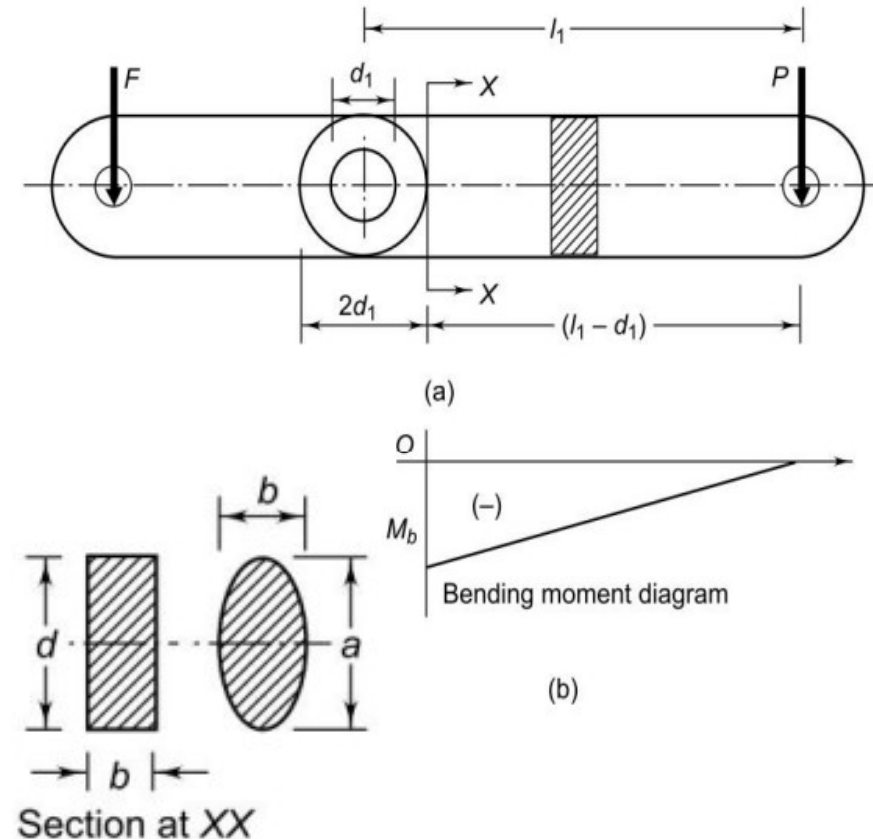
Section at XX



(b)

## Design of Lever Arm

- The thickness of lever (**d**) is kept uniform throughout.
- The width of the lever (**b**) is tapered from boss to the handle because the arm is subjected to varying bending moment which is maximum near the boss and decreases to the end and also for easy gripping of the hand on lever.

