Lecture # 4.1

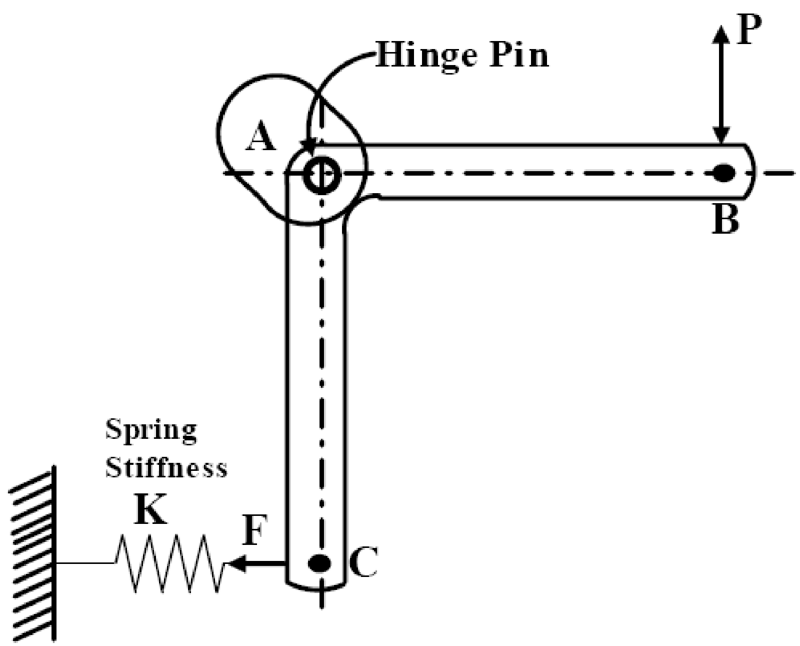
Stresses and Factor of Safety

Stresses

Introduction

Stresses are developed in machine elements due to applied load and machine design involves ensuring that the elements can sustain the induced stresses without yielding.

Consider a simple lever as shown in figure -1:

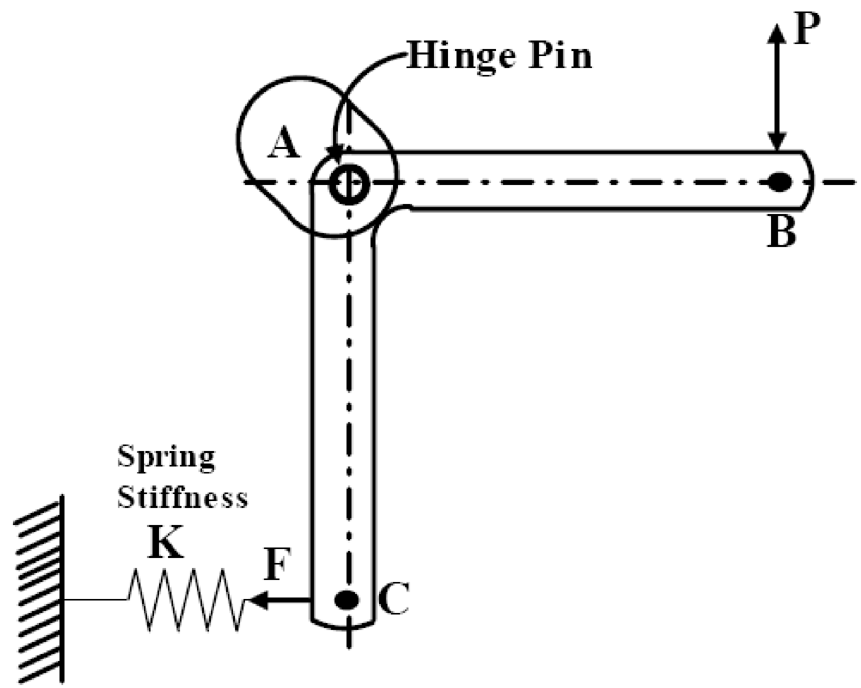


Stresses

A proper design of the spring would ensure the necessary force P at the lever end B.

