Int. J. Mech. Eng. & Rob. Res. 2014

International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 2, No. 3, July 2014

Research Paper

TRIBOLOGY: SCIENCE OF LUBRICATION TO REDUCE FRICTION AND WEAR

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In this ongoing project our objective is to study of elastic - plastic contact between two rough surfaces using lubricant to reduce the friction and wear between the two contact surfaces. As compared with the liquid lubricant we will use a thin layer of solid lubricant between the rough surfaces. This analysis will be based on the classical contact modeling of Hertzian stress-theory and Gaussian theory of elastic plastic contact with some primary assumptions needed for the formulation of the problem.

Keywords: Tribology, Friction, Lubrication, Wear, Surface, Surface texture

INTRODUCTION

Tribology is the science and technology of interacting surfaces in relative motion and of related subjects and practices. The word "Tribology" derives from the Greek "Tribos" meaning "rubbing" and "logos" meaning 'principle or logic'. It includes the study and application of the principles of friction control, technology of lubrication and prevention of wear.

FUNDAMENTAL OF TRIBOLOGY

The tribological interactions of a solid surface's exposed face with interfacing materials and environment may result in loss of material from the surface. The process leading to loss of material is known as "wear". Major types of wear include abrasion, adhesion (friction), erosion, and corrosion. Estimated direct and consequential annual loss to industries in USA due to wear is approximately 1-2% of GDP. (Heinz,1987). Wear can be minimized by modifying the surface properties of solids by one or more of "surface engineering" processes (also called surface finishing) or by use of lubricants (for frictional or adhesive wear). Engineered surfaces extend the working life of both original and recycled and resurfaced equipments, thus saving large sums of money and leading to conservation of material, energy and the environment. Methodologies to minimize wear include

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systematic approaches to diagnose the wear and to prescribe appropriate solution. Important ones include:

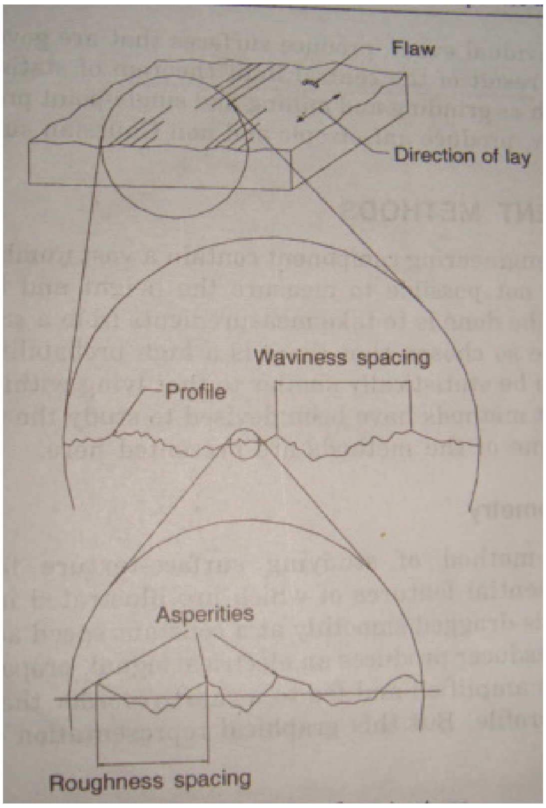
PROPERTIES OF SURFACE

Tribology is the science of interacting surfaces. So it is necessary to have a clear idea about what is meant by “surface”. In genaral, surface of a solid body is the geometrical boundary between the solid and the environment.but, in tribological term, Surface interactions are dependent both on the contacting materials and the shape of the surface. all solid surfaces are found to be rough. The roughness is characterized by asperities of varying amplitudes and spacing. the distribution of the asperities are found to be directional when the finishing process is direction dependent such as milling, turning etc., and homogeneous for the non-directional finishing process like lapping, electro-polishing etc. for the study of tribological behavior, one must know the methods of measuring and describing the surface shape in general, and the surface roughness in particular.

TYPE OF SURFACE TEXTURE

Roughness is produced by fluctuations of short wavelengths characterized by hill (local maxima) and valleys (local minima) of varying amplitudes spacing. These include the features intrinsic to the production process.Waviness is the surface irregularities of longer wavelengths and may result from factors such as machine or workpiece deflections, vibration, chatter, heat treatment or warping strains. Lay is the principal direction of the predominant surface pattern, usually determined by the production process. Flaw are unexpected and unintentional interruptions in the texture. Apart from these, the surface may contain large deviations from nominal shape of very large wavelength, which is known as error of form. These are not considered part of the surface texture.

Figure 1: Outline of a Surface Texture a General Typology of a Solid Surface is Shown in Figure Below



SURFACE SCIENCE

Surface science is the study of physical and chemical phenomena that occur at the interface of two phases, including solid-liquid interfaces, solid-gas interfaces, solid-vacuum interfaces, and liquid-gas interfaces. It includes the fields of surface chemistry and surface physics**.** Surface chemistry can be roughly defined as the study of chemical reactions at interfaces.

It is closely related to surface engineering, which aims at modifying the chemical composition of a surface by incorporation of selected elements or functional groups that produce various desired effects or improvements in the properties of the surface or interface. Surface chemistry also overlaps with electrochemistry. Surface science is of particular importance to the field of heterogeneous catalysis. Surface physics can be roughly defined as the study of physical changes that occur at interfaces. It overlaps with surface chemistry. Some of the things investigated by surface physics include surface diffusion, surface reconstruction, surface phonons and Plasmon's, epitaxial and surface enhanced Raman scattering, the emission and tunneling of electrons, spintronics, and the self-assembly of nanostructures on surfaces.

SURFACE CONTACT

When two objects touch, a certain portion of their surface areas will be in contact with each other. Contact area refers to the fraction of this area that consists of the atoms of one object being in contact with the atoms of the other object. Because objects are rarely perfectly flat, the actual contact area (on a microscopic scale) is usually much less than the contact area apparent on a macroscopic scale. Contact area may depend on the normal force between the two objects due to deformation.