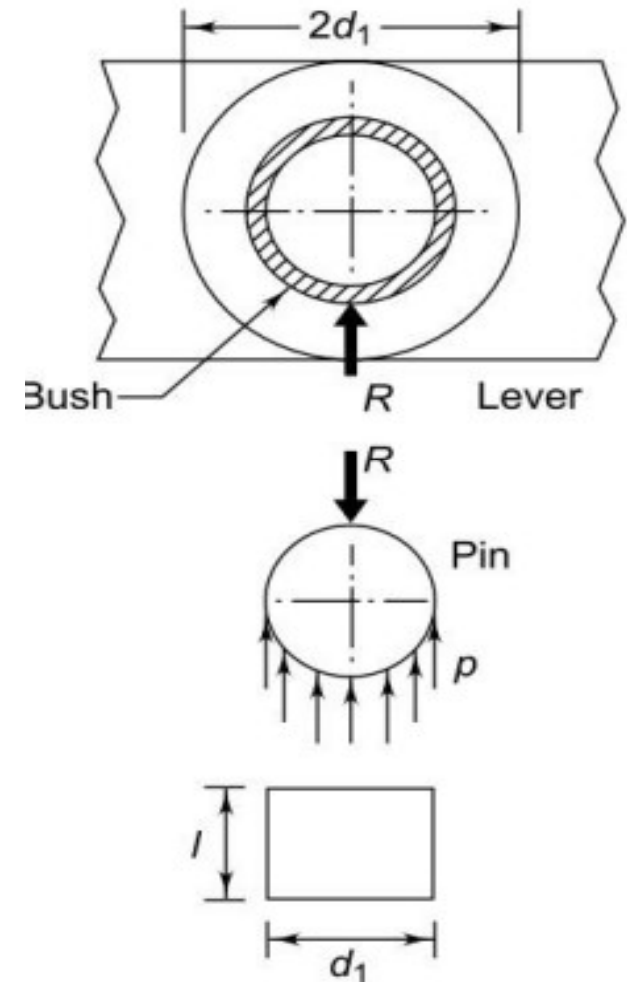


## Design of Fulcrum Pin

- The fulcrum pin is subjected to reaction  $R$  as shown.
- Dimensions of the pin i.e., **diameter  $d_1$**  and **length  $l_1$**  in lever boss are determined by bearing consideration and then checked for shearing.
- There is relative motion between the pin and the boss of lever and bearing pressure becomes the design criterion. The projected area of the pin is ( $d_1 \times l_1$ ). Therefore,

