MCE 321

FRICTION

Friction is the force resisting the relative motion of solid surfaces, fluid layers, and material elements sliding against each other. There are several types of friction:

- **Dry friction** resists relative lateral motion of two solid surfaces in contact. Dry friction is subdivided into *static friction* between non-moving surfaces, and *kinetic friction* between moving surfaces.
- **Fluid friction** describes the friction between layers of a viscous fluid that are moving relative to each other.
- **Lubricated friction** is a case of fluid friction where a lubricant fluid separates two solid surfaces.
- **Skin friction** is a component of drag, the force resisting the motion of a fluid across the surface of a body.
- **Internal friction** is the force resisting motion between the elements making up a solid material while it undergoes deformation.

When surfaces in contact move relative to each other, the friction between the two surfaces converts kinetic energy into thermal energy (that is, it converts work to heat). This property can have dramatic consequences, as illustrated by the use of friction created by rubbing pieces of wood together to start a fire. Kinetic energy is converted to thermal energy whenever motion with friction occurs, for example when a viscous fluid is stirred. Another important consequence of many types of friction can be wear, which may lead to performance degradation and/or damage to components. Friction is a component of the science of tribology.

Friction is not itself a fundamental force. Dry friction arises from a combination of inter-surface adhesion, surface roughness, surface deformation, and surface contamination. The complexity of these interactions makes the calculation of friction from first principles impractical and necessitates the use of empirical methods for analysis and the development of theory.

Friction is a non-conservative force - work done against friction is path dependent. In the presence of friction, some energy is always lost in the form of heat. Thus mechanical energy is not conserved.

Laws of dry friction

The elementary property of sliding (kinetic) friction were discovered by experiment and were expressed as three empirical laws:

- **Amontons' First Law**: The force of friction is directly proportional to the applied load.
- **Amontons' Second Law**: The force of friction is independent of the apparent area of contact.
- **Coulomb's Law of Friction**: Kinetic friction is independent of the sliding velocity.

Dry friction

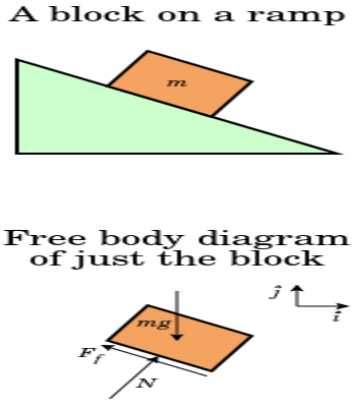
Dry friction resists relative lateral motion of two solid surfaces in contact. The two regimes of dry friction are 'static friction' between non-moving surfaces, and *kinetic friction* (sometimes called sliding friction or dynamic friction) between moving surfaces.

The Coulomb friction may take any value from zero up to one, and the direction of the frictional force against a surface is opposite to the motion that surface would experience in the absence of friction. Thus, in the static case, the frictional force is exactly what it must be in order to prevent motion between the surfaces; it balances the net force tending to cause such motion. In this case, rather than providing an estimate of the actual frictional force, the Coulomb approximation

provides a threshold value for this force, above which motion would commence. This maximum force is known as traction.

The force of friction is always exerted in a direction that opposes movement (for kinetic friction) or potential movement (for static friction) between the two surfaces. For example, a curling stone sliding along the ice experiences a kinetic force slowing it down. For an example of potential movement, the drive wheels of an accelerating car experience a frictional force pointing forward; if they did not, the wheels would spin, and the rubber would slide backwards along the pavement. Note that it is not the direction of movement of the vehicle they oppose; it is the direction of (potential) sliding between tire and road.

Normal force



From the figure above, the arrows are vectors indicating directions and magnitudes of forces, N is the normal force, mg is the force of gravity, and F_f is the force of friction.

The normal force is defined as the net force compressing two parallel surfaces together; and its direction is perpendicular to the surfaces. In the simple case of a mass resting on a horizontal surface, the only component of the normal force is the force due to gravity. In this case, the magnitude of the friction force is the product of the mass of the object, the acceleration due to gravity, and the coefficient of friction. However, the coefficient of friction is not a function of mass or volume; it depends only on the material. For instance, a large aluminum block has the same coefficient of friction as a small aluminum block. However, the magnitude of the friction force itself depends on the normal force, and hence on the mass of the block.

