# Lecture 9: Friction Part 2 –Engineering Applications of Friction

Friction forces appear extensively in engineering applications. Here we will investigate the action of these forces in the following systems

- Wedges
- Screws
- Journal bearings
- Thrust bearings (Disk friction)
- Flexible belts and cables

## Wedges

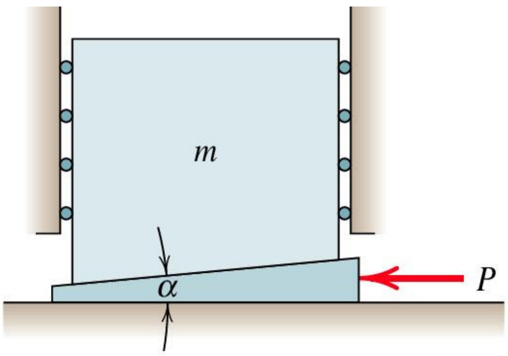



*Figure 1*

A wedge is a very simple tool used in mechanical applications and also found in everyday life, such as a door stopper. It is commonly used to ____________________ __________________or used to ____________________________________________ (see illustration in figure 1).

We will analyse the forces in the example system shown in figure 1.

***Force Analysis***

The wedge utilises the friction forces between itself and the object it is in contact with and also with the ground (or wall) it is resting upon.

A ______________________________________ is one whose friction forces acting on its surfaces are enough to keep the wedge and other objects it is in contact with, in ________________________________.

Consider the force *P* in figure 1. If its magnitude is large enough, it will move the wedge to the left and, as a result, the block of mass *m* will be pushed upwards.

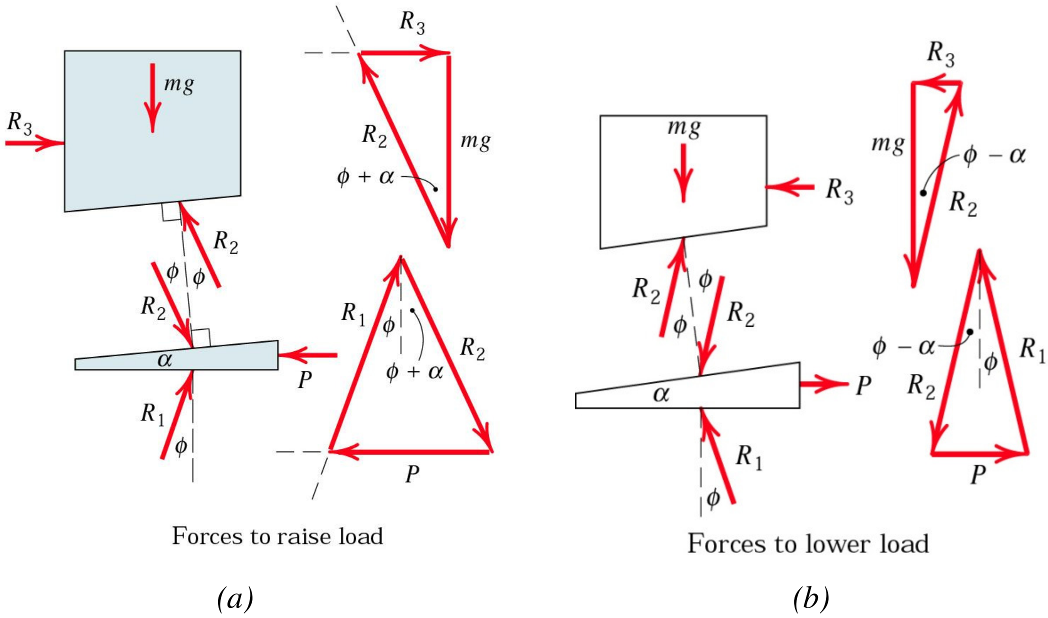



*Figure 2*

Now let us consider the free body diagrams of both blocks in such configuration as shown in figure 2a.

*Wedge:* $R_1$ is the resultant force exerted by the ground on the wedge. It is a combination of friction and a vertical component which supports the weight of the block. The reaction is inclined at an angle $\phi$ where $\tan\phi = \mu$.

$R_2$ is the resultant force exerted by the block on the wedge. It consists of the friction force between the block and the wedge, and the vertical component caused by the block's weight. This reaction is inclined at an angle $\phi$ to the normal to the wedge surface.

*Block:* The force $R_2$ that the block experiences is equal and opposite to the force $R_2$ acting on the wedge. A reaction $R_3$ must be present in order to keep the block in horizontal equilibrium. Finally, the weight of the block acts through its centre of gravity.