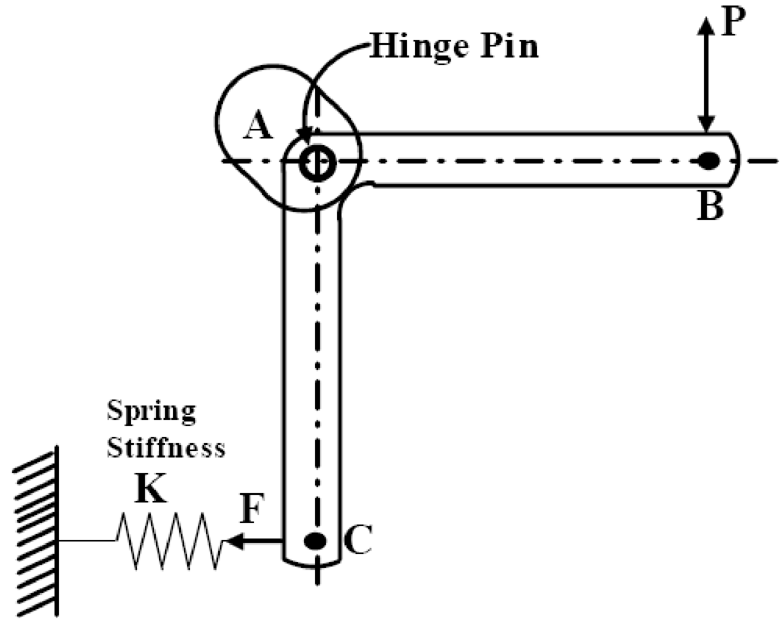
The stresses developed in sections AB and AC would decide the optimum cross-section of the lever provided that the material has been chosen correctly.

The design of the hinge depends on the stresses developed due to the reaction forces at A.



Stresses

A closer look at the arrangement would reveal that the following types of stresses are developed in different elements:



Lever arms AB and AC - Bending stresses

Hinge pin - Shear and bearing stresses.

Spring - Shear stress.

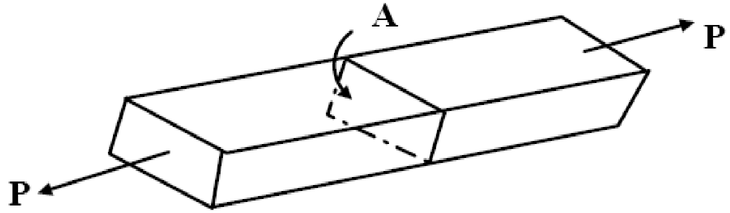
It is therefore important to understand the implications of these and other simple stresses.

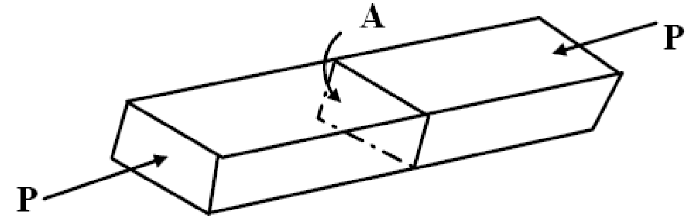
Stresses

Some basic types of simple stresses

Tensile stress

The stress developed in the bar (figure) subjected to tensile loading is given by $\sigma_t = \dfrac{P}{A}$

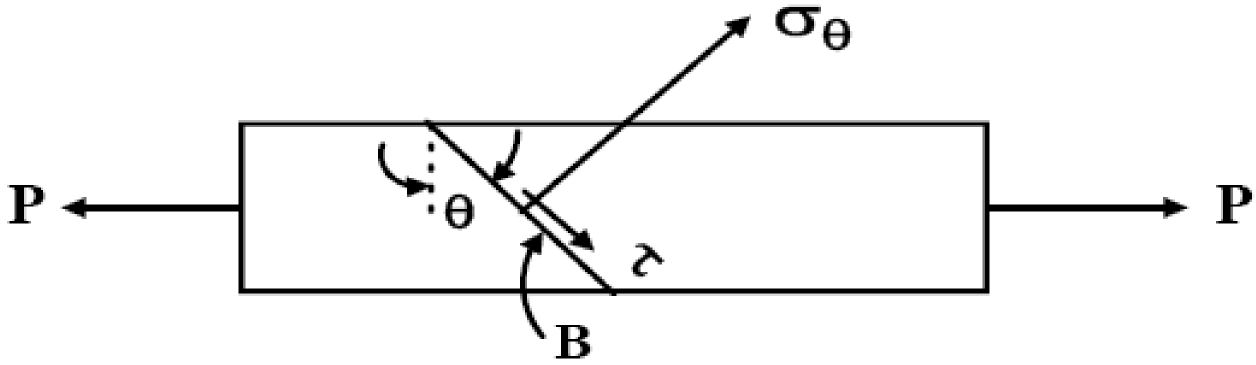




Compressive stress

The stress developed in the bar (figure) subjected to compressive loading is given by $\sigma_c = \dfrac{P}{A}$

