SIR CHHOTU RAM INSTITUTE OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF MECHANICAL ENGINEERING

RENEWABLE ENERGY RESOURCES (BT-806)

STUDY MATERIAL ON FRICTION

interlocking property of the projecting particles opposes the motion. This opposing force, which acts in the opposite direction of the movement of the block, is called *force of friction* or simply *friction*. It is of the following two types:

1. Static friction. 2. Dynamic friction.

6.2. Static Friction

It is the friction experienced by a body when it is at rest. Or in other words, it is the friction when the body tends to move.

6.3. Dynamic Friction

It is the friction experienced by a body when it is in motion. It is also called kinetic friction. The dynamic friction is of the following two types :

1. ***Sliding friction.*** It is the friction, experienced by a body when it slides over another body.
2. ***Rolling friction.*** It is the friction, experienced by a body when it rolls over another body.

6.4. Limiting Friction

It has been observed that when a body, lying over another body, is gently pushed, it does not move because of the frictional force, which prevents the motion. It shows that the force of the hand is being exactly balanced by the force of friction, acting in the opposite direction. If we again push the body, a little harder, it is still found to be in equilibrium. It shows that the force of friction has increased itself so as to become equal and opposite to the applied force. Thus the force of friction has a remarkable property of adjusting its magnitude, so as to become exactly equal and opposite to the applied force, which tends to produce motion.

There is, however, a limit beyond which the force of friction cannot increase. If the applied force exceeds this limit, the force of friction cannot balance it and the body begins to move, in the direction of the applied force. This maximum value of frictional force, which comes into play, when a body just begins to slide over the surface of the other body, is known as limiting friction. It may be noted that when the applied force is less than the limiting friction, the body remains at rest, and the friction is called static friction, which may have any value between zero and limiting friction.

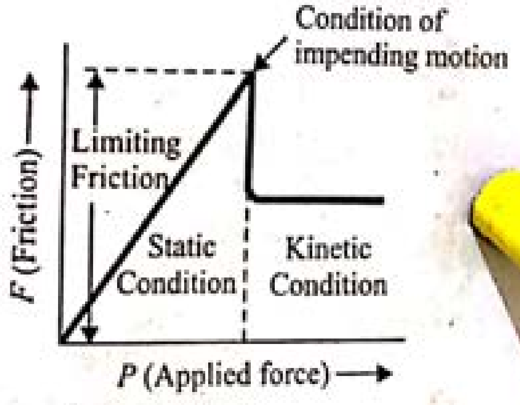


Fig. 6a

6.5. Normal Reaction

It has been experienced that whenever a body, lying on a horizontal or an inclined surface, is in equilibrium, its weight acts vertically downwards through its centre of gravity. The surface, in turn, exerts an upward reaction on the body. This reaction, which is taken to act perpendicular to the plane, is called normal reaction and is, generally, denoted by R. It will be interesting to know that the term 'normal reaction' is very important in the field of friction, as force of friction is directly proportional to it.

6.6. Angle of Friction

Consider a body of weight W resting on an inclined plane as shown in Fig. 6.1. We know that the body is in equilibrium under the action of the following forces :

1. Weight (W) of the body, acting vertically downwards,
2. Friction force (F) acting upwards along the plane, and
3. Normal reaction (R) acting at right angles to the plane.

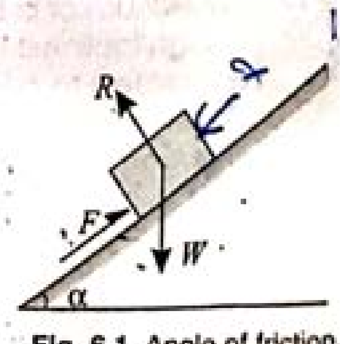


Fig. 6.1. Angle of friction.

Let the angle of inclination (α) be gradually increased, till the body just starts sliding down the plane. This angle of inclined plane, at which a body just begins to slide down the plane, is called the angle of friction. This is also equal to the angle, which the normal reaction makes with the vertical.