If an object is on a level surface and the force tending to cause it to slide is horizontal, the normal force between the object and the surface is just its weight, which is equal to its mass multiplied by the acceleration due to earth's gravity, g. If the object is on a tilted surface such as an inclined plane, the normal force is less, because less of the force of gravity is perpendicular to the face of the plane. Therefore, the normal force, and ultimately the frictional force, is determined using vector analysis, usually via a free body diagram. Depending on the situation, the calculation of the normal force may include forces other than gravity.

Coefficient of friction

The **coefficient of friction** (COF), often symbolized by the Greek letter μ, is a dimensionless scalar value which describes the ratio of the force of friction between two bodies and the force pressing them together. The coefficient of friction depends on the materials used; for example, ice on steel has a low coefficient of friction, while rubber on pavement has a high coefficient of friction.

Most dry materials in combination have friction coefficient values between 0.3 and 0.6. Values outside this range are rarer, but teflon, for example, can have a coefficient as low as 0.04. A value of zero would mean no friction at all, an elusive property. Rubber in contact with other surfaces can yield friction coefficients from 1 to 2. Occasionally it is maintained that μ is always < 1, but this is not true. While in most relevant applications μ < 1, a value above 1 merely implies that the force required to slide an object along the surface is greater than the normal force of the surface on the object. For example, silicone rubber or acrylic rubber-coated surfaces have a coefficient of friction that can be substantially larger than 1.
While it is often stated that the COF is a "material property," it is better categorized as a "system property."

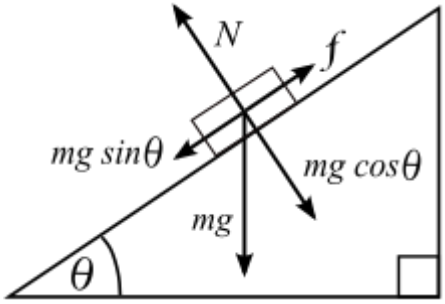
Static friction

An object experiences static friction when the object is not moving. The friction increases as the applied force increases until the block moves. After the block moves, it experiences kinetic friction, which is less than the maximum static friction.
Static friction is friction between two or more solid objects that are not moving relative to each other. For example, static friction can prevent an object from sliding down a sloped surface. The coefficient of static friction, typically denoted as μ_s, is usually higher than the coefficient of kinetic friction.
The static friction force must be overcome by an applied force before an object can move. The maximum possible friction force between two surfaces before sliding begins is the product of the coefficient of static friction and the normal force. The instant sliding occurs, static friction is no longer applicable—the friction between the two surfaces is then called kinetic friction.
An example of static friction is the force that prevents a car wheel from slipping as it rolls on the ground. Even though the wheel is in motion, the patch of the tire in contact with the ground is stationary relative to the ground, so it is static rather than kinetic friction.
The maximum value of static friction, when motion is impending, is sometimes referred to as **limiting friction**.

Kinetic friction

Kinetic friction, also known as **dynamic friction** or **sliding friction**, occurs when two objects are moving relative to each other and rub together. The coefficient of kinetic friction is typically denoted as μ_k, and is usually less than the coefficient of static friction for the same materials. The friction force between two surfaces after sliding begins is the product of the coefficient of kinetic friction and the normal force.
New models are beginning to show how kinetic friction can be greater than static friction. Kinetic friction is now understood, in many cases, to be primarily caused by chemical bonding between the surfaces, rather than interlocking asperities; however, in many other cases roughness effects are dominant, for example in rubber to road friction. Surface roughness and contact area affect kinetic friction for micro- and nano-scale objects where surface area forces dominate inertial forces.

Angle of friction



Angle of friction, θ, when block just starts to slide.

For certain applications it is more useful to define static friction in terms of the maximum angle before which one of the items will begin sliding. This is called the *angle of friction* or *friction angle*.

Fluid friction

Fluid friction occurs between fluid layers that are moving relative to each other. This internal resistance to flow is named *viscosity*. The viscosity of a fluid is described as its "thickness". Thus, water is "thin", having a lower viscosity, while honey is "thick", having a higher viscosity. The less viscous the fluid, the greater its ease of deformation or movement.

All real fluids (except superfluids) offer some resistance to shearing and therefore are viscous.

Lubricated friction

Lubricated friction is a case of fluid friction where a fluid separates two solid surfaces. Lubrication is a technique employed to reduce wear of one or both surfaces in close proximity moving relative to each another by interposing a substance called a lubricant between the surfaces.

In most cases the applied load is carried by pressure generated within the fluid due to the frictional viscous resistance to motion of the lubricating fluid between the surfaces. Adequate lubrication allows smooth continuous operation of equipment, with only mild wear, and without excessive stresses or seizures at bearings. When lubrication breaks down, metal or other components can rub destructively over each other, causing heat and possibly damage or failure.