Stresses



the normal stress perpendicular to the section is $\sigma_\theta = \dfrac{P\cos\theta}{A/\cos\theta}$

and shear stress parallel to the section $\tau = \dfrac{P\sin\theta}{A/\cos\theta}$

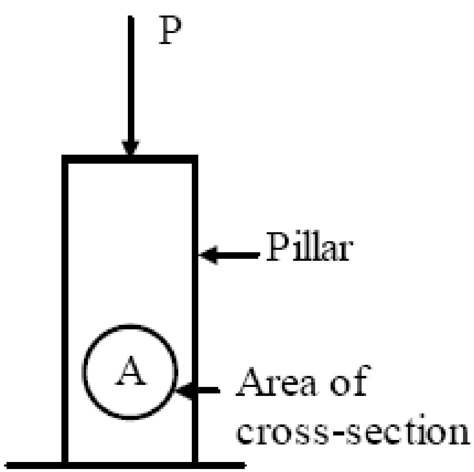
Stresses

Bearing stress

When a body is pressed against another, the compressive stress developed is termed bearing stress.

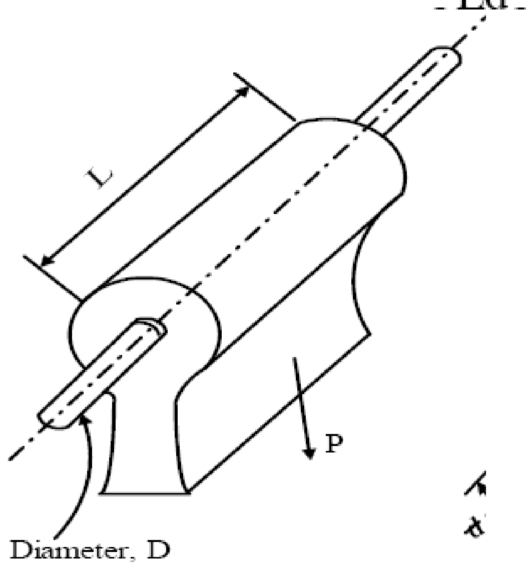
For example, bearing stress developed at the contact between a pillar and ground is

$$\sigma_{br} = \frac{P}{A}$$



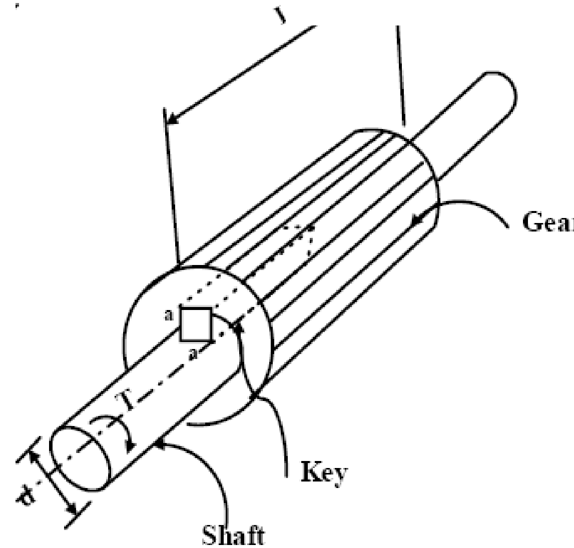
At the contact surface between a pin and a member with a circular hole is