Figure 2: The Top Image Shows Asperities Under No Load. The Bottom Image Depicts The Same Surface After a Load is Applied.

The contact area depends on the geometry of the contacting bodies, the load, and the material properties. The contact area between two parallel cylinders is a narrow rectangle. Two, non-parallel cylinders have an elliptical contact area, unless the cylinders are crossed at 90 degrees, in which case they have a circular contact area. Two spheres also have a circular contact area.

FRICTION AND CONTACT AREA

It is an empirical fact for many materials that $F = \mu N$, where F is the frictional force for sliding friction, μ is the coefficient of friction, and N is the normal reaction. There isn't a simple derivation for sliding friction's independence from area.

METHODS FOR DETERMINING CONTACT AREA

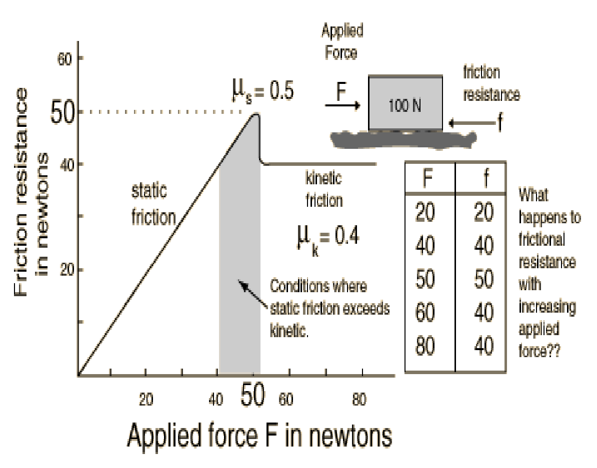
One way of determining the actual contact area is to determine it indirectly through a physical process that depends on contact area. For example, the resistance of a wire is dependent on the cross-sectional area, so one may find the contact area of a metal by measuring the current that flows through that area (through the surface of an electrode to another electrode, for example.)

FRICTION

Friction general and overview Friction is a force that resists relative motion between two surfaces in contact. Depending on the application, friction may be desirable or undesirable.

Two general cases of friction occur: sliding friction and rolling friction. Static frictional forces from the interlocking of the irregularities of two surfaces will increase to prevent any relative motion up until some limit where motion occurs. It is that threshold of motion which is characterized by the coefficient of static friction. The coefficient of static friction is typically larger than the coefficient of kinetic friction.When two surfaces are moving with respect to one another, the frictional resistance is almost constant over a wide range of low speeds, and in the standard model of friction the frictional force is described by the relationship below. The coefficient is typically less than the coefficient of static friction, reflecting the common experience that it is easier to keep something in motion across a horizontal surface than to start it in motion from rest.

Figure 3: Relation Between Applied Load and Friction Resistance



LAWS OF SLIDING FRICTION UNLUBRICATED SURFACES

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).

Laws of Sliding Friction lubricated Surfaces

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."

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. 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.Shear strength and pressure, 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

Rolling Friction

When a body rolls on a surface, the force resisting the motion is termed rolling friction or rolling resistance. Experience shows that much less force is required to roll an object than to slide or drag it. Because force is required to initiate and maintain rolling motion, there must be a definite but small amount of friction involved. Unlike the coefficient of sliding friction, the coefficient of rolling friction varies with conditions and has a dimension expressed in units of length.Ideally, a rolling sphere or cylinder will make contact with a flat surface at a single point or along a line (in the case of a cylinder). In reality, the area of contact is slightly larger than a point or line due to elastic deformation of either the rolling object or the flat surface, or both. Much of the friction is attributed to elastic hysteresis. A perfectly elastic object will spring back immediately after relaxation of the deformation. In reality, a small but definite amount of time is required to restore the object to original shape. As a result, energy is not entirely returned to the object or surface but is retained and converted to heat. The source of this energy is, in part, the rolling frictional force.

A certain amount of slippage (which is the equivalent of sliding friction) occurs in rolling friction. If the friction of an unhoused rolling object is measured, slippage effects are minimal. However, in practical applications such as a housed ball or roller bearing, slippage occurs and contributes to rolling friction. Neglecting slippage, rolling friction is very small compared to sliding friction.

Laws of Rolling Friction

The laws for sliding friction cannot be applied to rolling bodies in equally quantitative terms, but the following generalities can be given:

a. The rolling friction force F is proportional to the load L and inversely proportional to the radius of curvature r, or $F = \mu_r L/r$, where μ_r is the coefficient of rolling resistance, in meters (inches). As the radius increases, the frictional force decreases.

b. The rolling friction force F can be expressed as a fractional power of the load L times a constant k, or $F = kL^n$ where the constant k and the power n must be determined experimentally. n

c. The friction force F decreases as the smoothness of the rolling element improves.

FRICTION WEAR

Friction wear is defined as the progressive damage resulting in material loss due to relative contact between adjacent working parts. Although some wear is to be expected during normal operation of equipment, excessive friction causes premature wear, and this creates significant economic costs due to equipment failure, cost for replacement parts, and downtime.

Friction and wear also generate heat, which represents wasted energy that is not recoverable. Inother words, wear is also responsible for overall loss in system efficiency.The effects of wear arecommonly detected by visual inspection of surfaces. Surface damage can be classified as follows:

a. Surface damage without exchange of material:
   - Structural changes: aging, tempering, phase transformations, and recrystallization.
   - Plastic deformation: residual deformation of the surface layer.
   - Surface cracking: fractures caused by excessive contact strains or cyclic variations of thermally or mechanically induced strains.

b. Surface damage with loss of material (wear):
   - Characterized by wear scars of various shapes and sizes.
   - Can be shear fracture, extrusion, chip formation, tearing, brittle fracture, fatigue

fracture, chemical dissolution, and diffusion.

c. Surface damage with gain of material:

- Can include pickup of loose particles and transfer of material from the opposing surface.
- Corrosion: Material degradation by chemical reactions with ambient elements or elements from the opposing surface.

