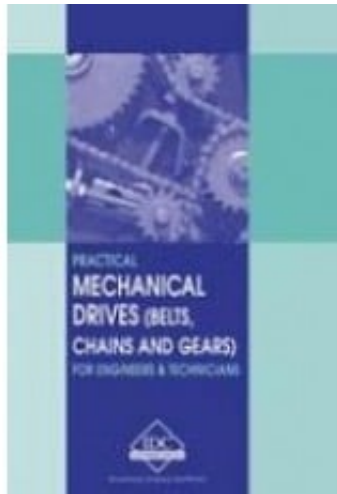


# MD-E - Practical Mechanical Drives (Belt, Chains and Gears) for Engineers and Technicians



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## Short Description

Most engineering professionals working with drives will confirm that there are major benefits in installing and maintaining mechanical drives correctly. Typical areas which can be dramatically improved include: less wear and tear on equipment; minimal unscheduled downtime and production losses and improved operating efficiencies. This manual examines most mechanical drives such as belts, chains, gears in terms of improved lubrication, proper alignment and fastening techniques. There is detailed coverage of troubleshooting techniques so that you can identify symptoms of failure well before the event and thus correct the problem.

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correct the problem.

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## **First Chapter**

### **Chapter: Laws of Motion**

**1**

### **Laws of Motion**

#### **1.1 Introduction**

The laws of motion as propounded by Newton are scientific laws related to the behavior of moving bodies and are fundamental to classical mechanics. These laws help prove many results concerning the motion of physical objects. The laws of motion in combination with the law of universal gravitation and the mathematical techniques associated with calculus, provide a unified quantitative explanation for a wide range of physical phenomena such as the motion of spinning bodies, projectiles, motion of bodies on an inclined plane, motion of bodies in fluids, motion of a pendulum, the tides and the orbits of the planets and the moon. Let us try and understand the significance of these laws of motion with relevance to power transmission.

#### **1.2 The meaning of force**

Force can be defined as a push or pull upon an object that results from its interaction with another object. An interaction between two objects always results in a force upon each of them. When this interaction ceases, these two objects no longer experience the force.

Forces can simply be categorized into two types, to enable better understanding. They are:

- Contact forces and
- Forces resulting from action at a distance.

Let us discuss these two categories in brief.

### **Contact forces**

These forces come into existence on account of physical contact between two interacting objects. Examples of such forces are normal forces, frictional forces, applied forces, tension forces etc.

### **Action-at-a-distance forces**

These forces are formed when two interacting objects are physically not in contact with each other but are yet able to exert a pull or a push even in the absence of a physical separation between the two. Examples include gravitational forces, electrical forces and magnetic forces.

## **1.3 Conservation of energy**

The magnitude as well as the distance of a force can never be increased at the same time in a machine. Therefore when there is an increase in the magnitude of a force produced by a machine, there has to be a proportionate decrease in the distance moved and conversely any increase in the distance will be accompanied by a proportionate decrease in the force. It follows from the principle of conservation of energy that the amount of work produced by a machine is always equal to the exact amount of work put into it, if machine inefficiency and frictional loss is not taken into consideration.

Since machines cannot produce more work than the work put into them, there obviously has got to be a tradeoff. This can be illustrated with the help of a simple example.

Let us assume that 100 joules of work is required in order to lift a 20 Newton weight up to a height of 5 meters. In order to pull the same weight up an inclined plane, a force of 10 Newton might be sufficient, but the distance over which it has to be pulled will be 10 meters instead of 5. Thus the tradeoff here is the additional distance of 5 meters.

## 1.4 First Law of Motion

The first law of motion is also known as Newton's first law or the law of inertia and basically deals with the concept of force and velocity change. It states that

“An object at rest continues to stay at rest and an object in motion continues to stay in motion with the same speed and in the same direction, unless acted upon by an external unbalanced force”.

In other words, if an object is not pushed or pulled upon, its velocity will naturally remain constant. This means that if an object is moving along, untouched by a force of any kind, it will continue to move along in a perfectly straight line at a constant speed. This also means that if an object is standing still and is not contacted by any forces, it will continue to remain motionless.