$$\sigma_{br} = \frac{P}{Ld}$$



At the faces of a rectangular key fixing a gear hub on a shaft is

$$\sigma_{br} = \frac{4T}{aLd}$$



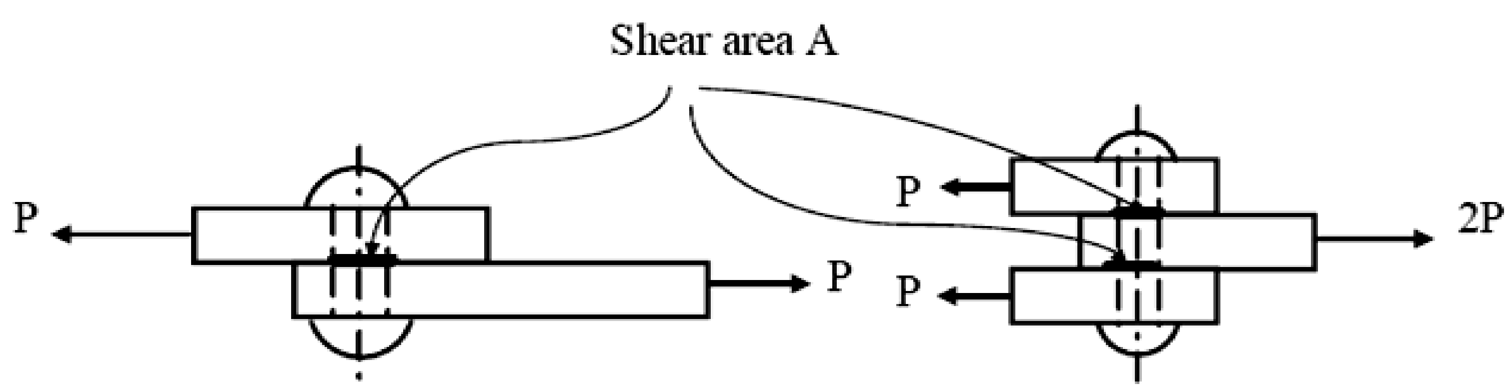
Stresses

Shear stress

When forces are transmitted from one part of a body to other, the stresses developed in a plane parallel to the applied force are the shear stresses (figure) and the average values of the shear stresses are given by

$$\tau = \frac{P}{A} \quad \text{in single shear}$$

$$\tau = \frac{P}{2A} \quad \text{in double shear}$$



Stresses

Bending Streses

For any fibre at a distance of y from the centre line we may therefore write

$$\sigma = \frac{My}{I}$$

We therefore have the general equation for pure bending as

$$\frac{\sigma}{y} = \frac{M}{I} = \frac{E}{R}$$

Stresses

Shear stress in bending

$$\tau = \frac{F}{I\,.\,b} \times A.\bar{y}$$

where F = Vertical shear force acting on the section,
I = Moment of inertia of the section about the neutral axis,
b = Width of the section under consideration,
A = Area of the beam above neutral axis, and
y = Distance between the C.G. of the area and the neutral axis.

Torsional Stress

the general torsion equation for circular shafts as

$$\frac{T}{J} = \frac{\tau}{r} = \frac{G\theta}{l}$$

Stresses

Buckling

The compressive stress of P/A is applicable only to short members but for long compression members there may be buckling, which is due to elastic instability.

The critical load for buckling of a column with different end fixing conditions is given by Euler's formula

$$P_{cr} = n \frac{\pi^2 EI}{l^2}$$

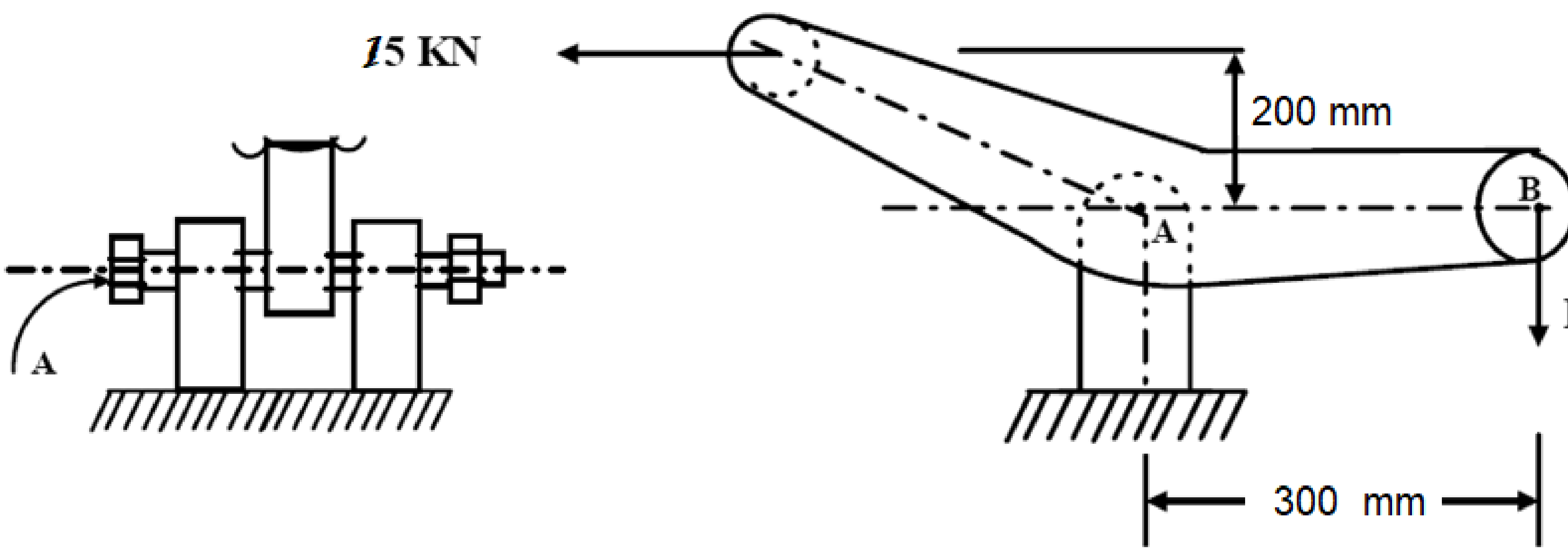
where E is the elastic modulus, I the second moment of area, l the column length and n is a constant that depends on the end condition.