Wear may also be classified as mild or severe. The distinguishing characteristics between mild and severe wear are as follows (Williams 1994):

a. Mild

- Produces extremely smooth surfaces - sometimes smoother than the original.
- Debris is extremely small, typically in the range of 100 nanometers (nm) (3.28 × 10 ft) -13 in diameter.
- High electrical contact resistance, but little true metallic contact.

b. Severe

- Rough, deeply torn surfaces - much rougher than the original.
- Large metallic wear debris, typically up to 0.01 mm (3.28 × 10 ft) in diameter. -5
- Low contact resistance, but true metallic junctions are formed.

TYPES OF FRICTION WEAR

Abrasive Wear

Occurs when a hard surface slides against and cuts grooves from a softer surface. This condition is frequently referred to as two-body abrasion. Particles cut from the softer surface or dust and dirt introduced between wearing surfaces also contribute to abrasive wear. This condition is referred to as three-body abrasion.

Adhesive Wear

Frequently occurs because of shearing at points of contact or asperities that undergo adhesion or cold welding. Shearing occurs through the weakest section, which is not necessarily at the adhesion plane. In many cases, shearing occurs in the softer material, but such a comparison is based on shear tests of relatively large pure samples. The adhesion junctions, on the other hand, are very small spots of weakness or impurity that would be insignificant in a large specimen but in practice may be sufficient to permit shearing through the harder material. In some instances the wearing surfaces of materials with different hardness can contain traces of material from the other face. Theoretically, this type of wear does not remove material but merely transfers it between wearing surfaces. However, the transferred material is often loosely deposited and eventually flakes away in microscopic particles; these, in turn, cause wear.

Pitting Wear

It is due to surface failure of a material as a result of stresses that exceed the endurance (fatigue) limit of the material. Metal fatigue is demonstrated by bending a piece of metal wire, such as a paper clip, back and forth until it breaks. Whenever a metal shape is deformed repeatedly, it eventually fails. A different type of deformation occurs when a ball bearing under a load rolls along its race. The bearing is flattened somewhat and the edges of contact are extended outward. This repeated flexing eventually results in microscopic flakes being removed from the bearing. Fatigue wear also occurs during sliding motion. Gear teeth frequently fail due to pitting.

Corrosive Wear

Occurs as a result of a chemical reaction on a wearing surface. The most common form of corrosion is due to a reaction between the metal and oxygen (oxidation); however, other chemicals may also contribute. Corrosion products, usually oxides, have shear strengths different from those of the wearing surface metals from which they were formed. The oxides tend to flake away, resulting in the pitting of' wearing surfaces. Ball and roller bearings depend on extremely smooth surfaces to reduce frictional effects. Corrosive pitting is especially detrimental to these bearings.

WEAR CONTROL

Compacted Oxide Layer Glaze

It describes the often shiny, wear-protective layer of oxide formed when two metals (or a metal and ceramic) are slid against each other at high temperature in an oxygen-containing atmosphere. The layer forms on either or both the surfaces in contact and can protect against wear.

Compacted Oxide Layers At Low Temperature

It can form due to sliding at low temperatures and offer some wear protection, however, in the absence of heat as a driving force (either due to frictional heating or higher ambient temperature), they cannot sinter together to form more protective 'glaze' layers.

Mitigation

The fundamental way to prevent fretting is to design for no relative motion of the surfaces at the contact. Surface finish plays an important role as fretting normally occurs by the contact at the asperities of the mating surfaces. Lubricants are often effective in mitigation of fretting by reducing friction and inhibiting oxidation (e.g., reducing the exposure of the surface to air). Soft materials often exhibit higher susceptibility to fretting than hard materials of a similar type. The hardness ratio of the two sliding materials also has an effect on fretting wear.

LUBRICATION

Introduction

Lubrication is the process, or technique employed to reduce wear of one or both surfaces in close proximity, and moving relative to each another, by interposing a substance called lubricant between the surfaces to carry or to help carry the load (pressure generated) between the opposing surfaces. The primary purpose of lubrication is to reduce wear and heat between contacting surfaces in relative motion. While wear and heat cannot be completely eliminated, they can be reduced to negligible or acceptable levels. Because heat and wear are associated with friction, both effects can be minimized by reducing the coefficient of friction between the contacting surfaces. Lubrication is also used to reduce oxidation and prevent rust; to provide insulation in transformer applications; to transmit mechanical power in hydraulic fluid power applications; and to seal against dust, dirt, and water.

Lubricants

Reduced wear and heat are achieved by inserting a lower-viscosity (shear strength) material between wearing surfaces that have a relatively high coefficient of friction. In effect, the wearing surfaces are replaced by a material with a more desirable coefficient of friction. Any material used to reduce friction in this way is a lubricant. Lubricants are available in liquid, solid, and gaseous forms. Industrial machinery ordinarily uses oil or grease. Solid lubricants such as molybdenum disulfide or graphite are used when the loading at contact points is heavy. In some applications the wearing surfaces of a material are plated with a different metal to reduce friction.

PROPERTIES OF LUBRICATING OILS

Oil Viscosity

Technically, the viscosity of an oil is a measure of the oil's resistance to shear. Viscosity is more commonly known as resistance to flow.

Shear

When viscosity is determined by directly measuring shear stress and shear rate, it is expressed in centipoise (cP) and is referred to as the absolute or dynamic viscosity. In the oil industry, it is more common to use kinematic viscosity, which is the absolute viscosity divided by the density of the oil being tested. Kinematic viscosity is expressed in centistokes (cSt). Viscosity in centistokes is conventionally given at two standard temperatures: 40°C and 100°C (104°F and 212°F).

Time

Another method used to determine oil viscosity measures the time required for an oil sample to flow through a standard orifice at a standard temperature. Viscosity is then expressed in SUS (Saybolt Universal Seconds). SUS viscosities are also conventionally given at two standard temperatures: 37°C and 98°C (100°F and 210°F). As previously noted, the units of viscosity can be expressed as centipoises (cP), centistokes (cST), or Saybolt Universal Seconds (SUS), depending on the actual test method used to measure the viscosity.

