Fundamentals of Mechanical Engineering

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IDC TECHNOLOGIES

Technology Training that Works

Presents

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Basics of Mechanical Engineering

Mechanical Engineering, as its name suggests, deals with the mechanics of operation of mechanical systems. This is the branch of engineering which includes design, analysis, testing, manufacturing and maintenance of mechanical systems. The mechanical engineer may design a component, a machine, a system or a process. Mechanical engineers will analyze their design using the principles of motion, energy, and force to ensure the product functions safely, efficiently, reliably, and can be manufactured at a competitive cost.

Learning objectives

- Basic concepts
- Units for engineering quantities
- Friction and its importance

1.1 Introduction

Mechanical engineering plays a dominant role in enhancing safety, economic vitality, enjoyment and overall quality of life throughout the world. Mechanical engineers are concerned with the principles of force, energy and motion.

Mechanical engineering is a diverse subject that derives its breadth from the need to design and manufacture everything from small individual parts and devices (e.g. microscale sensors and inkjet printer nozzles) to large systems (e.g. spacecraft and machine tools). The role of a mechanical engineer is to take a product from an idea to the marketplace. In order to accomplish this, a broad range of skills are needed. Since these skills are required for virtually everything that is made, mechanical engineering is perhaps the broadest and most diverse of engineering disciplines.

Mechanical engineers play a central role in such industries as automotive (from the car chassis to its every subsystem — engine, transmission, sensors); aerospace (airplanes, aircraft engines, control systems for airplanes and spacecraft); biotechnology (implants, prosthetic devices, fluidic systems for pharmaceutical industries); computers and electronics (disk drives, printers, cooling systems, semiconductor tools); microelectromechanical systems (MEMS) (sensors, actuators, micropower generation); energy conversion (gas turbines, wind turbines, solar energy, fuel cells); environmental control (HVAC, air-conditioning, refrigeration, compressors); automation (robots, data and image acquisition, recognition, control) and manufacturing (machining, machine tools, prototyping, micro fabrication).

The main areas of study in this branch are:

- Materials
- Solid and fluid mechanics
- Thermodynamics
- Heat transfer
- Control, instrumentation
- Specialized mechanical engineering subjects include biomechanics, cartilage-tissue engineering, energy conversion, laser-assisted materials processing, combustion, MEMS, micro fluidic devices, fracture mechanics, nanomechanics, mechanisms, micropower generation, tribology (friction and wear) and vibrations.

1.2 Basic concepts

1.2.1 Force

A foundation concepts in physics, a force may be thought of as any influence which tends to change the motion of an object. A force can be described as the push or pull upon an object resulting from the object's interaction with another object. Whenever there is an interaction between two objects, there is a force upon each of the objects. When the interaction ceases, the two objects no longer experience the force. Forces only exist as a result of an interaction.

There are four fundamental forces in the universe: the gravity force, the nuclear weak force, the electromagnetic force, and the nuclear strong force in ascending order of strength. In mechanics, forces are seen as the causes of linear motion, whereas the cause of rotational motion is called a torque. The action of forces in causing motion is described by Newton's Laws.

Force is a quantity which is measured using the standard metric unit called the Newton. A Newton is abbreviated by a "N". To say "10.0 N" means 10 Newtons of force. One Newton is the amount of force required to give a 1 kg mass an acceleration of 1 m/s^2.

Force = mass x acceleration
$F = m \times a \;\; = 1\ kg \times 1\ m / s^2$

A force is a vector quantity — it has both magnitude and direction. To fully describe the force acting upon an object, you must describe both the magnitude (size or numerical value) and the direction. Thus, 10 Newtons is not a full description of the force acting upon an object. In contrast, 10 Newtons downwards is a complete description of the force acting upon an object; both the magnitude (10 Newtons) and the direction (downwards) are given.

A torque is a special form of force that turns an axle in a given direction. It is sometimes called a rotational force. You can create a torque by pushing on a rod or lever that rotates an axle. Likewise, a torque on an axle can result in a linear force at a distance from the center of the axle.