There are two parts to the above statement. While one predicts the behavior of stationary objects, the other concerns the behavior of moving bodies. This can in turn be summarized by the following diagram.

**Figure 1.1:** *Newton's first law of motion*

## 1.5 Inertia and mass

The first law of motion brings out the natural tendency of objects to resist changes in their state of motion. This tendency on the part of the objects to resist changes in their state of motion is known as “inertia”. Although all objects have this tendency called inertia, some objects have more of this tendency to resist changes in their state of motion, than others. This is on account of the fact that inertia is further dependent on mass. The more an object's mass, the more inertia it possesses, i.e. more the tendency to resist changes in its state of motion.

A typical example of the inertia phenomenon is the sudden jerk that one traveling in a vehicle tends to experience, on sudden application of the brakes and also when the vehicle suddenly starts to move from a stationary position. One also tends to experience this phenomenon, when alighting from a moving vehicle. The reason for this could be best explained as follows. In the case of inertia experienced when the vehicle is braking to a halt, the force of the road on the

locked wheels provides the unbalanced force needed to change the state of motion of the vehicle. On the other hand, there is no unbalanced force that could change our own state of motion. Thus we continue to be in motion sliding along the seat in forward motion. But the presence of a seat belt used for safety purposes provides the unbalanced force to bring us to a state of rest from a state of motion.

## 1.6 State of motion

The state of motion of a moving body is defined by its velocity, i.e. speed in a particular direction. Inertia can thus be defined as “the tendency of a body to resist changes in its velocity”. An object possesses zero velocity at rest and in the absence of an unbalanced force will remain with a zero velocity. Further, an object with zero velocity i.e. an object not changing its velocity will have zero acceleration. The definition for inertia can thus also be rephrased as “the tendency of an object to resist accelerations”.

## 1.7 Balanced and unbalanced forces

To understand the concept of balanced and unbalanced forces as applicable to the first law of motion, let us consider the example of a wooden block resting on a table.

### **Figure 1.2:** *Illustration of unbalanced and balanced forces*

From the figure, it is seen that there are basically two forces that are acting upon the block. While one force in the form of the earth’s gravitational pull exerts a downward force, the other referred to as the normal force which is the push of the table on the block, exerts an upward force on the block. These forces being equal in magnitude and opposite in direction, balance each other out such that the block is said to be in equilibrium. Since there is no unbalanced force acting on the block, its state of motion is maintained. Irrespective of the number of forces acting on a body, in the event of all the forces balancing out each other, the body will not accelerate and will be in equilibrium.

To understand the concept of unbalanced forces acting on a body, let us again

consider the example of a wooden block on a table, but this time the block being set in motion and sliding across the table from left to right. Our focus here is not on how the block attained motion from a position of rest, but only on the current situation wherein the block is sliding across the table. The various forces acting on the block are depicted in the diagram below.

### **Figure 1.3: Unbalanced forces**

As seen from the figure, while the force of gravity and the force of the table pushing upwards on the book are equal in magnitude and opposite in direction and therefore balance out each other, the force of friction has no other force balancing it. As the block moves to the right, the frictional force acts to the left, thereby slowing down its movement. As this constitutes an unbalanced force, the state of motion of the block is changed. The block is not in equilibrium and therefore acceleration will take place. But in this case, the unbalanced force is directed opposite the motion of the block and therefore causes deceleration and subsequent slowing down of the object.

To determine the nature of the force acting on a body, an analysis has to be carried out on the type of the forces acting and the direction in which they are acting. A body is said to be acted upon by an unbalanced force only if there is an individual force that is not being balanced by a force of equal magnitude and in the opposite direction.

## **1.8 The concept of friction**

The concept of inertia was initially conceived by Galileo. He reasoned that moving objects eventually come to a halt because of a force known as friction. In experiments conducted using a pair of inclined planes facing each other, Galileo observed that a ball will roll down one plane and up the opposite plane at roughly the same height. With smoother planes, the ball was observed to attain a height even closer to the original height. The reason for the difference in heights was reasoned by Galileo to be on account of the presence of friction. He postulated that by eliminating this friction, the ball could be made to attain the original height. It was further observed that regardless of the angle of orientation of the planes, the final height was almost always equal to the initial height. With a reduction in

the slope of the opposite incline, the ball would roll a further distance in order to attain the original height.