6.7. Coefficient of Friction

It is the ratio of limiting friction to the normal reaction, between the two bodies, and is generally denoted by μ.

Mathematically, coefficient of friction,

$$\mu = \frac{F}{R} = \tan\phi \qquad \text{or} \qquad F = \mu R$$

where ϕ = Angle of friction,
F = Limiting friction, and
R = Normal reaction between the two bodies.

6.7.1. Cone of Friction

The Fig. 8b shows a body of weight W acted upon by a force P. If the line OA making the maximum angle of friction ϕ with the normal, is revolved about OB as an axis, the cone generated is called the **cone of friction**.

If the resultant R of the normal reaction N and the force of friction F, falls within the cone of friction, the forces acting on the body are not great enough to cause the motion.

This principle is used in **self locking mechanisms** and also **in taperpins**. For example, if the angle of taper pin is less than the angle of friction, no force at right angle to the axis of the pim could cause it to move in the direction of its axis.

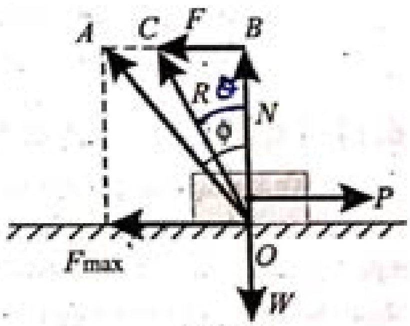


Fig. 6b

Note : *The problem on friction can be solved by resolving the forces parallel and perpendicular to the plane. However, use of Lami's theorem proves quite convenient when three coplanar concorrent forces keep the body in equilibrium.*

6.8. Laws of Friction

Prof. Coulomb, after extensive experiments, gave some laws of friction, which may be grouped under the following heads :

1. Laws of static friction, and
2. Laws of kinetic or dynamic friction.

6.9. Laws of Static Friction

Following are the laws of static friction :

1. The force of friction always acts in a direction, opposite to that in which the body tends to move, if the force of friction would have been absent.
2. The magnitude of the force of friction is exactly equal to the force, which tends to move the body.
3. The magnitude of the limiting friction bears a constant ratio to the normal reaction between the two surfaces. Mathematically :

$$\frac{F}{R} = \text{Constant}$$

where F = Limiting friction, and
R = Normal reaction.

4. The force of friction is independent of the area of contact between the two surfaces.
5. The force of friction depends upon the roughness of the surfaces.

This rock climber uses the static frictional force between his hands and feet and the vertical rock walls.

6.10. Laws of Kinetic or Dynamic Friction

Following are the laws of kinetic or dynamic friction :

1. The force of friction always acts in a direction, opposite to that in which the body is moving.
2. The magnitude of kinetic friction bears a constant ratio to the normal reaction between the two surfaces. But this ratio is slightly less than that in case of limiting friction.
3. For moderate speeds, the force of friction remains constant. But it decreases slightly with the increase of speed.

6.11. Equilibrium of a Body on a Rough Horizontal Plane

We know that a body, lying on a rough horizontal plane will remain in equilibrium. But whenever a force is applied on it, the body will tend to move in the direction of the force. In such cases, equilibrium of the body is studied first by resolving the forces horizontally and then vertically. Now the value of the force of friction is obtained from the relation :

$$F = \mu R$$

where μ = Coefficient of friction, and

R = Normal reaction.

Example 6.1. *A body of weight 300 N is lying on a rough horizontal plane having a coefficient of friction as 0.3. Find the magnitude of the force, which can move the body, while acting at an angle of 25° with the horizontal.*

Solution. Given: Weight of the body (W) = 300 N; Coefficient of friction (μ) = 0.3 and angle made by the force with the horizontal (α) = 25°

Let P = Magnitude of the force, which can move the body,

F = Force of friction.