Torque equals force multiplied by moment arm. Pushing on a rod that rotates an axle can create a torque on that axle. Likewise, a torque on an axle can result in a linear force at a radius from the center.
The relationship between torque and force is:

$$T = FR$$

or

$$F = T/R$$

where
T is the torque in newton-meters
F is the force (Newtons)
R is the radius or distance from the center to the edge (meters)

R is also sometimes called the *moment arm*. The force, **F**, is applied perpendicular to the radius, lever or moment arm.

1.2.2 Work

Work refers to an activity involving a force and movement in the direction of the force.
A work is done on an object when the force acts on it in the direction of motion or has component in the direction of motion.
In order to accomplish work on an object there must be a force exerted on the object and it must move in the direction of the force.
Work = Force x distance moved in direction of force
Work is measured in joules (J). The formula for this is:

$$J = N \times m$$

Where force is measured in Newtons and distance in meters.

For a constant force F which moves an object in a straight line from x1 to x2, the work done by the force

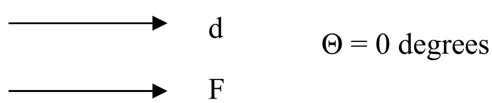
Work = force x (x2-x1)

Mathematically, work can be expressed by the following equation:

$$W = F \times d \times \cos \Theta$$

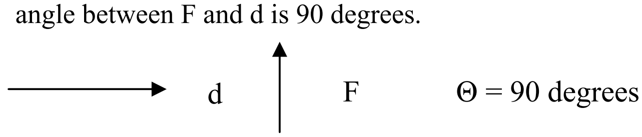
where F is the force, d is the displacement, and the angle (theta) is defined as the angle between the force and the displacement vector. Perhaps the most difficult aspect of the above equation is the angle "theta." Theta is defined as the angle between the force and the displacement.

- A force acts from the right on an object and it is displaced to the right. In such an instance, the force vector and the displacement vector are in the same direction. Thus, the angle between F and d is 0 degrees.



- A force acts from the left on an object and it is displaced to the right. In such an instance, the force vector and the displacement vector are in the opposite direction. Thus, the angle between F and d is 180 degrees.

- A force acts upward on an object as it is displaced to the right. In such an instance, the force vector and the displacement vector are at right angles to each other. Thus, the angle between F and d is 90 degrees.



For the more general case of a variable force F(x) which is a function of x, the work is still the area under the force curve, and the work expression becomes an integral.

$$\text{Work} = \int_{x_1}^{x_2} F(x)\,dx$$

Work is not done when there is no motion or when the force is perpendicular to the motion.
Let us apply the work equation to determine the amount of work done by the applied force in each of the three situations described below.

Diagram A	Diagram B	Diagram C

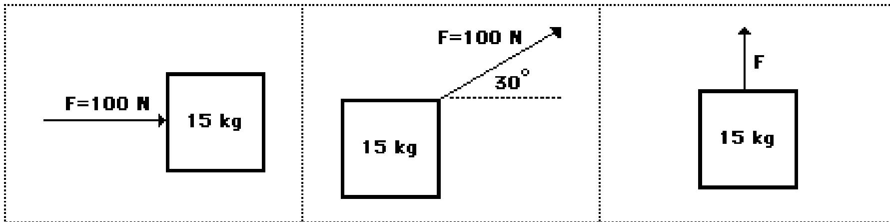


Diagram A	Diagram B	Diagram C
A 100 N force is applied to move a 15 kg object a horizontal distance of 5 meters at constant speed.	A 100 N force is applied at an angle of 30° to the horizontal to move a 15 kg object at a constant speed for a horizontal distance of 5 m.	An upward force is applied to lift a 15 kg object to a height of 5 meters at constant speed.

Diagram A Answer:
W = (100 N) x (5 m) x cos (0 degrees) = 500 J
The force and the displacement are given in the problem statement. It is said (or shown or implied) that the force and the displacement are both to the right. Since F and d are in the same direction, the angle is 0 degrees.