These discoveries of Galileo were further built-on and developed by Newton. In order to illustrate the effect of friction on a moving body, let us consider the figure given below.

### **Figure 1.4: *Friction***

Figure 1.4 shows a wooden block sliding across a table from left to right and coming to rest. As depicted in the figure, the frictional force acts on the block to slow it down and bring it to rest. The rest position is not attained due to the absence of any force; rather it is due to the presence of the force of friction. In the absence of this frictional force, the block would continue in motion with the same speed and in the same direction, forever or at least to the end of the table. It is therefore seen that while a force is not required to keep a moving object such as the block in motion, it is actually a force which brings the object to rest.

## **1.9 Second Law of Motion**

While the first law of motion concerns the behavior of objects for which all existing forces are balanced, the second law of motion also known as Newton's second law deals with the behavior of objects for which all existing forces are not balanced. It explains how an object will change its velocity when pushed or pulled upon.

The law states that “the acceleration of a body as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force and inversely proportional to the mass of the object. Alternatively, it can also be stated as

“The rate of change in momentum of an object is directly proportional to the net force acting on the object and takes place in the direction of the force”.

Further explaining this, the law firstly states that when an object is subjected to force, it changes its velocity i.e. it accelerates, with the change in velocity

occurring in the direction of the applied force.

Secondly, this acceleration is directly proportional to the force. To explain this more clearly, suppose a body is being subjected to a pushing force causing it to accelerate and then three times the pushing force is made to act on the body, the acceleration will also be three times greater.

Thirdly, the acceleration is inversely proportional to the mass of the body. To consider an example, suppose two bodies, one with a body mass thrice that of the other, are being subjected to a pushing force, the object with the heavier mass will accelerate at 1/3 rd the acceleration of the lighter object.

The second law of motion can be mathematically expressed as

$$F = m \times a$$

Where:

F is the net force acting on the object

m is the mass of the object under consideration and

a is the acceleration of the object.

The net force is the vector sum of all the forces which act upon an object. That is to say, the net force is the sum of all the forces, taking into account the fact that a force is a vector and two forces of equal magnitude and opposite direction will cancel each other out. This net force acting on the object can be determined if all the individual forces acting on the object are known. The mass “m” in the above equation is the constant of proportionality and is a characteristic of the object. While the acceleration can be directly measured, the net force cannot be and therefore the second law has a meaning only if the value of F is asserted in advance. Taken together with the third law of motion, the second law of motion implies the law of conservation of momentum.

### **1.10 Third Law of Motion**

The third law of motion is also known as Newton’s third law or law of reciprocal



actions.

Force results from an interaction between objects that may in turn be contact interactions like in the case of contact forces such as normal, frictional and tensile forces or distant interactions like in the case of gravitational, magnetic and electrical forces. According to this law, two objects that interact with each other exert forces upon each other. These two forces known as action and reaction forces form the core principle around which the third law of motion is centered. The third law states that “for every action, there is an equal and opposite reaction”. It can also be alternatively defined as “For every force, there is an equal and opposite force”.

According to this law, a pair of forces acts on the interacting objects during every interaction such that the size of the forces acting on the first object equals the size of the forces acting on the second object. The direction of the force on the first object is opposite to the direction of the force on the second object. Forces always come in pairs - equal and opposite action-reaction force pairs.

Consider two objects A and B interacting with each other. Let  $F_{ab}$  represent the force exerted on object A by object B and  $F_{ba}$  represent the force exerted on object B by object A. The third law of motion can be mathematically expressed as:

$$F_{ab} = - F_{ba}$$

Considering an example; when we push on a wall, the wall will push back on us as hard as we are pushing on it. Considering another example to illustrate the concept of action and reaction forces, when we sit on a chair, our body exerts a downward force on the chair and the chair exerts an upward force on our body. The two forces under consideration here, the force on the chair and the force on our body are called action and reaction forces.

