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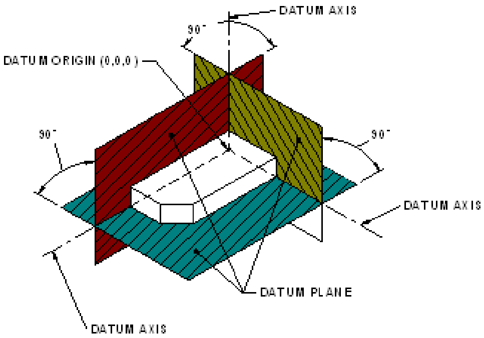

PDH Storm, by Engineers Edge, LLC

Chapter 2
Lubrication Principles

2-1. Friction

a. Definition of friction.

(1) Friction is a force that resists relative motion between two surfaces in contact. Depending on the application, friction may be desirable or undesirable. Certain applications, such as tire traction on pavement and braking, or when feet are firmly planted to move a heavy object, rely on the beneficial effects of friction for their effectiveness. In other applications, such as operation of engines or equipment with bearings and gears, friction is undesirable because it causes wear and generates heat, which frequently lead to premature failure.

(2) For purposes of this manual, the energy expended in overcoming friction is dispersed as heat and is considered to be wasted because useful work is not accomplished. This waste heat is a major cause of excessive wear and premature failure of equipment. Two general cases of friction occur: sliding friction and rolling friction.

b. Sliding friction.

(1) To visualize sliding friction, imagine a steel block lying on a steel table. Initially a force F (action) is applied horizontally in an attempt to move the block. If the applied force F is not high enough, the block will not move because the friction between the block and table resists movement. If the applied force is increased, eventually it will be sufficient to overcome the frictional resistance force f and the block will begin to move. At this precise instant, the applied force F is equal to the resisting friction force f and is referred to as the force of friction.

(2) In mathematical terms, the relation between the normal load L (weight of the block) and the friction force f is given by the coefficient of friction denoted by the Greek symbol μ. Note that in the present context, "normal" has a different connotation than commonly used. When discussing friction problems, the normal load refers to a load that is perpendicular to the contacting surfaces. For the example used here, the normal load is equal to the weight of the block because the block is resting on a horizontal table. However, if the block were resting on an inclined plane or ramp, the normal load would not equal the weight of the block, but would depend on the angle of the ramp. Since the intent here is to provide a means of visualizing friction, the example has been simplified to avoid confusing readers not familiar with statics.

c. Laws of sliding friction. The following friction laws are extracted from the Machinery Handbook, 23rd Revised Edition.

(1) Dry or unlubricated surfaces. Three laws govern the relationship between the frictional force f and the load or weight L of the sliding object for unlubricated or dry surfaces:

(a) "For low pressures (normal force per unit area) the friction force is directly proportional to the normal load between the two surfaces. As the pressure increases, the friction does not rise proportionally; but when the pressure become abnormally high, the friction increases at a rapid rate until seizing takes place."

(b) The value of f/L is defined as the coefficient of friction μ. "The friction both in its total amount and its coefficient is independent of the area of contact, so long as the normal force remains the same. This is true for moderate pressures only. For high pressures, this law is modified in the same way as the first case."

(c) "At very low velocities, the friction force is independent of the velocity of rubbing. As the velocities increase, the friction decreases."

The third law (c) implies that the force required to set a body in motion is the same as the force required to keep it in motion, but this is not true. Once a body is in motion, the force required to maintain motion is less than the force required to initiate motion and there is some dependency on velocity. These facts reveal two categories of friction: static and kinetic. Static friction is the force required to initiate motion (F_s). Kinetic or dynamic friction is the force required to maintain motion (F_k).

(2) Lubricated surfaces. The friction laws for well lubricated surfaces are considerably different than those for dry surfaces, as follows:

(a) "The frictional resistance is almost independent of the pressure (normal force per unit area) if the surfaces are flooded with oil."

(b) "The friction varies directly as the speed, at low pressures; but for high pressures the friction is very great at low velocities, approaching a minimum at about 2 ft/sec linear velocity, and afterwards increasing approximately as the square root of the speed."

(c) "For well lubricated surfaces the frictional resistance depends, to a very great extent, on the temperature, partly because of the change in viscosity of the oil and partly because, for journal bearings, the diameter of the bearing increases with the rise in temperature more rapidly than the diameter of the shaft, thus relieving the bearing of side pressure."

(d) "If the bearing surfaces are flooded with oil, the friction is almost independent of the nature of the material of the surfaces in contact. As the lubrication becomes less ample, the coefficient of friction becomes more dependent upon the material of the surfaces."

(3) The coefficient of friction. The coefficient of friction depends on the type of material. Tables showing the coefficient of friction of various materials and combinations of materials are available. Common sources for these tables are Marks Mechanical Engineering Handbooks and Machinery's Handbook. The tables show the coefficient of friction for clean dry surfaces and lubricated surfaces. It is important to note that the coefficients shown in these tables can vary.

(4) Asperities. Regardless of how smooth a surface may appear, it has many small irregularities called asperities. In cases where a surface is extremely rough, the contacting points are significant, but when the surface is fairly smooth, the contacting points have a very modest effect. The real or true surface area refers to the area of the points in direct contact. This area is considerably less than the apparent geometric area.

(5) Adhesion. Adhesion occurs at the points of contact and refers to the welding effect that occurs when two bodies are compressed against each other. This effect is more commonly referred to as "cold welding" and is attributed to pressure rather than heat, which is associated with welding in the more familiar sense. A shearing force is required to separate cold-welded surfaces.

(6) Shear strength and pressure. As previously noted, the primary objective of lubrication is to reduce friction and wear of sliding surfaces. This objective is achieved by introducing a material with a low shear strength or coefficient of friction between the wearing surfaces. Although nature provides such materials in the form of oxides and other contaminants, the reduction in friction due to their presence is insufficient for machinery operation. For these conditions, a second relationship is used to define the coefficient of friction: $\mu = S/P$, where S is the shear strength of the material and P is pressure (or force) contributing to compression. This relationship shows that the coefficient of friction is a function of the force required to shear a material.

(7) Stick-slip. To the unaided eye the motion of sliding objects appears steady. In reality this motion is jerky or intermittent because the objects slow during shear periods and accelerate following the shear.
This process static friction
force F_s cont he speed and
the object a erated at the
proper speec mes heard in
machine op a lathe, are
subject to sti ss than F_k.

d. Roll

(1) Whe on or rolling
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of friction i n varies with
conditions a

(2) Idea int or along a
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elastic defor is attributed
to elastic h ation of the
deformation ct to original
shape. As a converted to
heat. The sc

(3) A c lling friction.
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practical ap tes to rolling
friction. Ne

e. Law ies in equally
quantitative

(1) The the radius of
curvature r, As the radius
increases, th