Diagram B Answer:
W = (100 N) x (5 m) x cos (30 degrees) = 433 J
The force and the displacement are given in the problem statement. It is said that the displacement is to the right. It shows that the force is 30 degrees above the horizontal. Thus, the angle between F and d is 30 degrees.

Diagram C Answer:
W = (147 N) x (5 m) x cos (0 degrees) = 735 J

1.2.3 Energy

Energy is the capacity for doing work. You must have energy to accomplish work – it is like the "currency" for performing work. In the process of doing work, the object which is doing the work exchanges energy with the object upon which the work is done. When the work is done on the object it gains energy. The energy acquired by the objects upon which work is done is known as mechanical energy.

Mechanical energy is the energy which is possessed by an object due to its motion or due to its position. Mechanical energy can be either kinetic energy (energy of motion) or potential energy (stored energy of position). Objects have mechanical energy if they are in motion and/or if they are at some position relative to a zero potential energy position.

Mechanical energy = Kinetic energy + Potential energy
Potential Energy PE = mass of the object x acceleration of gravity x height of the object

PE = m x g x h
g represents the acceleration of gravity (9.8 m/s/s on Earth)

Kinetic Energy is depend on two variables: the mass and the speed

The following equation is used to represent the kinetic energy (KE) of an object.

KE = 1/ 2 x m x v ^{2}

1.2.4 Power

Power is the rate at which work is done. It is the work/time ratio. Mathematically, it is computed using the following equation.

Power = work / time = (force x displacement) / time

The standard metric unit of power is the Watt. As is implied by the equation for power, a unit of power is equivalent to a unit of work divided by a unit of time. Thus, a Watt is equivalent to a Joule/second. For historical reasons, the term ‘horsepower’ is occasionally used to describe the power delivered by a machine. One horsepower is equivalent to approximately 750 Watts.

Most machines are designed and built to do work on objects. All machines are typically described by a power rating. The power rating indicates the rate at which that machine can do work upon other objects. Thus, the power of a machine is the work/time ratio for that particular machine. The power rating relates to how rapidly the engine can accelerate the car.

1.3 Units of engineering quantities

Table 1.1 gives the most common units of engineering quantities that you will come across.

Figure 1.1 shows a representation of the linkage of basic mechanical units.

Table 1.1
Units of engineering quantities

	SI units	US common
Length (L)	Meter m	Foot ft
Time (T)	Second s	Second s
Mass (M)	Kilogram kg	Slug
Velocity (L/T)	m / s	ft/s
Acceleration (L/T2)	m/ s^2	ft/ s^2
Force (M L/ T^2)	kg m / s^2 = Newton N	slug ft/ s^2 = pound lb
Work (M L^2/ T^2)	N m = J joule	lb ft = ft lb
Energy (M L^2/ T^2)	joule	ft lb
Power (M L^2/ T^3)	J / s = W watts	ft lb/s