To understand more precisely the law of action and reaction, let us consider a fish swimming in water. The fish makes use of its fins to push the water backwards. This serves to accelerate the water and the water in turn reacts by pushing the fish forward and thereby propelling the fish through the water. The size of the force on the water equals the size of the force on the fish. The direction of the force on the water backwards, is opposite the direction of the force on the fish forwards.

## 1.11 Mechanical Advantage

Eminent Scientist and engineer, Archimedes, who is credited with the development of many modern day mechanical and mathematical principles was one of the earliest to fully comprehend and understand the concept of mechanical advantage. Mechanical advantage is defined as the ratio of the load; to the applied force, although this ratio is not entirely accurate since some amount of force is needed to overcome friction as well. Mechanical advantage can be mathematically represented as:

$$MA = \frac{\text{Load}}{\text{Applied force}}$$

A good mechanical advantage has a value greater than 1. The greater the mechanical advantage, smaller is the applied force required to accomplish the task. Although less force is used by machines to accomplish a given task, there is usually a trade-off in the form of the force being applied for a longer distance or longer period of time.

A mechanical advantage results when a machine takes a small input force and produces an output force with increased magnitude. For example let us consider a machine delivering an output force of 100 kgf after taking in a 10 kgf input force. The mechanical advantage in this case is given by

$$MA = \frac{\text{Output force}}{\text{Input force}} = \frac{100}{10} = 10$$

One of the most common devices used to produce a mechanical advantage is the automobile jack. Here, a small force exerted by the operator in the form of a force applied to the jack handle, results in a larger force required to lift the vehicle.

### Mechanical Advantage and Friction

Measuring the mechanical advantage is a mathematical way of determining the effect of a machine on the amount of force needed to do work. Theoretical mathematical advantage is the advantage obtained if the machine were perfect. But complete perfection is not possible in machines, with the main source of

imperfection being friction. By always opposing motion, friction makes doing work harder. Since friction is present in almost every machine, the actual mechanical advantage that is obtained is always less than the theoretical mechanical advantage.

## **Types of motion**

Machines and machine components are used to transform motion. The study of motion is called kinematics and there are basically four types of motion concerning basic machines. Let us discuss them in brief, with the help of practical examples.

- Linear Motion which is motion in a straight line.

Example: The movement of a train on a track.

- Reciprocating motion which is linear motion going back and forth.

Example: Piston movement in an internal combustion engine.

- Rotary motion which is circular motion

Typical examples of this type of motion are the movement of the hands of a clock and a wheel moving on an axle.

- Oscillating motion which is circular or back and forth arc-motion.

Example: Pendulum swing in a clock and turning of a doorknob.

## **1.12 Basic Machines**

A Machine may be described as any mechanical or electrical device that transmits or modifies energy in order to perform or assist in accomplishing a desired task. It can also be defined as a device that makes work easier. It is normally referred to an assembly of parts operating together to perform work. For performing a desired task, the machine normally requires an input trigger. This in turn is modified by the machine and this energy is transmitted to an output which performs the desired task. The basic difference between simple tools and

mechanisms is that, while it involves a somewhat independent operation in the case of the former, a power source is normally used in the latter.

Machines are categorized into various types, based on their capabilities and functions, some of which include

- Transformation of energy from one type to the other.

Considering an example; while in the case of a generator, mechanical energy is converted into electrical energy, a steam turbine produces mechanical energy from thermal energy or heat.

- Transfer of energy

An example of this is the transfer of energy from the transmission or gear box, to the rear wheels of an automobile.

- Multiplication of force

An example of this function is the ability of a pulley or a jack to lift more weight with less force.

- Multiplication or increase in speed

A small effort in the form of pedaling a bicycle, results in a faster movement of its wheels.

- Reducing friction
- Changing the direction of force

An example of this is the pulling down of the flag pole pulley for hoisting the flag.

Some of the common simple machines or mechanical components include the likes of:

- Inclined Plane
- Rotating wheel and axle
- Pulley
- Lever
- Screw

- Spring
- Wedge
- Winch
- Gear and belt
- Bearing
- Drive shaft
- Cam and crank

Let us discuss these simple machines/components in brief, in order to understand their principle of working and function.