Viscosity Index

The viscosity index, commonly designated VI, is an arbitrary numbering scale that indicates the changes in oil viscosity with changes in temperature. Viscosity index can be classified as follows: low VI - below 35; medium VI - 35 to 80; high VI - 80 to 110; very high VI - above 110. A high viscosity index indicates small oil viscosity changes with temperature. A low viscosity index indicates high viscosity changes with temperature. Therefore, a fluid that has a high viscosity index can be expected to undergo very little change in viscosity with temperature extremes and is considered to have a stable viscosity. A fluid with a low viscosity index can be expected to undergo a significant change in viscosity as the temperature fluctuates.

Pour Point

The pour point is the lowest temperature at which an oil will flow. This property is crucial for oils that must flow at low temperatures. A commonly used rule of thumb when selecting oils is to ensure that the pour point is at least 10°C (20°F) lower than the lowest anticipated ambient temperature.

Cloud Point

The cloud point is the temperature at which dissolved solids in the oil, such as paraffin wax, begin to form and separate from the oil. As the temperature drops, wax crystallizes and becomes visible. Certain oils must be maintained at temperatures above the cloud point to prevent clogging of filters.

Flash Point and Fire Point

The flash point is the lowest temperature to which a lubricant must be heated before its vapor, when mixed with air, will ignite but not continue to burn. The fire point is the temperature at which lubricant combustion will be sustained. The flash and fire points are useful indetermining a lubricant's volatility and fire resistance. The flash point can be used to determine the transportation and storage temperature requirements for lubricants. Lubricant producers can also use the flash point to detect potential product contamination. A lubricant exhibiting a flash point significantly lower than normal will be suspected of contamination with a volatile product. Products with a flash point less than 38° C (100°F) will usually require special precautions for safe handling. The fire point for alubricant is usually 8 to 10 percent above the flash point. The flash point and fire point should not be confused with the auto-ignition temperature of a lubricant, which is the temperature at which a lubricant will ignite spontaneously without an external ignition source.

Acid Number or Neutralization Number

The acid or neutralization number is a measure of the amount of potassium hydroxide required to neutralize the acid contained in a lubricant. Acids are formed as oils oxidize with age and service. The acid number for an oil sample is indicative of the age of the oil and can be used to determine when the oil must be changed.

Oil classification and grading system: Professional societies classify oils by viscosity ranges or grades. The most common systems are those of the SAE (Society of Automotive Engineers), the AGMA (American Gear Manufacturers Association), the ISO (International Standards Organization), and the ASTM (American Society for Testing and Materials). Other systems are used in special circumstances.

The variety of grading systems used in the lubrication industry can be confusing. A specification giving the type of oil to be used might identify an oil in terms of its AGMA grade, for example, but an oil producer may give the viscosity in terms of cSt or SUS. Conversion charts between the various grading systems are readily available from lubricant suppliers. Conversion between cSt and SUS viscosities at standard temperatures can also be obtained from ASTM D 2161.

THE METHODS OF LUBRICATION

As the load increases on the contacting surfaces three distinct situations can be observed with respect to the mode of lubrication, which are called regimes of lubrication:

Fluid Film Lubrication

It is the lubrication regime in which through viscous forces the load is fully supported by the lubricant within the space or gap between the parts in motion relative to one another (the lubricated conjunction) and solid-solid contact is avoided.

Hydrostatic Lubrication

It is when an external pressure is applied to the lubricant in the bearing, to maintain the fluid lubricant film where it would otherwise be squeezed out.

Hydrodynamic Lubrication

It is where the motion of the contacting surfaces, and the exact design of the bearing is used to pump lubricant around the bearing to maintain the lubricating film. This design of bearing may wear when started or stopped, as the lubricant film breaks down.

Elasto-hydro Dynamic Lubrication

The opposing surfaces are separated but there occurs some interaction between the raised solid features called asperities, and there is an elastic deformation on the contacting surface enlarging the load bearing area whereby the viscous resistance of the lubricant becomes capable of supporting the load.

Boundary Lubrication (Also Called Boundary Film Lubrication)

The bodies come into closer contact at their asperities; the heat developed by the local pressures causes a condition which is called stick-slip and some asperities break off. At the elevated temperature and pressure conditions chemically reactive constituents of the lubricant react with the contact surface forming a highly resistant tenacious layer, or film on the moving solid surfaces (boundary film) which is capable of supporting the load and major wear or breakdown is avoided. Boundary lubrication is also defined as that regime in which the load is carried by the surface asperities rather than by the lubricant.

Oiliness Concept - Boundary Lubrication

Lubricants required to operate under boundary lubrication conditions must possess an added quality referred to as “oiliness” or “lubricity” to lower the coefficient of friction of the oil between the rubbing surfaces. Oiliness is an oil enhancement property provided through the use of chemical additives known as antiwear (AW) agents. AW agents have a polarizing property that enables them to behave in a manner similar to a magnet. Like a magnet, the opposite sides of the oil film have different polarities. When an AW oil adheres to the metal wear surfaces, the sides of the oil film not in contact with the metal surface have identical polarities and tend to repel each other and form a plane of slippage. Most oils intended for use in heavier machine applications contain AW agents. Examples of equipment that rely exclusively on boundary lubrication include reciprocating equipment such as engine and compressor pistons, and slow-moving equipment such as turbine wicket gates. Gear teeth also rely on boundary lubrication to a great extent.

TYPES OF LUBRICANTS

Graphite and mica are the examples of solid lubricants. Graphite is often mixed with oil to lubricate automobile springs. Graphite is also used as cylinder lubricant, both in power and colloidal form. It has low co-efficient of friction and is stable at high temperatures. Semi-solid lubricants such as grease, are used in chassis lubrication. Grease is widely used in automobiles at places where retention of liquid lubricant is difficult and where high temperatures are encountered, like in axles.