For columns with both ends hinged n=1, columns with one end free and other end fixed n=0.25,

columns with one end fixed and other end hinged n=2, and for columns with both ends fixed n=4.

Stresses

What stresses are developed in the pin A for the bell crank mechanism shown in the figure.? Find the safe diameter of the pin if the allowable tensile and shear stresses for the pin material are 350 MPa and 170 MPa respectively.



Factor of Safety

Factor of safety is defined as the "ratio of critical load to safe load".

When related to stresses it is defined as the "ratio of Ultimate stress to design stress"

The factor of safety provides the margin by which there is safety even when unseen situations arise.

Factor of Safety

If we design with the exact breaking stress, then there is risk that the component will fail as soon as any undesirable situation results in higher stress than that of breaking stress.

On the other hand, choosing higher factor of safety will result in heavier design and more material cost.

So wise selection of the factor of safety is necessary so as to reach the golden point between economy and safety.

Factor of Safety

$$Factor\ of\ safety = \frac{Yield\ stress}{Design\ stress} ......For\ ductile\ material$$

$$Factor\ of\ safety = \frac{Ultimate\ stress}{Design\ stress} ......For\ brittle\ material$$

Factor of Safety

Following are the factors which are mainly considered while deciding the appropriate value of factor of safety.

1) Type/Nature of load:

Different types of loads demand different values of factor of safety.

When the load is certain and not changing, we may go for lower value of factor of safety,

but for the impact or suddenly applied load or the load which fluctuates more, we need to have higher value of FOS.

Factor of Safety

2) Certainity of load analysis :

If the given load is expected to have very less variations, though uncertain, the recommended FOS can be a low value.

But if the uncertainity is of larger magnitude and exact load analysis is not known it is better to go for the higher fos.

3) Expected overloading :

Engineering objects are always subjected to overload during their use.

Such overload cannot be ignored, so sufficient strength must be kept reserved for such situations.

Factor of Safety

4) Type of material used :

certain materials like rolled Steel bars, forged materials etc are very reliable in their strength.

but some materials like wood, stone, cast iron are not reliable in their strength.

for lesser reliable materials higher factor of safety is choosen.

Factor of Safety

5) Type of manufacturing process :

certain manufacturing processes does not hamper the strength prediction of material,

but some manufacturing processes like welding alter the strength of material.

Hence in such situations where the manufacturing process impacts the strength of material,

It is wise to choose higher factor of safety.

Factor of Safety

6) Risk of life :

if the failure of the component can result in loss of human life damage to the property it is always preferred to have how a factor of safety.

7) Economical consideration :

as we go for higher factor of safety the design goes on becoming more and more bulky, as well as no cost is involved,

so from economy point of view we always try to keep the value of factor of safety to an optimum level.

References

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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.

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Stresses

Force at B = $\frac{5x0.1}{0.15} = 3.33\,KN$

Resultant force at A= $\sqrt{5^2 + 3.33^2}$ kN = 6 kN.

Stresses developed in pin A: (a) shear stress (b) bearing stress

Considering double shear at A, pin diameter d = $\sqrt{\frac{2x6x10^3}{\pi x170x10^6}}\ m = 4.7\,mm$

Considering bearing stress at A, pin diameter d = $\frac{6x10^3}{0.01x7.5x10^6}\,m = 8mm$

A safe pin diameter is 10 mm.