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Back To Basics Series

TRIBOLOGY:
THE SCIENCE OF COMBATTING WEAR

Part IX

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PART 9- Boundary Lubrication (BL)

Boundary lubrication (BL) is defined as a condition of lubrication of metals in which the friction and wear between two surfaces in relative motion are determined by the properties of the surfaces and by the properties of the lubricant other than viscosity. Metal to metal contact occurs and the chemistry of the system is involved. Physically adsorbed or chemically reacted soft solid films (usually very thin) support contact loads. As a result some wear is inevitable. See Ref. (1).

Industrial Significance

Why Boundary Lubrication is needed:

For maximum service life and reliability, minimum energy and material loss, sliding or rolling on continuous oil films by hydrodynamic and elastohydrodynamic lubrication is preferred. However, conditions may not permit the formation of an oil film or may cause it to fail, then metal-to-metal contact occurs And Boundary Lubrication is required to prevent severe damage. Boundary Lubrication is needed:

- If calculations of expected oil film thickness indicate that films at least five times as thick of the sum of the surface roughnesses cannot be developed.
- When equipment will be required to operate repeatedly under start-up and shut down conditions, or at high loads, shock loads, low speeds, or high temperatures.
- When the geometry of the part, the use of low viscosity oils, interrupted oil supply, or misalignment, do not permit the oil films to form.

Devices requiring boundary lubrication

Many commonly used components require Boundary Lubrication:

- Gears, during the sliding part of tooth engagement, and during operation at high loads and slow speeds.
- Hypoid differentials, hypoid gears are a classic case of the need for Boundary Lubrication for reduction of wear and the prevention of scuffing. Hypoid gear geometry inhibits oil film formation. In addition contact loads are high in order to reduce size.
- Valve trains, especially cams and followers.
- Metal cutting and forming operations.
- Rolling element bearings at the pure sliding sites, and during oscillatory motion.(continued on next page)
- Sliding bearings at low speed, high load, start up, shut down, and oscillatory operation.
- Hydraulic pumps, such as the vane pump shown in Fig. 1.

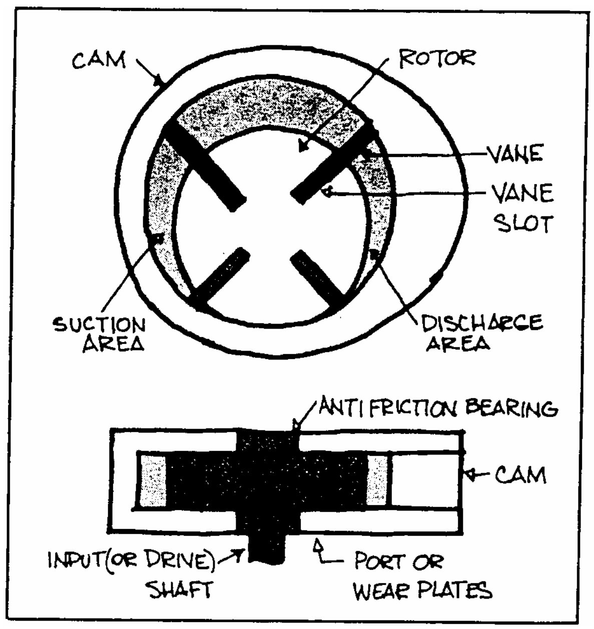

FIGURE 1– HYDRAULIC VANE PUMP

Solid surface films protect during Boundary Lubrication

The primary requirement for Boundary Lubrication is the formation of adsorbed and chemical reaction films on the metal surfaces. Sliding occurs on the film, or the film is sheared, without damage to the underlying metal. Formation of these films depend upon:

- **Chemical properties of the base oils and the additives—** Under mild sliding conditions and moderate temperatures, the Boundary Lubrication films may be simply adsorbed polar molecules from the base oil, such as nitrogen compounds, or from additives such as amines or alcohols. Effectiveness increases with increased chain length above 12 carbon atoms, and with the chemical reactivity of the adsorbed molecules. But the adsorption is reversible, that is desorption occurs at higher temperatures, so the protection is lost.

Lubricity, or friction reduction, is imparted to lubricants primarily by the chemical reaction of long chain polar organic compounds with the surface. An example is the reaction of the fatty acid, oleic acid, reacting with an iron surface to form a film of the soap iron oleate.

Anti-wear property is also imparted to the system by additives. Zinc dialkyidithiophosphate (ZDDP) is the most common anti-wear additive and is present in most engine oils. Tri-cresyl phosphate is often used in synthetic oils.

Anti-scuff property is imparted to the system when chemically active additives react with the metal surface to form metal salts on the surface. The classic example is the reaction of sulfur compounds in the oil with steel to form a tarnish film of iron sulfide.

• **Chemical properties of the metal surfaces—** The chemical reactivity of the metals effects Boundary Lubrication film formation. For example copper and iron base alloys, or their surface oxides, readily react with the adsorbed molecules from the oil. The reaction is essentially corrosion. In contrast, stainless steel, aluminum, and noble metals are less reactive and thus less responsive to boundary lubricants.