Grease is a suspension of metallic soap (calcium or sodium soap of fatty acids) dispersed in a lubricating oil. Liquid lubricants are used in automobile engine lubricating system such as transmission system and rear axle system. Lubricating oils are classified according to their source-as animal, vegetable, minerals.

COMMON TYPES OF SOLID LUBRICANTS

Graphite Characteristics Graphite has a low friction coefficient and very high thermal stability (2000°C [3632°F] and above). However, practical application is limited to a range of 500 to 600°C (932 to 1112°F) due to oxidation. Furthermore, because graphite relies on adsorbed moisture or vapors to achieve low friction, use may be further limited. At temperatures as low as 100°C (212°F), the amount of water vapor adsorbed may be significantly reduced to the point that low friction cannot be maintained. In some instances sufficient vapors may be extracted from contaminants in the surrounding environment or may be deliberately introduced to maintain low friction. When necessary, additives composed of inorganic compounds may be added to enable use at temperatures to 550°C (1022°F). Another concern is that graphite promotes electrolysis. Graphite has a very noble potential of + 0.25V, which can lead to severe galvanic corrosion of copper alloys and stainless steels in saline waters Molybdenum Disulfide Coating Services Molybdenum disulfide (MoS_2). Like graphite, MoS_2 has a low friction coefficient, but, unlike graphite, it does not rely on adsorbed vapors or moisture. In fact, adsorbed vapors may actually result in a slight, but insignificant, increase in friction. MoS_2 also has greater load-carrying capacity and its manufacturing quality is better controlled. Thermal stability in non oxidizing environments is acceptable to 1100°C (2012°F), but in air it may be reduced to a range of 350 to 400°C (662 to 752°F). It is often used in two-stroke engines; e.g., motorcycle engines. MoS2 is also used in CV and universal joints. During the Vietnam War, the molybdenum disulfide product “Dri-Slide” was used to lubricate weapons, although it was supplied from private sources, not the military. MoS2-coatings allow bullets easier passage through the rifle barrel with less deformation and better ballistic accuracy. Soft Metal Film Lubrication Soft metal films. Many soft metals such as lead, gold, silver, copper, and zinc, possess low shear strengths and can be used as lubricants by depositing them as thin films on hard substrates. Deposition methods include electroplating, evaporating, sputtering, and ion plating. These films are most useful for high temperature applications up to 1000°C (1832°F) and roller bearing applications where sliding is minimal. Surface Treatment for Lubrication Surface treatments commonly used as alternatives to surface film depositions include thermal diffusion, ion implantation, and chemical conversion coatings.Thermal diffusion, This is a process that introduces foreign atoms into a surface for various purposes such as increasing wear-resistance by increasing surface hardness; producing low shear strength to inhibit scuffing or seizure; and in combination with these to enhance corrosion-resistance.Ion implantation This is a recently developed method that bombards a surface with ions to increase hardness, which improves wear- and fatigue-resistance.Chemical conversion coatings, Frequently, solid lubricants will not adhere to the protected metal surface. A conversion coating is a porous nonlubricating film applied to the base metal to enable adherence of the solid lubricant. The conversion coating by itself is not a suitable lubricant. Polymers, Polymers are used as thin films, as self-lubricating materials, and as binders for lamellar solids. Films are produced by a process combining spraying and sintering. Alternatively, a coating can be produced by bonding the polymer with a resin. Sputtering can also be used to produce films. The most common polymer used for solid lubrication is PTFE The main advantages of PTFE are low friction coefficient, wide application range of -200 to 250°C (-328 to 418°F), and lack of chemical reactivity. Disadvantages include lower load-carrying capacity and endurance limits than other alternatives. Low thermal conductivity limits use to low speed sliding applications where MoS_2 is not satisfactory. Common applications include antistick coatings and self-lubricating composites

METHODS OF APPLYING SOLID LUBRICANTS

Powdered solids. Burnishing: Burnishing is a rubbing process used to apply a thin film of dry powdered solid lubricant such as graphite, MoS_2 , etc., to a metal surface. This process produces a highly polished surface that is effective where lubrication requirements and wear-life are not stringent, where clearance requirements must be maintained, and where wear debris from the lubricant must be minimized. Surface roughness of the metal substrate and particle size of the powder are critical to ensure good application. Hand rubbing: Hand rubbing is a procedure for loosely applying a thin coating of solid lubricant. Dusting, Powder is applied without any attempt to evenly spread the lubricant. This method results in a loose and uneven application that is generally unsatisfactory.

Tumbling

Parts to be lubricated are tumbled in a powdered lubricant. Although adhesion is not very good, the method is satisfactory for noncritical parts such as small threaded fasteners and rivets.

Dispersions

Dispersions are mixtures of solid lubricant in grease or fluid lubricants. The most common solids used are graphite, MoS_2 , PTFE, and Teflon®. The grease or fluid provides normal lubrication while the solid lubricant increases lubricity and provides extreme pressure protection. Addition of MoS_2 to lubricating oils can increase load-carrying capacity, reduce wear, and increase life in roller bearings, and has also been found to reduce wear and friction in automotive applications. However, caution must be exercised when using these solids with greases and lubricating fluids. Grease and oil may prevent good adhesion of the solid to the protected surface. Detergent additives in some oils can also inhibit the wear-reducing ability of MoS_2 and graphite, and some antiwear additives may actually increase wear. Solid lubricants can also affect the oxidation stability of oils and greases. Consequently, the concentration of oxidation inhibitors required must be carefully examined and controlled. Aerosol sprays are frequently used to apply solid lubricant in a volatile carrier or in an air-drying organic resin. However, this method should be limited to short-term uses or to light- or moderate-duty applications where thick films are not necessary. Specifications for solid lubricant dispersions are not included in this manual. Before using dispersions, users should become familiar with their applications and should obtain information in addition to that provided in this manual. The information should be based on real-world experiences with similar or comparable applications.

Self-lubricating Composites

The primary applications for self-lubricating composites include dry bearings, gears, seals, sliding electrical contacts, and retainers in roller bearings. Composites may be polymer, metal-solid, carbon and graphite, and ceramic and cermets.