Resolving the forces horizontally,

$$F = P\cos\alpha = P\cos 25° = P \times 0.9063$$

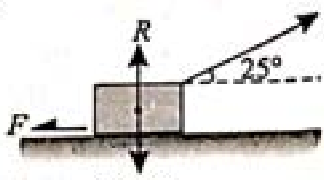


Fig. 6.2.

and now resolving the forces vertically,

$$R = W - P\sin\alpha = 300 - P\sin 25°$$
$$= 300 - P \times 0.4226$$

We know that the force of friction (F),

$$0.9063\,P = \mu R = 0.3 \times (300 - 0.4226\,P) = 90 - 0.1268\,P$$

or

$$90 = 0.9063\,P + 0.1268\,P = 1.0331\,P$$

$$\therefore \quad P = \frac{90}{1.0331} = 87.1 \text{ N} \quad \textbf{Ans.}$$

Example 6.2. *A body, resting on a rough horizontal plane, required a pull of 180 N inclined at 30° to the plane just to move it. It was found that a push of 220 N inclined at 30° to the plane just moved the body. Determine the weight of the body and the coefficient of friction.*

Solution. Given: Pull = 180 N; Push = 220 N and angle at which force is inclined with horizontal plane (α) = 30°

Let W = Weight of the body

R = Normal reaction, and

μ = Coefficient of friction.

First of all, consider a pull of 180 N acting on the body. We know that in this case, the force of friction (F_1) will act towards left as shown in Fig. 6.3. (*a*).

Resolving the forces horizontally,

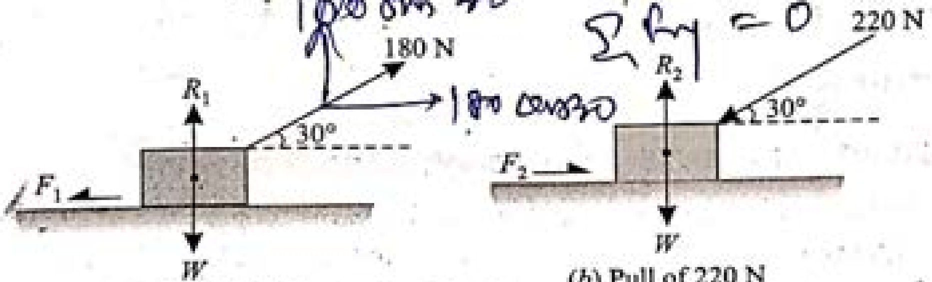
$$F_1 = 180 \cos 30° = 180 \times 0.866 = 155.9 \text{ N}$$

and now resolving the forces vertically,

$$R_1 = W - 180 \sin 30° = W - 180 \times 0.5 = W - 90 \text{ N}$$

We know that the force of friction (F_1),

$$155.9 = \mu R_1 = \mu (W - 90) \qquad ...(i)$$



(*a*) Pull of 180 N

(*b*) Pull of 220 N

Fig. 6.3.

Now consider a push of 220 N acting on the body. We know that in this case, the force of friction (F_2) will act towards right as shown in Fig. 6.3 (*b*).

Resolving the forces horizontally,

$$F_2 = 220 \cos 30° = 220 \times 0.866 = 190.5 \text{ N}$$

and now resolving the forces horizontally,

$$R_2 = W + 220 \sin 30° = W + 220 \times 0.5 = W + 110 \text{ N}$$

We know that the force of friction (F_2),

$$190.5 = \mu . R_2 = \mu (W + 110) \qquad ...(ii)$$

Dividing equation (*i*) by (*ii*)

$$\frac{155.9}{190.5} = \frac{\mu (W - 90)}{\mu (W + 110)} = \frac{W - 90}{W + 110}$$

$$155.9\ W + 17\ 149 = 190.5\ W - 17\ 145$$

$$34.6\ W = 34\ 294$$

or $$W = \frac{34\ 294}{34.6} = 991.2 \text{ N} \qquad \textbf{Ans.}$$

Now substituting the value of W in equation (*i*),

$$155.9 = \mu (991.2 - 90) = 901.2\ \mu$$

$\therefore$ $$\mu = \frac{155.9}{901.2} = 0.173 \qquad \textbf{Ans.}$$