Similarly, if the force $P$ reverses its direction, the impending motion will result in the block being lowered. The free body diagrams of the block and the wedge are shown in figure 2b.

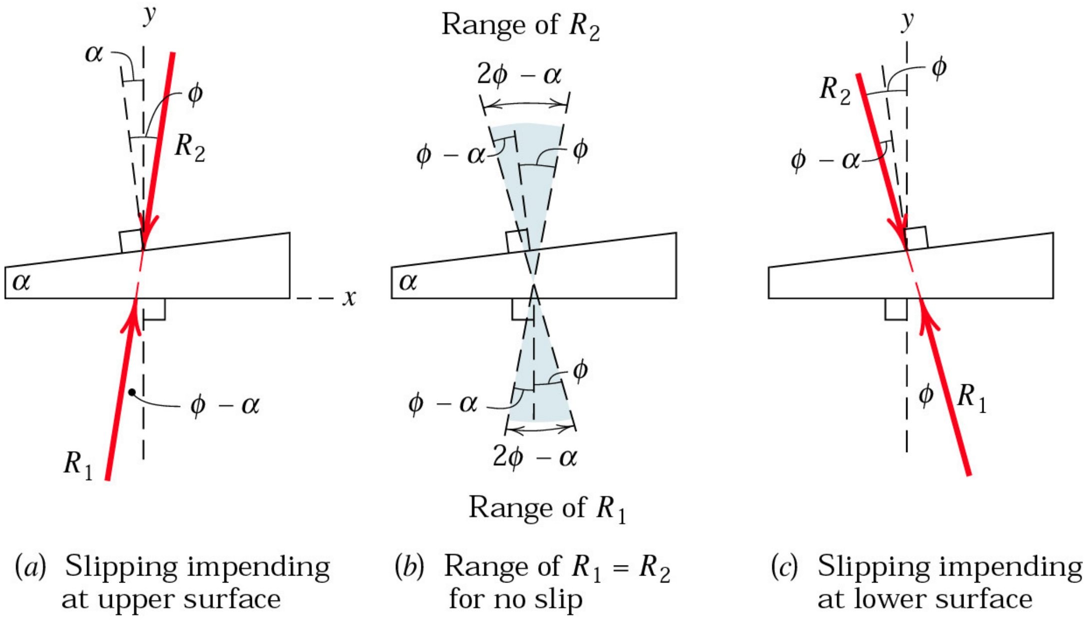



*Figure 3*

This system has three possible scenarios.

1. The block is ________________________________________. This is possible if the force $P$ is __________________________ enough to overcome the friction forces and the horizontal component of the weight $mg$. See figure 3a.

2. The block is ________________________________________. This is possible if (1) the force P is _______________________than the maximum possible combined horizontal force resisting the motion or (2) the force $P$ is ___________________ and the friction force is able to ____________________ the impending motion of the block due to its own weight. See figure 3b.

3. The block is _________________________. This is possible if (1) the direction of force P is __________________________ and the maximum friction force is _________________________ to resist the motion or (2) the force $P$ is _________________________ and the coefficient of friction between the surfaces is so _________________________ that slipping occurs. See figure 3c.

## Screws

Screws are used to ______________________________ or _______________________.

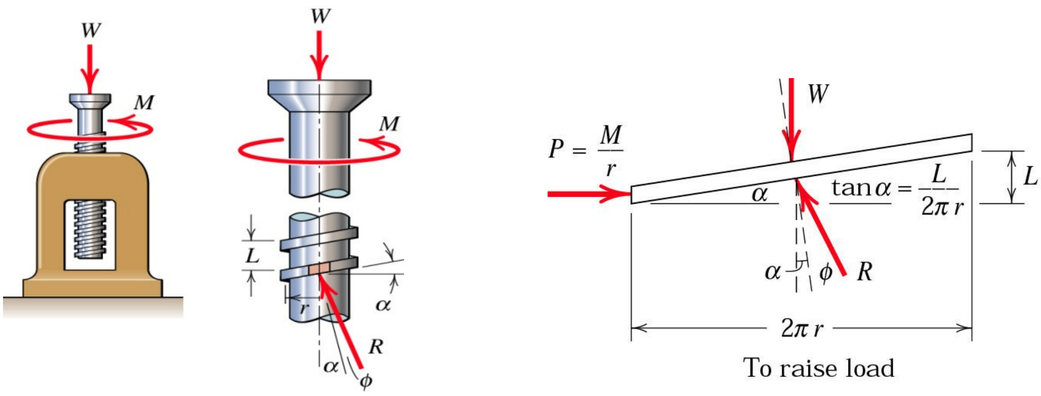
They function by employing the ______________________________________________.