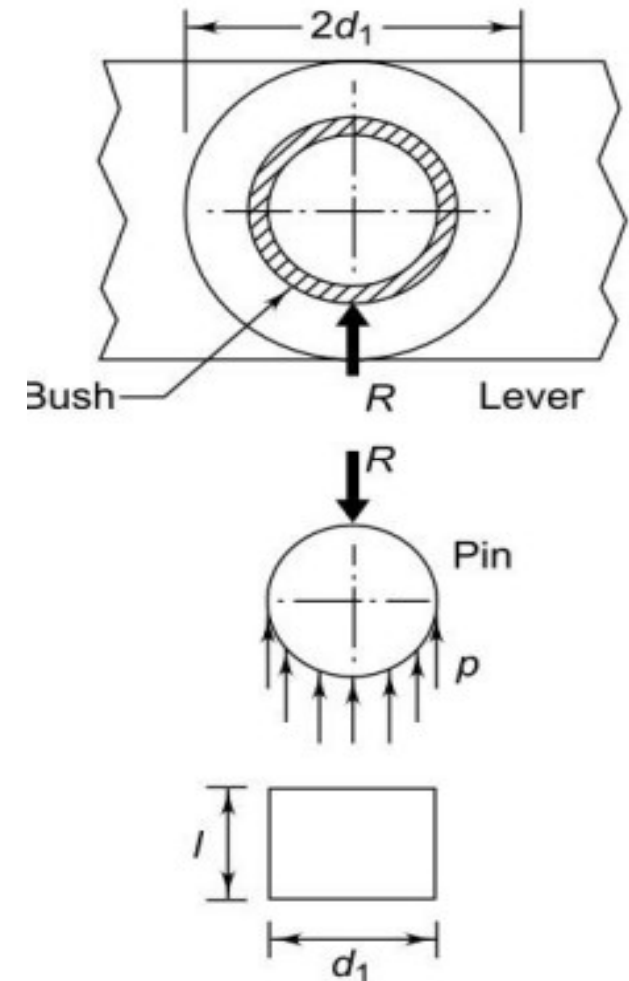
$$R = p_b(d_1 \times l_1)$$

where  $p_b$  is the permissible bearing pressure

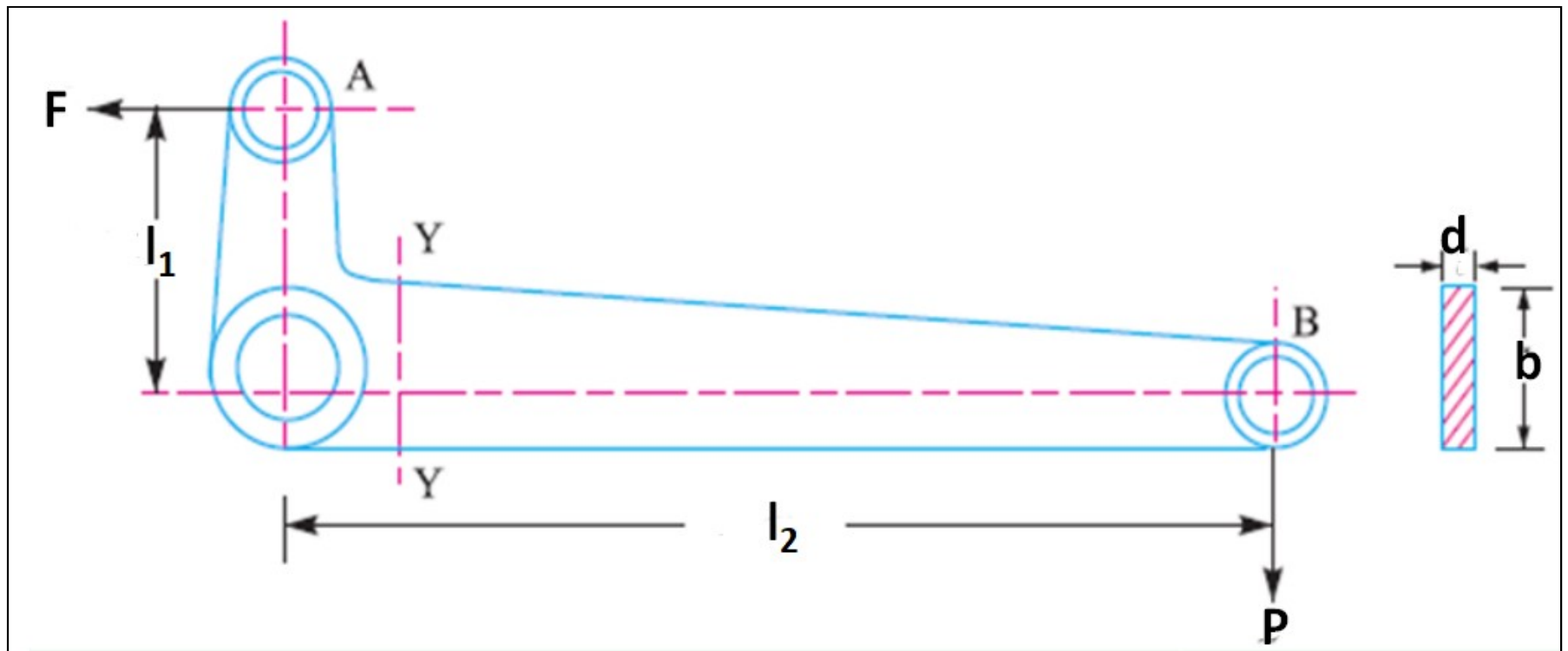


## Design of Fulcrum Pin

- For the fulcrum pin, the ratio of length to diameter ( $l_1/d_1$ ) is usually taken from 1 to 2.
- The outside diameter of the boss in the lever is taken as twice of the diameter of the pin, i.e., ( $2d_1$ ).
- A phosphor bronze bush, usually 3 mm thick, is fitted inside the boss to reduce the friction. The permissible bearing pressure for a phosphor bronze bush is 5 to 10 N/mm<sup>2</sup>.



Q Design a bell crank lever to carry a load of 35 kN at the end of a vertical arm. The mechanical advantage is 5 and the effort is to be applied in vertical direction at the end of a horizontal arm 800 mm in length. The allowable stresses in tension and shear for both lever and pin materials are 80 and 50 N/mm<sup>2</sup> respectively and allowable bearing pressure is 12 N/mm<sup>2</sup>. Take a phosphorus bronze bush of 2.5 mm thickness.



## Design steps

### 1. Calculation of Load or Effort or their lengths:

$$\text{Mechanical Advantage (M.A.)} = \frac{F}{P} = \frac{l_2}{l_1}$$

where, P = Small Effort to be applied (N)

F = Load to be moved (N)

$l_1$  = length of load arm (mm)

$l_2$  = length of effort arm (mm)

From the given information, find the effort P and length  $l_1$ .