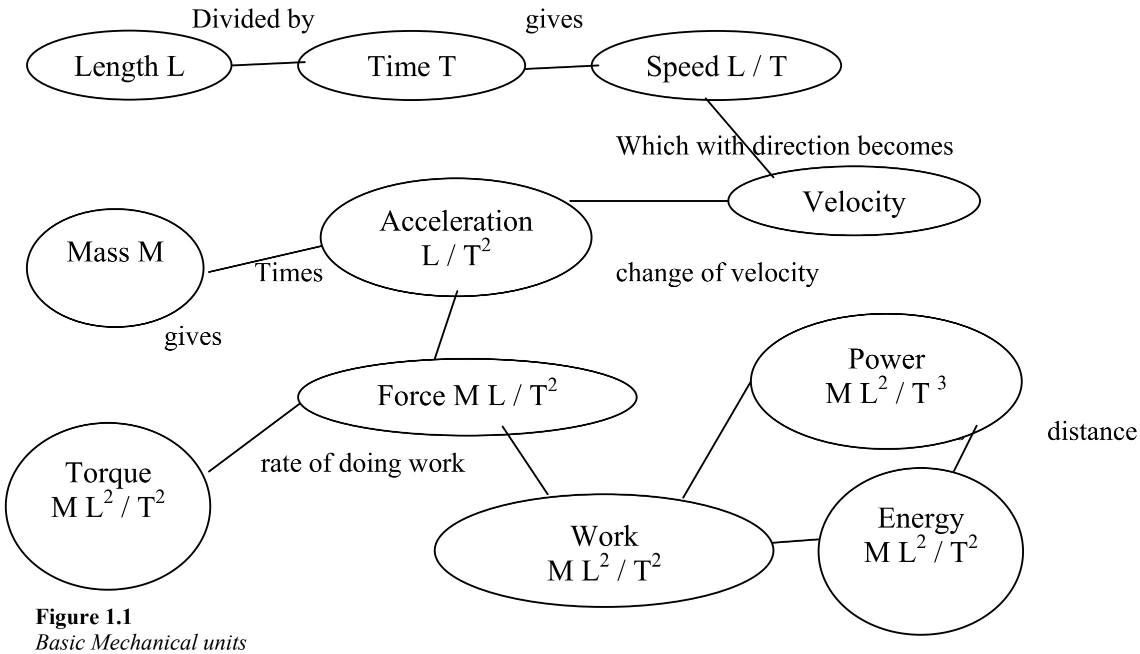


Figure 1.1
Basic Mechanical units

1.4 Friction

Friction is a force that is created whenever two surfaces move or try to move across each other. Friction always opposes the motion or attempted motion of one surface across another surface. Friction is dependant on the texture of both surfaces and the amount of contact force pushing the two surfaces together.

In a machine, friction reduces the ratio of output to input. An automobile, for instance, uses one-quarter of its energy on reducing friction. Yet it is also friction in the tires that allows the car to stay on the road, and friction in the clutch that makes it possible to drive at all. From matches to machines to molecular structures, friction is one of the most significant phenomena in the physical world.

There are advantages and disadvantages of friction. Since friction is a resistance force that slows down or prevents motion, it is necessary in many applications to prevent slipping or sliding. But it can also be a nuisance because it can hinder motion and cause the need for expending energy. A good compromise is necessary to get just enough friction.

Disadvantages of friction:

- makes movement difficult
- machine parts get overheated
- wastes energy
- any device that has moving parts can wear out rapidly due to friction. Lubrication is used not only to allow parts to move easier but also to prevent them from wearing out.

The force of friction is a force that resists motion when two objects are in contact. If we look at the surfaces (Figure 1.2) of all objects, there are tiny bumps and ridges. Those microscopic peaks and valleys catch on one another when two objects are moving past each other.

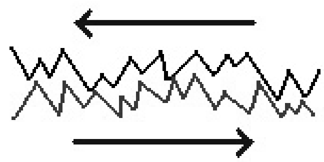


Figure 1.2
Typical surface

There are two types of friction

- Static
- Kinetic

If we try to slide two objects past each other, a small amount of force will result in no motion. The force of friction is greater than the applied force. This is static friction. (Figure 1.3) If we apply a little more force, the object 'breaks free' and slides, although we still need to apply force to keeps the object sliding. This is kinetic friction (Figure 1.4). We need not apply quite as much force to keep the object sliding as we originally needed to break free from the static friction.