Note that all screws analysed here are confined to those with square thread.

***Force Analysis***

In the following analysis, we will use the screw model shown in figure 4a. The length $L$ represents the ________________________________________________________.

The force $W$ may also represent a load, hence the entire system can be thought of as a jack which can lower or raise the load whose weight is $W$.




*(a)* *(b)*

*Figure 4*

*Raising the weight*

The free body diagram shown in figure 4b is a ________________________________ of the screw thread whose length is of one revolution; hence its height is represented by the lead $L$. The equilibrium equations of the system can be simplified to give the relationship

________________________________________

*Lowering the weight*

Using a similar approach, the free body diagrams of the straightened portion of the screw thread with impending downward motion are shown in figure 5.

In the case of figure 5a, the friction exerted on the screw is enough to keep the system ______________________________ even if the force $P$ _________________________, i.e. ________________________________________. Mathematically, this will happen if __________________. The equilibrium equation of this system is given by

__________________________________

In the case of figure 5b, the friction is so ______________________ that the load *W* will push the screw downward if force *P* is absent. The moment required to prevent unwinding is given by

__________________________________

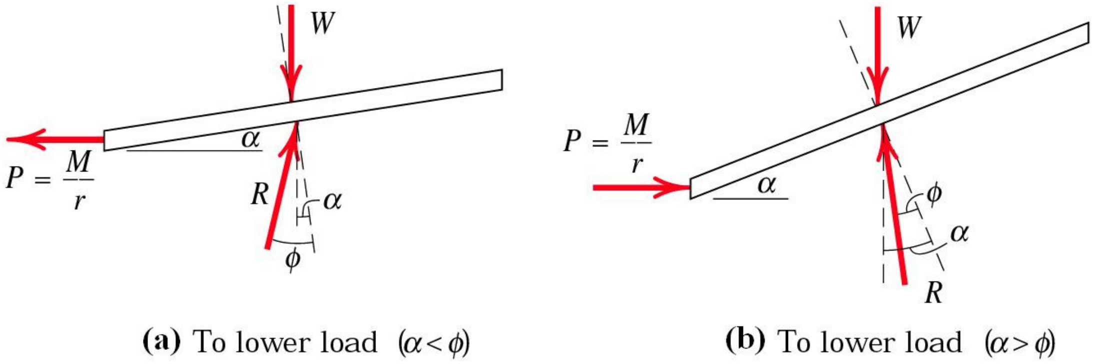



*Figure 5*

## Journal Bearings

A journal bearing gives ___________________________ support to a shaft. The cross section of the bearing in figure 6 is supporting a rotating shaft within its ring. The contact between the shaft and the bearing is assumed to be partially lubricated and the theory of dry friction can be applied here.

***Force Analysis***

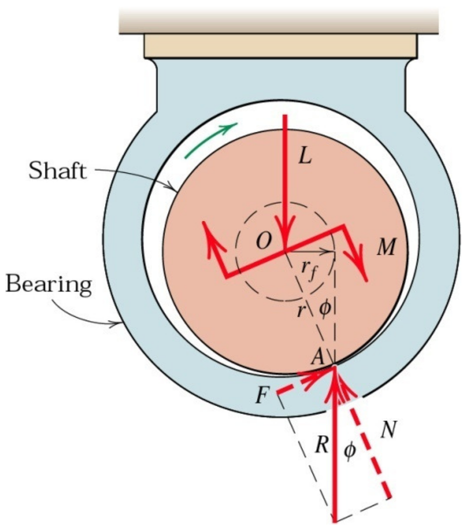


*Figure 6*

The shaft is rotating in the anticlockwise direction and the forces and moments acting on it are shown. The rotating shaft seems to have climbed up the bearing slightly, so that the reaction force is now not collinear with the weight vector. Thus, taking the ______________________________________________ gives

________________________________.

Since the friction angle $\phi$ is assumed small, it can be approximated that ____________________________ without error. Recall that the coefficient of friction is defined $\mu = \tan\phi$ , the equilibrium equation now becomes

_______________________________

## Thrust Bearings (Disk Friction)

A good example of a disk friction is the use of _____________________ in vehicles. This application of friction forces involves a rotating surface about an axis and the torque required to start a rotation.

***Force Analysis***

Let us consider a pair of circular discs of radius *R* mounted on collinear axles as shown in figure 7. An axial force *P* brings the two discs in contact with each other while moments *M* cause the discs to rotate in opposing directions.