• **Surface temperature—** The effectiveness of Boundary Lubrication surface films is limited by the melting point of the adsorbed species or its reaction product. Metallo-organic reaction products, such as the soap iron stearate, melt at about 65°C (1*50°F),* and provide only moderate protection. At the other end of the scale, the metal salts such as the iron sulfide have high melting points, over 1,000°C (1,832°F), and protect the surface from scuffing at high temperatures. Of course the rate of any chemical reaction increases with temperature and some additives require heat to form films.

Some wear during Boundary Lubrication is inevitable because metal is in the film that is worn away, or sacrificed. Films must be constantly replenished or regenerated for continued surface protection. Tribologists must match the lubricant to the requirements of the operation. For example, in metal forming processes where metal is rapidly forced through a die, the chemical reaction needs to occur quickly to prevent welding of the metal to the die surface. However, if the reaction is too aggressive, excessive corrosion will occur and the metal will be damaged, perhaps by staining. The critical balance then is achieved when the reaction is just right to allow the metal to pass through the die without damage to either surface.

Application of boundary lubrication for wear control Deliberately planning for Boundary Lubrication permits design advantages. Primarily is the reduction in size of a component by increased allowable contact loads. Also the use of Boundary Lubrication would permit extended service life and reliability.

When Boundary Lubrication is expected there are three questions to be asked:

• What are the maximum allowable friction-induced temperatures?
• Can higher friction be permitted?
• What rate of wear is tolerable?

Answers:

Maximum allowable friction induced temperature— Since the coefficient of friction in Boundary Lubrication is relatively high (0.05 to 0.2) frictional heating can cause high temperatures. Materials selection requires an estimate of operating temperature derived by comparing the energy input from friction and the heat dissipation capabilities of the component. Lubricants that can perform acceptably at that temperature can then be selected or design steps can be taken to reduce the operating temperature to an acceptable level. For example, if mineral oil-soap gelled greases are to be used as a lubricant the temperature must be below 150°C (300°F). If higher temperatures are expected, a grease with synthetic base oil and a synthetic or clay gelling agent should be selected.

Higher friction—The higher friction associated with Boundary Lubrication, compared to hydrodynamic lubrication, means that more energy is required to drive the component. This could mean the use of a higher horsepower motor.

Tolerable amount of wear— Boundary Lubrication results in measurable amounts of wear of the contacting surfaces. The tolerable amount of wear for a desired service life needs to be estimated. The estimate requires knowledge of the wear rates of the materials and lubricant combination. Some general ideas of wear rates are available, but experiments are often needed to measure wear rates. The wear equation in part 3

$$V = \frac{kWL}{H}$$

shows that the volume of metal worn off, V, is directly proportional to a constant, k, times the load, W, times the sliding distance, L, and inversely proportional to the hardness of the material, H. Fein (2) has measured" k" values for Boundary Lubrication:

Materials	Lubricant	K
Bronze vs. Steel	Gear Lubricant	2.5×10^{-8}
Steel vs. Steel	Gear oil	1.6×10^{-9}
52100 Steel vs. 52000 Steel	Engine Oil	2.0×10^{-10}

Therefore knowing k, load, an assumed distance slid, and metal hardness, one can calculate the volume of metal that would be removed. Obviously wear can be reduced by increasing the hardness of the metal, reducing the load, or selecting a better boundary lubricant with a lower k. k would be higher for conditions other than uniform pure sliding, such as reciprocation, shock loads, or frequent starts and stops.

Once a component is in service, operators should monitor the amount of wear to check theory against fact. A convenient way is to measure the amount of worn off metal in the oil, and examine the nature of the wear fragments. Under good Boundary Lubrication conditions the wear fragments will consist of very small particles of the film material. The amount can be measured by emission spectroscopy. The appearances of large, rough particles of metal indicate a failure of Boundary Lubrication and probably scuffing. Abrasion would be indicated by small chip-shaped particles, and fatigue by particles with one sliding surface somewhat preserved. These particles are best detected by ferrography or by microscopic examination of particles separated from the oil by sedimentation and washed with hydrocarbon solvents.

In some expensive machinery, such as railroad locomotives, wear debris analysis has advanced to serve as both the monitor of lubrication adequacy and an indicator for engine overhaul.

An example of wear due to the use of the wrong Lubricant

This example shows how a non-boundary lubricant caused costly wear.—

A massive coal loader contained pulleys supported by journal bearings. Operation indicated boundary lubrication conditions. However, the bearings were lubricated with a simple oil, which allowed severe wear resulting in failure. Replacing the bearings created enormous financial losses for the company. Parts of the coal loader had to be dismantled and replaced. A crane was needed to hoist maintenance workers. Labor costs were high and production came to a halt.

If the operators had used a boundary lubricant, the wear would have been tolerable, and the company could have avoided a major malfunction and subsequent costs. This case exemplifies the importance of applying know-how already gained from tribology research to prevent serious wear.

References

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2) Fein, R. S., "AWN (Anti Wear Number) – A Proposed Quantitative Measure of Wear Protection," *Lubr. Eng.,* **31,** pp 581-582 (1975).

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