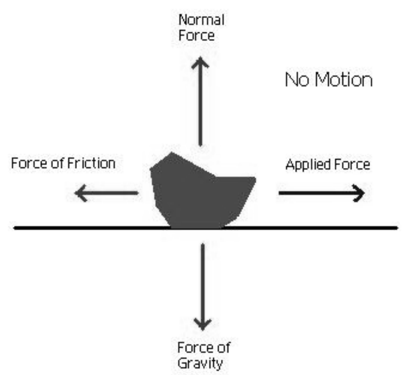


Figure 1.3
Static friction

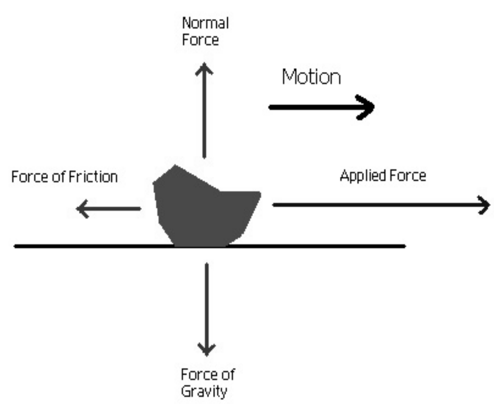


Figure 1.4
Kinetic friction

Figure 1.5 shows the relationship between applied force and frictional force.

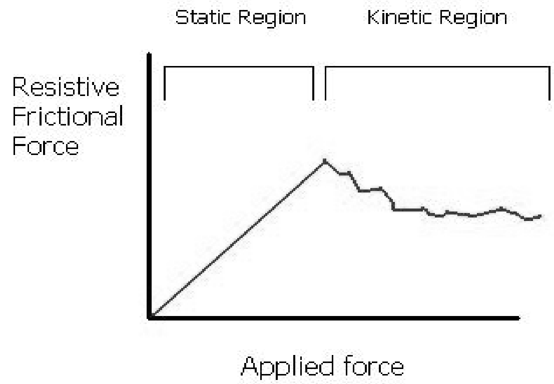


Figure 1.5
Relationship between applied and frictional force

Let's examine the relationship between these two forces and the applied force that creates them. Figure 1.5 shows static frictional force increasing to a maximum with the application of a force then dropping off sharply to a lesser value (kinetic friction) once the object starts moving. We can conclude few points from this graph such as those listed below.

Static friction:

- Static friction f_s is proportional to F_n (surface normal force)
- It is independent of area
- It reaches a maximum value (which depends on the surface materials) in preventing motion between surfaces, and then drops to the lower value of sliding friction as the object begins to move.

Kinetic friction:

- Kinetic friction f_k is proportional to F_n
- It is also independent of area and speed of surfaces
- It is always less than static friction $f_k < f_s$ (meaning it's easier to push an object once it's moving)

Since friction is proportional to the force pressing the surfaces together (Fn)

$f \alpha \; F_n$
which means that,

$f / F_n = \text{constant}$

This constant is known as coefficient of friction: μ (the Greek letter 'mu'). Thus we can write the equation as:

$f = \mu \times F_n$

Since static friction and kinetic friction are different, there is a μ for each one:

μ_s = coefficient of static friction
μ_k = coefficient of kinetic friction

Table 1.2 shows some common values of coefficients of kinetic and static friction.

Static friction $f_s \leq \mu_s F_n$

Kinetic $f_k = \mu_k F_n$

Note that static friction is expressed as an inequality in the above equation. This is because it varies from zero to a maximum. At the maximum value, and only at the maximum value (just before the object moves), the static frictional force is exactly equal to $\mu_s F_n$, or

$f_{s\ max} = \mu_s\ F_n$

Coefficient of friction $\mu = f / F_n$

Table 1.2

Some common values of coefficients of kinetic and static friction

Surfaces	**μ (static) μ_s**	**μ (kinetic) μ_k**
Steel on steel	0.74	0.57
Glass on glass	0.94	0.40
Metal on Metal (lubricated)	0.15	0.06
Ice on ice	0.10	0.03
Teflon on Teflon	0.04	0.04
Tire on concrete	1.00	0.80
Tire on wet road	0.60	0.40
Tire on snow	0.30	0.20

These values are approximate.

1.5 Summary

Mechanical Engineering deals with mechanics of operation on different systems. The various functions that fall within the scope of this branch are designing, manufacturing and maintenance. For this purpose it uses laws of physics and applies them to analyze their performance.

Friction is a force which is created when two surfaces move across each other. It plays very important role in some situations like walking, writing, etc. where you could not do without the force of friction. In some cases friction is less required, so compromise is required.