Polymer Lubrication

The low thermal conductivity of polymers inhibits heat dissipation, which causes premature failure due to melting. This condition is exacerbated if the counterface material has the same or similar thermal conductivity. Two polymers in sliding contact will normally operate at significantly reduced speeds than a polymer against a metal surface. The wear rate of polymer composites is highly dependent upon the surface roughness of the metal counterfaces. In the initial operating stages, wear is significant but can be reduced by providing smooth counterfaces. As the run-in period is completed, the wear rate is reduced due to polymer film transfer or by polishing action between the sliding surfaces. Environmental factors also influence wear rate. Increased relative humidity inhibits transfer film formation in polymer composites such as PTFE, which rely on transfer film formation on counterfaces. The presence of hydrocarbon lubricants may also produce similar effects. Composites such as nylons and acetals, which do not rely on transfer film formation, experience reduced wear in the presence of small amounts of hydrocarbon lubricants.

Metal-solid Lubrication

Composites containing lamellar solids rely on film transfer to achieve low friction. The significant amount of solids required to improve film transfer produces a weak composite with reduced wear life. Addition of nonlamellar solids to these composites can increase strength and reduce wear. Various manufacturing techniques are used in the production of metal-solid composites. These include powder metallurgy, infiltration of porous metals, plasma spraying, and electrochemical code position. Another fabrication technique requires drilling holes in machine parts and packing the holes with solid lubricants. One of the most common applications for these composites is self-lubricating roller bearing retainers used in vacuum or high temperatures up to 400°C (752°F). Another application is in fail-safe operations, where the bearing must continue to operate for a limited time following failure of the normal lubrication system.

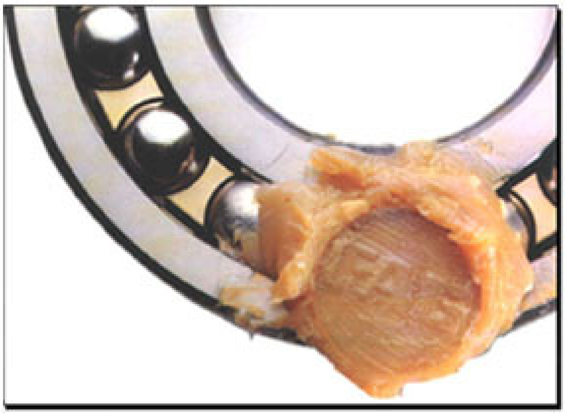
Carbon and Graphites

The primary limitations of bulk carbon are low tensile strength and lack of ductility. However, their high thermal and oxidation stabilities at temperatures of 500 to 600°C (932 to 1112°F) (higher with additives) enable use at high temperatures and high sliding speeds. For graphitic carbons in dry conditions, the wear rate increases with temperature. This condition is exacerbated when adsorbed moisture inhibits transfer film formation. Furthermore, dusting may also cause failure at high temperatures and sliding speeds. However, additives are available to inhibit dusting.

Ceramics and Cermets

Ceramics and cermets can be used in applications where low wear rate is more critical than low friction. These composites can be used at temperatures up to 1000°C (1832°F). Cermets have a distinct advantage over ceramics in terms of toughness and ductility. However, the metal content tends to reduce the maximum temperature limit. Solid lubricant use with bulk ceramics is limited to insertion in machined holes or recesses.

Figure 4: Grease in Ball Bearing



GREASE-SEMI SOLID LUBRICATION

General Description

Grease is a semifluid to solid mixture of a fluid lubricant, a thickener, and additives. The fluid lubricant that performs the actual lubrication can be petroleum (mineral) oil, synthetic oil, or vegetable oil. The thickener gives grease its characteristic consistency and is sometimes thought of as a “three-dimensional fibrous network” or “sponge” that holds the oil in place. Common thickeners are soaps and organic or inorganic nonsoap thickeners. The majority of greases on the market are composed of mineral oil blended with a soap thickener. Additives enhance performance and protect the grease and lubricated surfaces. Grease has been described as a temperature-regulated feeding device: when the lubricant film between wearing surfaces thins, the resulting heat softens the adjacent grease, which expands and releases oil to restore film thickness.

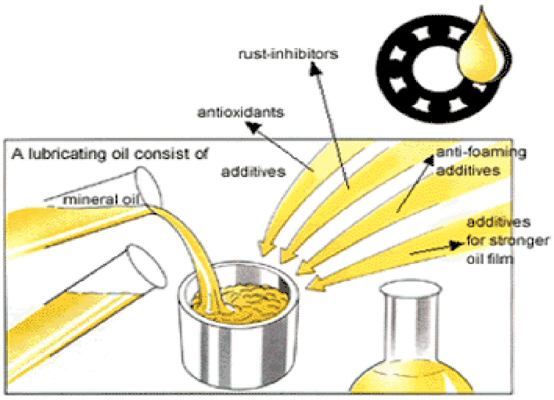
Function of Grease

“The function of grease is to remain in contact with and lubricate moving surfaces without leaking out under gravity or centrifugal action, or be squeezed out under pressure. Its major practical requirement is that it retain its properties under shear at all temperatures that it is subjected to during use. At the same time, grease must be able to flow into the bearing through grease guns and from spot to spot in the lubricated machinery as needed, but must not add significantly to the power required to operate the machine, particularly at startup.” (Boehringer 1992)

Application of Grease

Grease is used when it is not practical or convenient to use oil. The lubricant choice for a specific application is determined by matching the machinery design and operating conditions with desired lubricant characteristics. Grease is generally used for, Machinery that runs intermittently or is in storage for an extended period of time. Because grease remains in place, a lubricating film can instantly form, Machinery that is not easily accessible for frequent lubrication. High-quality greases can lubricate isolated or relatively inaccessible components for extended periods of time without frequent replenishing. These greases are also used in sealed-for-life applications such as some electrical motors and gearboxes. Machinery operating under extreme conditions such as high temperatures and pressures, shock loads, or slow speed under heavy load. Under these circumstances, grease provides thicker film cushions that are required to protect and adequately lubricate, whereas oil films can be too thin and can rupture.Worn components. Grease maintains thicker films in clearances enlarged by wear and can extend the life of worn parts that were previously oil lubricated. Thicker grease films also provide noise insulation.