### **Typical application of simple machines involves situations**

- Where the amount of force to perform a particular task is large and which cannot be applied without the use of a machine.

For example: Pushing of a heavy box up a ramp for loading into a truck.

- When the direction of an applied force is not in the desired direction.

When the rope on a flag pole is pulled down, the system makes use of a pulley to move the flag in the opposite direction.

### **Machines can be mainly categorized as**

- Simple Machines and
- Compound machines

While simple machines are able to do work with just one movement, compound machines require more than one movement to do work. This is accomplished by simply changing the intensity and/or direction of the input force supplied to the machine. While the amount of force that is put into a machine is called the effort force, the amount of force required by the machine to do work is called the resistance force. Additionally, the work done on the machine is called input work while the work done by the machine is known as output work.

Let  $F_e$  represent the effort force and  $D_e$ , the distance that the effort force has to move. The work input represented by  $W_i$  can then be determined from the equation:

$$W_i = F_e \times D_e$$

Similarly, let  $F_r$  and  $D_r$  represent the resistance force and the distance that the resistance force has to move, respectively. The work output is then given by:

$$W_o = F_r \times D_r$$

Although in reality,  $W_i$  can never be equal to  $W_o$  on account of friction, under design conditions, the machines are imagined as ideal machines i.e. machines having no friction. These machines would have their work input equal to the work output or  $W_i = W_o$ .

There are six basic types of machines that are grouped into the following categories.

- **Lever family**
  - Lever
  - Wheel and axle
  - Pulley
- **Inclined plane family**
  - Inclined plane
  - Screw
  - Wedge

When considered individually, each of the above is a simple machine in itself. When two or more of these machines combine in such a way that they function as a single mechanism, they are categorized as complex machines. Let us discuss these simple machines/components individually, in order to understand their principle of working and function.

## **Lever**

It is a rigid bar rotating about a fixed point known as the fulcrum. The bar may be either straight or curved. Figure below shows a simple lever mechanism.

### **Figure 1.5: Lever**

In a lever, the mechanical advantage is given by the ratio of the length of the

lever on the side of the fulcrum where the applied force acts, to the length of the lever on the side of the fulcrum where the resistance force acts. Let us consider the following example.

**Figure 1.6:** *Example of a lever mechanism*

The mechanical advantage in the example shown above is 10, which means an applied force of 10 kgs will balance a resistance force of 100 kgs and the applied force end of the lever must move 10 meters for every 1 meter the resistance force is raised.

There are three different classes of levers. The class of a lever is in turn determined by the location of both the applied and the resistance force, relative to the fulcrum. Let us discuss them one by one.

**First-class lever**

In a first-class lever, the location of the fulcrum is at some point between the effort and resistance forces. Some of the common types of first-class levers include the likes of crowbars, scissors, pliers and seesaws. Here, the direction of the force is always changed, i.e. an upward effort force on the lever results in a downward movement of the resistance force. As the fulcrum gets closer to the resistance; the output force increases, along with a corresponding decrease in both output speed and distance. Figure below illustrates a first-class lever mechanism. Conversely, the output force decreases with a corresponding increase in output speed and distance, when the fulcrum is closer to the effort.

**Figure 1.7:** *First class lever*

**Second-class lever**

In a second-class lever, the resistance is located between the fulcrum and the effort force. Common examples of this type include nut crackers, bottle openers and wheel barrows. Here, unlike in the case of the first-class lever, no change in direction of the force occurs. When the location of the fulcrum is closer to the resistance than to the force; mechanical advantage in the form of an increase in

force, results. A second-class lever mechanism is shown in the figure below.

**Figure 1.8:** *Second class lever*

### **Third-class lever**

In this type, the application of the effort force is between the fulcrum and the resistance force. Examples of third-class levers include the likes of tweezers and shovels. In a third-class lever illustrated below, there is always a gain in speed and distance, with a corresponding decrease in force. It also does not lead to a change in direction of the force.