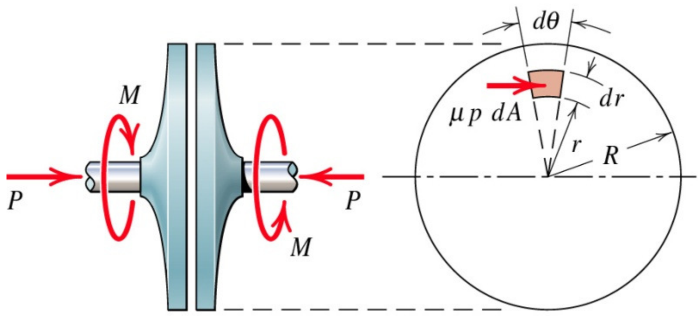



*Figure 7*

The impending motion is a rotation about the axle, hence the friction ___________ ______________________________________________________________.

Let us consider the circular cross section area shown on the right of figure 7.

The moment about the centre of the disc caused by the friction force on the elemental area $dA$ is given by

________________________________________

Integrating the above expression over the entire area of the disc to obtain the total frictional moment to obtain

________________________________________

Let us assume further that the disc we are analysing is new and its surface is ____________________ so that the pressure $P$ is __________________________________, i.e. the pressure per unit area is_______________________. Finally, in the case of circular discs here, we can include the limits of integration to obtain

$$\mathrm{M} = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ = \frac{2}{3}\mu \mathrm{PR}$$

## Flexible Belts and Cables

The belt drives, band brakes and hoisting rigs all make use of friction forces between the ____________________________________________________________________.

***Force Analysis***

Figure 8 shows a drum and a belt under tension over it. The drum can rotate about its centre. The tension ________________________________________, hence it generates a moment about the centre of the drum which is counteracted by the moment $M$ to prevent any motion.

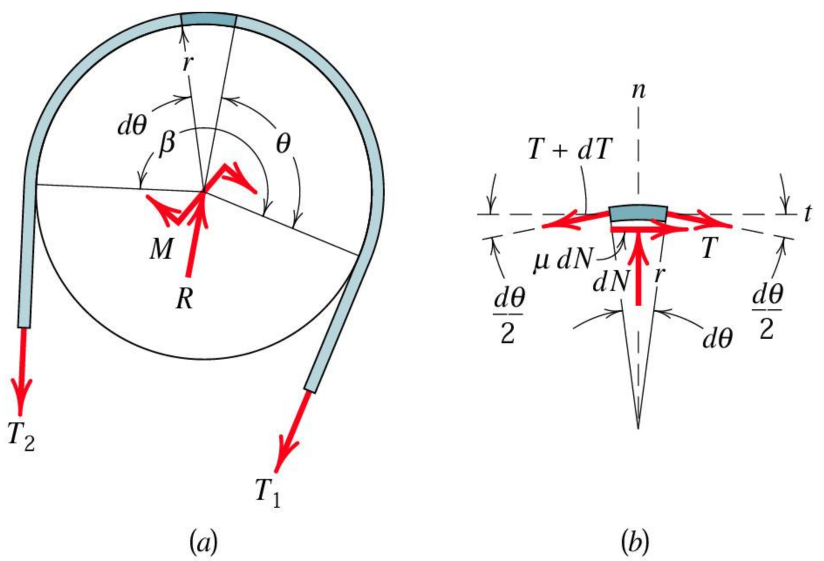



*Figure 8*

Let us consider only a small element of the belt whose free body diagram is shown in figure 8b. This element is in equilibrium, therefore by resolving the forces in the ______________________________ we obtain

__________________________

_________________________

Note that cosine of a small angle is __________________________________________, i.e. $\cos d\theta \approx 1$. Similarly, the equilibrium equation in the _________________________ gives

__________________________

_________________________

Here we use an assumption that sine of a small angle is equal to the angle itself, i.e. $\sin d\theta \approx d\theta$, and the products of two differentials are considered small and can be neglected.

Combining the two equilibrium equations to obtain

$$\frac{dT}{T} = \mu \; d\theta$$

Integrating both sides with the limits shown in figure 8 yields

$$\int_{T_1}^{T_2} \frac{dT}{T} = \int_0^{\beta} \mu \; d\theta$$

$$\ln \frac{T_2}{T_1} = \mu\beta$$

Rearranging the solution to obtain

_______________________________

where $\beta$ represents the ____________________________________________________.
Remember that __________________________________________________________
_______________________________________.