Figure 5: Gradients of Lubricating Oil



TYPES OF OIL-LIQUID LUBRICATION

Classification of Oils

Oils are generally classified as refined and synthetic. Paraffinic and naphthenic oils are refined from crude oil while synthetic oils are manufactured. Literature on lubrication frequently makes references to longchain molecules and ring structures in connection with paraffinic and naphthenic oils, respectively. These terms refer to the arrangement of hydrogen and carbon atoms that make up the molecular structure of the oils. Paraffinic oils are distinguished by a molecular structure composed of long chains of hydrocarbons, i.e., the hydrogen and carbon atoms are linked in a long linear series similar to a chain. Paraffinic oils contain paraffin wax and are the most widely used base stock for lubricating oils. In comparison with naphthenic oils, paraffinic oils have:Excellent stability (higher resistance to oxidation). Higher pour point.Higher viscosity index. Low volatility and, consequently, high flash points. Low specific gravities In contrast to paraffinic oils, naphthenic oils are distinguished by a molecular structure composed of “rings” of hydrocarbons, i.e., the hydrogen and carbon atoms are linked in a circular pattern. These oils do not contain wax and behave differently than paraffinic oils. Naphthenic oils have. Good stability. Lower pour point due to absence of wax. Lower viscosity indexes. Higher volatility (lower flash point). Higher specific gravities.

Naphthenic oils are generally reserved for applications with narrow temperature ranges and where a low pour point is required.

Synthetic Oils

Synthetic lubricants are produced from chemical synthesis rather than from the refinement of existing petroleum or vegetable oils. These oils are generally superior to petroleum (mineral) lubricants in most circumstances. Synthetic oils perform better than mineral oils in the following respects, Better oxidation stability or resistance. Better viscosity index. Much lower pour point, as low as -46°C (-50°F). Lower coefficient of friction. The advantages offered by synthetic oils are most notable at either very low or very high temperatures. Good oxidation stability and a lower coefficient of friction permits operation at higher temperatures. The better viscosity index and lower pour points permit operation at lower temperatures. The major disadvantage to synthetic oils is the initial cost, which is approximately three times higher than mineral-based oils. However, the initial premium is usually recovered over the life of the product, which is about three times longer than conventional lubricants. The higher cost makes it inadvisable to use synthetics in oil systems experiencing leakage. Plant Engineering magazine's "Exclusive Guide to Synthetic Lubricants," which is revised every three years, provides information on selecting and applying these lubricants. Factors to be considered when selecting synthetic oils include pour and flash points; demulsibility; lubricity; rust and corrosion protection; thermal and oxidation stability; antiwear properties; compatibility with seals, paints, and other oils; and compliance with testing and standard requirements.

EXTREME PRESSURE (EP) LUBRICATION

Extreme Pressure (EP) Lubrication General

Definition. AW agents are effective only up to a maximum temperature of about 250°C (480°F). Unusually heavy loading will cause the oil temperature to increase beyond the effective range of the antiwear protection. When the load limit is exceeded, the pressure becomes too great and asperities make contact with greater force. Instead of sliding, asperities along the wear surfaces experience shearing, removing the lubricant and the oxide coating. Under these conditions the coefficient of friction is greatly increased and the temperature rises to a damaging level. Applications under extreme pressure conditions rely on additives. Lubricants containing additives that protect against extreme pressure are called EP lubricants, and oils containing additives to protect against extreme pressure are classified as EP oils. EP lubrication is provided by a number of chemical compounds. The most common are compounds of boron, phosphorus, sulfur, chlorine, or combinations of these. The compounds are activated by the higher temperature resulting from extreme pressure, not by the pressure itself. As the temperature rises, EP molecules become reactive and release derivatives of phosphorus, chlorine, or sulfur (depending on which compound is used) to react with only the exposed metal surfaces to form a new compound such as iron chloride or iron sulfide. The new compound forms a solid protective coating that fills the asperities on the exposed metal. Thus, the protection is deposited at exactly the sites where it is needed. AW agents in the EP oil continue to provide antiwear protection at sites where wear and temperature are not high enough to activate the EP agents.

WATER-OIL EMULSIONS

Oil-in-water, These fluids consist of very small oil droplets dispersed in a continuous water phase. These fluids have low viscosities, excellent fire-resistance, and good cooling capability due to the large proportion of water. Additives must be used to improve their inherently poor lubricity and to protect against rust.

Water-in-oil

The water content of water-in-oil fluids may be approximately 40 percent. These fluids consist of very small water droplets dispersed in a continuous oil phase. The oil phase provides good to excellent lubricity while the water content provides the desired level of fire-resistance and enhances the fluid cooling capability. Emulsifiers are added to improve stability. Additives are included to minimize rust and to improve lubricity as necessary. These fluids are compatible with most seals and metals common to hydraulic fluid applications. The operating temperature of water-in-oil fluids must be kept low to prevent evaporation and oxidation. The proportion of oil and water must be monitored to ensure that the proper viscosity is maintained especially when adding water or concentrated solutions to the fluid to make up for evaporation. To prevent phase separation, the fluid should be protected from repeated cycles of freezing and thawing.