**Figure 1.9:** *Third class lever*

### **Wheel and axle**

It is a simple machine comprising of a large wheel secured rigidly to a smaller wheel or shaft called the axle. A rotation of either the wheel or the axle results in the rotation of the other part. An illustration of a simple wheel and axle arrangement is shown below.

**Figure 1.10:** *Wheel and Axle*

When force is applied to the wheel in order to rotate the axle, the distance and the speed get reduced, with a corresponding increase in the force. Conversely, on applying force to the axle in order to turn the wheel, the force decreases with an increase in speed and distance. Here, the mechanical advantage is given by the ratio of the radius of the wheel to the radius of the axle. For example, if the radius of the wheel is twice that of the axle, the mechanical advantage will be 2.

The wheel and axle unit can also be used to increase the speed by subjecting the axle to input force, rather than the wheel. This increase will be directly proportional to the ratio of the diameter of the wheel to that of the axle. If the diameters of the wheel and the axle are 5 meters and 2 meters respectively, the increase in output speed will be 2.5 times that of input speed. The relationship



between the input speed and the axle diameter and the output speed and the wheel diameter is given by the equation:

$$S_1 \times d_1 = S_2 \times d_2$$

Where  $S_1$  and  $S_2$  are the input and output speeds and  $d_1$  and  $d_2$  are the axle and wheel diameters respectively.

## **Pulley**

A pulley is a device used to gain a mechanical advantage or simply to change the direction of the force, its function in turn being determined by the type of arrangement of the pulley.

### **Arrangement 1: Fixed Pulley**

A pulley is considered to be fixed if it does not rise or fall with the load being moved. In this case, only the direction of the force applied is changed and no mechanical advantage is derived. Figure 1.11 shows a fixed pulley arrangement.

**Figure 1.11:** *Fixed pulley arrangement*

### **Arrangement 2: Moveable pulley**

In the case of a moveable pulley, the pulley rises and falls with the load being moved. Here, while a mechanical advantage is obtained, there is no change in direction of the force. Figure below shows such an arrangement.

**Figure 1.12:** *Moveable Pulley arrangement*

The mechanical advantage that is obtained from a moveable pulley is equal to the number of ropes that support the pulley, with each end of the rope being

considered as a separate entity. Say for example, if two rope ends support the moveable pulley, an effort force of 50 kgs will lift a resistance force of 100 kgs, the mechanical advantage in this case being 2.

Many applications involve using both the fixed and the moveable pulleys in combination to form a device called Block and Tackle, which is capable of creating a mechanical advantage as well as changing the direction of a force.

## **Inclined Plane**

### **Figure 1.13: *Inclined Plane***

It is an even sloping surface and may slope at any angle between the horizontal and the vertical. The inclined plane which is illustrated in the figure below makes the task of moving a weight from a lower elevation to a higher elevation easier. Assuming that the effort force is applied parallel to the slope, the mechanical advantage in an inclined plane is equal to the ratio of the length of the slope and the height of the inclined plane.

### **Figure 1.14: *Inclined Plane dimensions***

Considering the figure shown above, Let us consider the example of an inclined plane having a slope length of 8 meters and height equal to 2 meters. The mechanical advantage in this case is given by:

$$MA = \frac{\text{Slope length of the inclined plane}}{\text{Height of the inclined plane}} = \frac{8}{2} = 4$$

Height of the inclined plane

In order for the inclined plane to produce a mechanical advantage, the distance through which the force must move, must be increased. In the example given above, the object moved 8 meters along the slope in order to increase the

vertical distance by 2 meters.

## Wedge

### Figure 1.15: *Wedge*

Wedges are variants of the inclined plane and are used either as separating or holding devices. The two main differences that sets a wedge apart from the inclined plane are

- A wedge moves while the inclined plane remains stationary.
- While the effort force is applied to the vertical edge of a wedge, in the case of an inclined plane, the effort force is applied parallel to its slope.

A wedge can be composed of either one or two inclined planes and a double wedge can be considered as two inclined planes joined together with their sloping surfaces outward as illustrated in the diagram below.