Skin friction

Skin friction arises from the interaction between the fluid and the skin of the body, and is directly related to the area of the surface of the body that is in contact with the fluid. Skin friction follows the drag equation and rises with the square of the velocity.

Skin friction is caused by viscous drag in the boundary layer around the object. There are two ways to decrease skin friction: the first is to shape the moving body so that smooth flow is possible, like an airfoil. The second method is to decrease the length and cross-section of the moving object as much as is practicable.

Internal friction

Internal friction is the force resisting motion between the elements making up a solid material while it undergoes deformation.

Plastic deformation in solids is an irreversible change in the internal molecular structure of an object. This change may be due to either (or both) an applied force or a change in temperature. The change of an object's shape is called strain. The force causing it is called stress.
Elastic deformation in solids is reversible change in the internal molecular structure of an object. Stress does not necessarily cause permanent change. As deformation occurs, internal forces oppose the applied force. If the applied stress is not too large these opposing forces may completely resist the applied force, allowing the object to assume a new equilibrium state and to return to its original shape when the force is removed. This is known as elastic deformation or elasticity.

Reducing friction

Devices

Devices such as wheels, ball bearings, roller bearings, and air cushion or other types of fluid bearings can change sliding friction into a much smaller type of rolling friction.
Many thermoplastic materials such as nylon, HDPE and PTFE are commonly used in low friction bearings. They are especially useful because the coefficient of friction falls with increasing imposed load. For improved wear resistance, very high molecular weight grades are usually specified for heavy duty or critical bearings.

Lubricants

A common way to reduce friction is by using a lubricant, such as oil, water, or grease, which is placed between the two surfaces, often dramatically lessening the coefficient of friction. The science of friction and lubrication is called tribology. Lubricant technology is when lubricants are mixed with the application of science, especially to industrial or commercial objectives.
Superlubricity, a recently discovered effect, has been observed in graphite: it is the substantial decrease of friction between two sliding objects, approaching zero levels. A very small amount of frictional energy would still be dissipated.
Lubricants to overcome friction need not always be thin, turbulent fluids or powdery solids such as graphite and talc; acoustic lubrication actually uses sound as a lubricant.
Another way to reduce friction between two parts is to superimpose micro-scale vibration to one of the parts. This can be sinusoidal vibration as used in ultrasound-assisted cutting or vibration noise, known as dither.

Applications

Friction is an important factor in many engineering disciplines.

Transportation

- Automobile brakes inherently rely on friction, slowing a vehicle by converting its kinetic energy into heat. Incidentally, dispersing this large amount of heat safely is one technical challenge in designing brake systems.
- Rail adhesion refers to the grip wheels of a train have on the rails.
- Road slipperiness is an important design and safety factor for automobiles
    - Split friction is a particularly dangerous condition arising due to varying friction on either side of a car.
    - Road texture affects the interaction of tires and the driving surface.

Household usage

- Friction is used to heat and ignite matchsticks (friction between the head of a matchstick and the rubbing surface of the match box).

Advantages and Disadvantages of Friction

Advantages of friction:

- Friction enables us to walk freely.
- It helps to support ladder against wall.
- It becomes possible to transfer one form of energy to another.
- Objects can be piled up without slipping.
- Breaks of vehicles work due to friction.

Disadvantages of friction:

- It always resists the motion, so extra energy is required to overcome it.
- It causes wear and tear of machines.
- It decreases the life expectancy of moving parts of vehicles.

Since friction is very useful in some cases while harmful in some cases, friction is called a *necessary evil.*

Methods of increasing friction: In many cases, friction is very useful. So, enough friction is required and hence become necessary to increase the friction. Some of the common methods of increasing friction are:

- Spreading sand in slippery roads.
- Making rough shoe soles.
- Making surface of footpath rough.
- Fitting spikes in sport shoes.

Methods of reducing friction: In many cases, friction is very harmful. So, friction needs to be reduced. Some of the ways of reducing frictions are:

- Polishing or smoothing the surfaces.
- By the use of lubricants which increases the smoothness of the surface.
- Giving streamlines shape to submarines, jets etc
- By using ball bearing in wheels.

Review Questions

1. What is friction?
2. Describe the following: dry friction, fluid friction, lubricated friction, skin friction and internal friction.
3. Explain the term “coefficient of friction”
4. How can friction be reduced?
5. What are the applications of friction?
6. What are the advantages and disadvantages of friction?
7. How can friction be increased?