Synthetic Fire-Resistant Fluids

Three types of synthetic fire-resistant fluids are manufactured: phosphate esters, chlorinated (halogenated) hydrocarbons, and synthetic base (a mixture of these two). These fluids do not contain water or volatile materials, and they provide satisfactory operation at high temperatures without loss of essential elements (in contrast to water-based fluids). The fluids are also suitable for high-pressure applications. Synthetic fluids have a low viscosity index, anywhere from 80 to - 400, so their use should be restricted to relatively constant operating temperatures. When required to operate at low temperatures, these fluids may require auxiliary heating. Synthetic fluids also have high specific gravities so pump inlet conditions must be carefully selected to prevent cavitation. Phosphate esters have flash points above 204°C (400°F) and auto-ignition temperatures above 483°C (900°F), making these fluids less likely to ignite and sustain burning. Halogenated hydrocarbon fluids are inert, odorless, nonflammable, noncorrosive, and have low toxicity. Seal compatibility is very important when using synthetic fluids. Most commonly used seals such as Nitrile (Buna) and Neoprene are not compatible with these fluids.

HYDRAULIC FLUIDS

The primary purpose of any hydraulic fluid is to transmit power mechanically throughout a hydraulic power system. To ensure stable operation of components, such as servos, the fluid must flow easily and must be incompressible.

Lubrication

Hydraulic fluids must provide the lubricating characteristics and qualities necessary to protect all hydraulic system components against friction and wear, rust, oxidation, corrosion, and demulsibility.

Sealing

Many hydraulic system components, such as control valves, operate with tight clearances where seals are not provided. In these applications hydraulic fluids must provide the seal between the lowpressure and high-pressure side of valve ports. The amount of leakage will depend on the closeness or the tolerances between adjacent surfaces and the fluid viscosity.

Cooling

The circulating hydraulic fluid must be capable of removing heat generated throughout the system.

Viscosity of Hydraulic Fluid

As with lubricating oils, viscosity is the most important characteristic of a hydraulic fluid and has a significant impact on the operation of a hydraulic system. If the viscosity is too high then friction, pressure drop, power consumption, and heat generation increase. Furthermore, sluggish operation of valves and servos may result. If the viscosity is too low, increased internal leakage may result under higher operating temperatures. The oil film may be insufficient to prevent excessive wear or possible seizure of moving parts, pump efficiency may decrease, and sluggish operation may be experienced.

Compressibility of Hydraulic Fluid

Compressibility is a measure of the amount of volume reduction due to pressure. Compressibility is sometimes expressed by the “bulk modulus,” which is the reciprocal of compressibility. Petroleum fluids are relatively incompressible, but volume reductions can be approximately 0.5 percent for pressures ranging from 6900 kPa (1000 lb/sq in) up to 27,600 kPa (4000 lb/sq in). Compressibility increases with pressure and temperature and has significant effects on high-pressure fluid systems. Problems directly caused by compressibility include the following: servos fail to maintain static rigidity and experience adverse effects in system amplification or gain; loss in efficiency, which is counted as power loss because the volume reduction due to compressibility cannot be recovered; and cavitation, which may cause metal fracture, corrosive fatigue, and stress corrosion.

Stability of Hydraulic Fluid

The stability of a hydraulic fluid is the most important property affecting service life. The properties of a hydraulic fluid can be expected to change with time. Factors that influence the changes include: mechanical stress and cavitation, which can break down the viscosity improvers and cause reduced viscosity; and oxidation and hydrolysis which cause chemical changes, formation of volatile components, insoluble materials, and corrosive products. The types of additives used in a fluid must be selected carefully to reduce the potential damage due to chemical breakdown at high temperatures.

TYPES OF HYDRAULIC FLUIDS

Petroleum

Petroleum-based oils are the most commonly used stock for hydraulic applications where there is no danger of fire, no possibility of leakage that may cause contamination of other products, no wide temperature fluctuations, and no environmental impact.

Fire Resistant

In applications where fire hazards or environmental pollution are a concern, waterbased or aqueous fluids offer distinct advantages. The fluids consist of water-glycols and water-in-oil fluids with emulsifiers, stabilizers, and additives. Due to their lower lubricity, piston pumps used with these fluids should be limited to 20,670 kPa (3000 lb/sq in). Furthermore, vane pumps should not be used with water-based fluid unless they are specifically designed to use such fluids.

Water-glycol Hydraulic Fluid

Water-glycol fluids contain from 35 to 60 percent water to provide the fire resistance, plus a glycol antifreeze such as ethylene, diethylene, or propylene which is nontoxic and biodegradable, and a thickener such as polyglycol to provide the required viscosity. These fluids also provide all the important additives such as antiwear, foam, rust, and corrosion inhibitors. Operating temperatures for water-glycol fluids should be maintained below 49°C (120°F) to prevent evaporation and deterioration of the fluid. To prevent separation of fluid phases or adverse effects on the fluid additives, the minimum temperature should not drop below 0° C (32° F).Viscosity, pH, and water hardness monitoring are very important in water-glycol systems. If water is lost to evaporation, the fluid viscosity, friction, and operating temperature of the fluid will increase. The end result is sluggish operation of the hydraulic system and increased power consumption. If fluid viscosity is permitted to drop due to excessive water, internal leakage at actuators will increase and cause sluggish operation. A thin fluid is also more prone to turbulent flow which will increase the potential for erosion of system components. Under normal use, the fluid pH can be expected to drop due to water evaporation, heat, and loss of corrosion inhibitors. The fluid pH should be slightly alkaline (i.e., above pH8) to prevent rust. However, because of their volatility and toxicity, handling of the amine additives that stabilize the pH is not recommended. Therefore, these essential additives are not usually replenished. Fluids with pH levels that drop below 8 should be removed and properly discarded. Make-up water added to the system must be distilled or soft deionized. The calcium and magnesium present in potable water will react with lubricant additives causing them to floc or come out of solution and compromise the fluid's performance. When this condition occurs the fluid is permanently damaged and should be replaced. To prolong the fluid and component life, water added to the system should have a maximum hardness of 5 parts per million (ppm).

CONCLUSION

We have discussed about the brief introduction to the theory of tribology. To define tribology we discussed about the area where it is needed i.e. the area related to friction and wear. To overcome the problem of friction and wear we discussed the general process for controlling those problems like lubricants, mitigation etc and their analysis techniques.. There is detail discussion of lubricants like properties of lubrication, method of lubrication, types of lubricant, why lubrication is necessary in the industry.

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