### Figure 1.16: *Double Wedge*

The mechanical advantage in a wedge is obtained by the ratio of the length of either slope, to the thickness of the big end. Let us assume a wedge with a length of 15 meters and thickness equal to 3 meters. The mechanical advantage is then equal to  $15/3 = 5$ . As in the case with the inclined plane, mechanical advantage in a wedge is obtained with a corresponding increase in the distance.

## Screw

The screw can be considered a modified version of the inclined plane in the sense that the threads in a screw can be thought of as a type of circular ramp.

In a screw, the vertical distance between two adjacent threads is known as the pitch. For the screw to move into an object a distance equal to the screw pitch, it has to undergo one complete revolution.

Considering an example, assume that ten threads are counted in a distance of 1 inch. The pitch of the screw in this case will be 1/10. Since there are 10 threads per inch of the screw, the distance between two adjacent screw threads is 1/10<sup>th</sup> of an inch. One complete revolution of the screw will move the screw into an object a distance equal to the screw pitch. It can thus be concluded from the above that one complete revolution of a screw of pitch 1/10 will move it through a distance of 1/10 of an inch into an object. The mechanical advantage in a screw is given by the ratio of the circumference of the screw to the pitch of the screw, i.e.

$$MA = \frac{\text{circumference}}{\text{Pitch}}$$

Pitch

By knowing the mechanical advantage of a machine, the force required to lift a given object can be predicted. In actual applications, the screw is often turned by another simple machine such as a lever, in which case the total mechanical advantage is given by the ratio of the circumference of the simple machine to which the effort force is applied, to the pitch of the screw.

For example, let us assume that a screw driver having a handle diameter of 1 inch turns a screw with 12 threads per inch.

The pitch of the screw is given by:

$$P = 1/12 = 0.083$$

The circumference of the screwdriver handle is given by:

$$C = \pi d, \text{ where } d \text{ is the handle diameter}$$

$$\text{Therefore } C = 3.14 \times 1 = 3.14 \text{ inches}$$

Mechanical Advantage is given by:

$$MA = \frac{\text{circumference}}{\text{Pitch}} = \frac{3.14}{0.083} = 38 \text{ approximately}$$

$$\text{Pitch} \quad 0.083$$

## 1.13 Friction

Friction is an important property governing power transmission. It arises on account of the resistance to movement, caused due to the interlocking of small surface irregularities on the two contacting surfaces and is a measure of the force parallel to the sliding faces of two bodies in contact. This is shown in the figure below.

### Figure 1.17: *Frictional force*

The force of friction can be considered to be both a necessity as well as a nuisance. A necessity because, even a basic movement such as one's walk, is determined by the friction between the shoes and the ground. The automobiles run on the roads on account of friction between the tires and the ground while their braking function is a measure of the brake friction. Friction is considered a nuisance because of the losses they bring about when power is being transmitted. This frictional loss in power can occur through moving objects such as bearings, gears, chain drives etc.

The frictional force that exists between two surfaces is proportional to the pressure that exists between the two surfaces. For any relative movement of the two contacting surfaces to occur, this frictional force needs to be overcome. When movement is about to occur, the frictional force is equal to some fraction of the normal force between the two surfaces which in turn is known as the coefficient of friction represented by  $\mu$ .

To help understand the concept of friction better, let us consider the following example.

Suppose a vehicle weighs 2000 kilograms and the coefficient of friction between its wheels and the road is 0.025. For simplicity sake, let us assume that there is no friction in any other part of the vehicle including the bearings. Now if the vehicle has to be moved, a pushing or pulling force slightly exceeding the frictional force should be used.

The frictional force is given by:

$$F = \mu N$$

Where

$\mu$  is the coefficient of friction and

N is the normal force between the wheels and the ground.

The frictional force as calculated from the above equation is:

$$F = 0.025 \times 2000 = 50 \text{ kgs}$$

One important point to be noted is that this frictional force reverses when the vehicle is pushed backward, i.e. the frictional force always opposes motion. Actually the coefficient of friction may have more than one value i.e. the static coefficient of friction opposing the start of motion is always larger than the dynamic coefficient of friction that comes into effect after the body attains motion.