## Design steps

### 2. Lever Pin Design:

a) Resultant load on pin,  $R = \sqrt{F^2 + P^2}$

b) From bearing consideration of pin,  $R = p_b ld$

where,  $l$  is the length of pin

And  $d$  is the diameter of pin

Taking,  $\frac{l}{d} = 1 - 2.5$ , solve and find  $l$  and standard  $d$  of the pin.

c) Considering the double shear failure of pin

$$R = 2 \cdot \tau \cdot \frac{\pi}{4} d^2$$

We find induced shear stress in pin as  $\tau_i$  and check that it is  $< \tau_{per}$  of pin material.

d) Bending stress in pin,

$$\sigma_b = \frac{M}{z} = \frac{Rl/6}{(\pi/32)d^3}$$

check that it is  $< \sigma_{per}$  of pin material. Else we increase diameter  $d$  of the pin

## Design steps

### 3. Checking the safety of boss:

Considering a brass bush of thickness  $t$  mm

Diameter of bush,  $d' = d + 2t$

Outer diameter of boss,  $D = 2d$

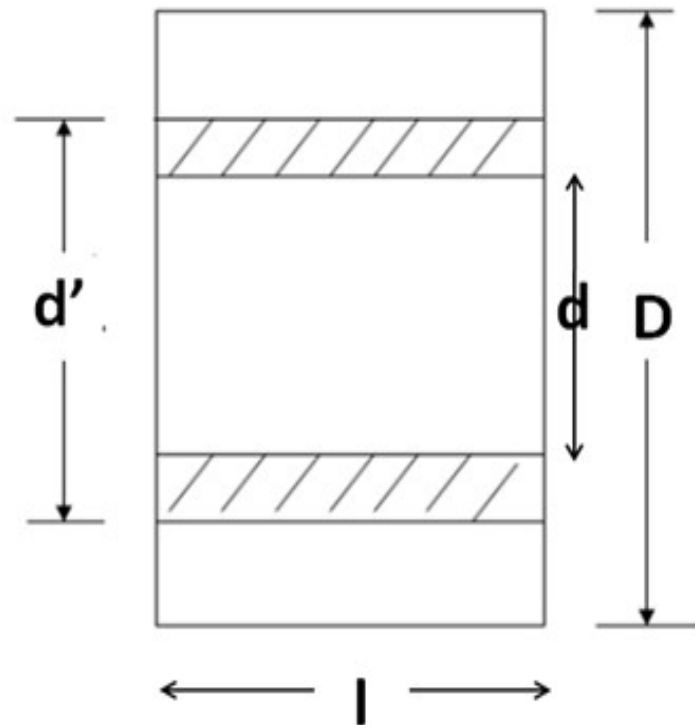
Section Modulus of boss section,

$$z' = \frac{\frac{1}{12}l(D^3 - d^3)}{\frac{D}{2}}$$

Bending stress at boss,

$$\sigma_b = \frac{M}{z'} = \frac{Pl_2}{z'}$$

Check that above  $\sigma_b < \sigma_{\text{per}}$  of lever material. Else we increase diameter  $D$  of the boss in steps of 2 mm until this condition is met.



## Design steps

### 4. Lever Pin Design:

Considering  $b/d$  = width to depth ratio of lever body as 1/4 to 1/3.

Considering section at length  $l'$  near fulcrum so that  $l' = l_2 - (30 - 50mm)$

Bending stress at this section

$$\sigma_{b'} = \frac{M}{z''} = \frac{Pl'}{\frac{bd^2}{6}} = \sigma_{per} \text{ of lever material}$$

Find  $b$  &  $d$ . and check that  $d < 1$ , Else reiterate.

## Design steps

### 5. Effort Pin Design:

e) Load on effort pin is 'P' N

f) From bearing consideration of pin,  $P = p_b l_e d_e$

where,  $l_e$  is the length of effort pin

and  $d_e$  is the diameter of effort pin

Taking,  $\frac{l_e}{d_e} = 1 - 2.5$ , solve and find  $l_e$  and standard  $d_e$  of the pin.

g) Considering the double shear failure of pin

$$W = 2 \cdot \tau \cdot \frac{\pi}{4} d_e^2$$

We find induced shear stress in effort pin as  $\tau_i$  and check that it is  $< \tau_{per}$  of pin material.

h) Bending stress in effort pin,

$$\sigma_b = \frac{M}{z} = \frac{Pl_e/6}{(\pi/32)d_e^3}$$

check that it is  $< \sigma_{per}$  of effort pin material. Else we increase diameter  $d$  of the effort pin.

### 6. Load Pin Design:

Due to comparable loads we use the same load pin as the fulcrum pin.