Sumitomo Drive Technologies

GEARBOX LUBRICATION & EFFICIENCY

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Gearbox Efficiency and Lubrication

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Introduction

Can lubricants improve gearbox efficiency? This paper will explore how oil selection can affect gearbox efficiency. According to the US Energy Information Administration, the United States generated 1,006 billion kWh of electricity in 2007. (EIA) It is generally accepted that electrical motors account for about seventy percent of industrial electrical power consumption. Assuming that electric motors are all driving gearboxes, then every one percent increase in gearbox efficiency saves the equivalent yearly output of an 800 MW power plant. Small changes in efficiency can have a large aggregate impact. Unlike other efficiency-improving ideas, lubrication changes require no changes to existing equipment.

Oil churning, seal drag, and friction account for most of the losses in gearboxes. To some extent these three sources are all affected by lubrication. Seals ride on a thin oil lubricant film. Churning losses are due to the gearbox components moving through the oil sump.

Fluid Friction

The Stribeck Curve, shown in Figure 1 (Maru), relates friction between load-bearing surfaces as a function of relative oil film thickness and lubrication regime. Relative oil film thickness is the ratio of film thickness to surface roughness. The thicker the film relative to surface roughness indicates a reduced likelihood of contact by surface asperities. Figures 2 through 4 illustrate the relationship between film thickness and surface roughness.

Figure 1. Stribeck Curve.

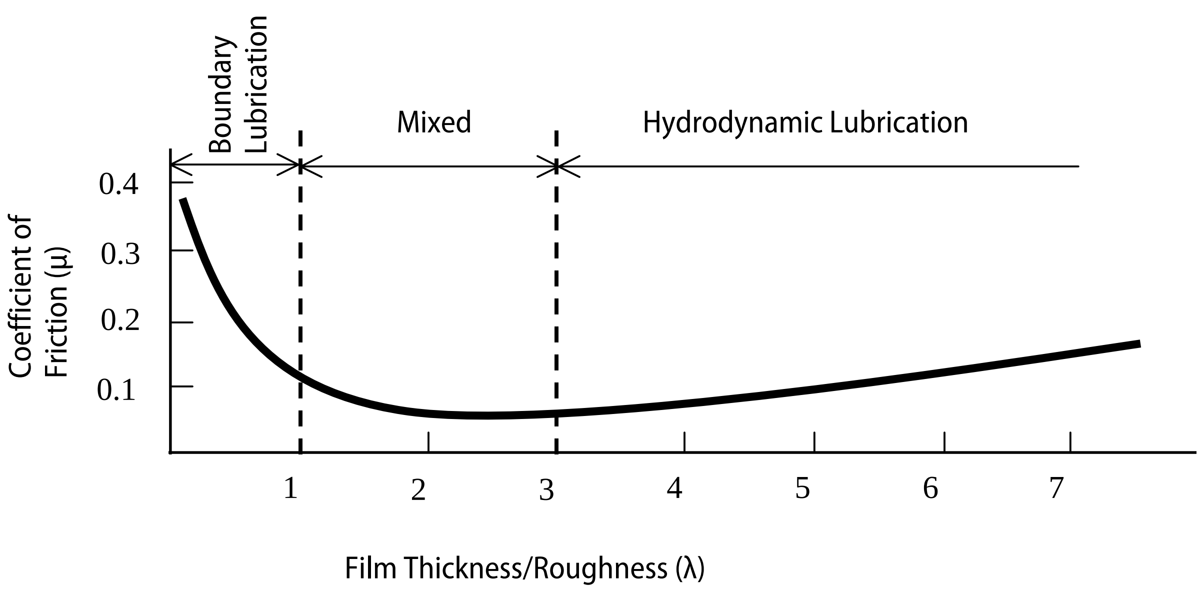
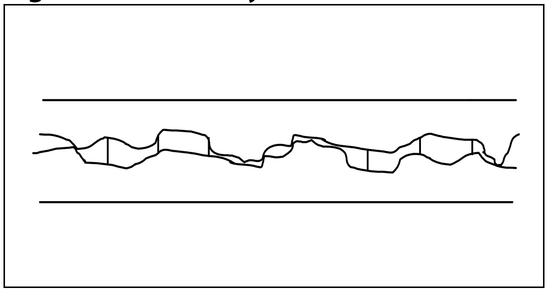


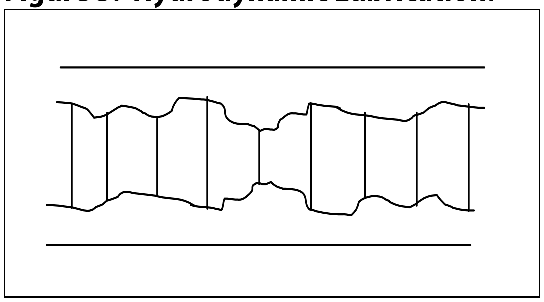
Figure 2. Boundary Lubrication.



Boundary lubrication occurs when the load-bearing surfaces come into contact. Boundary lubrication can occur when the relative speed between mating surfaces is low, there are high loads, or changes in direction.

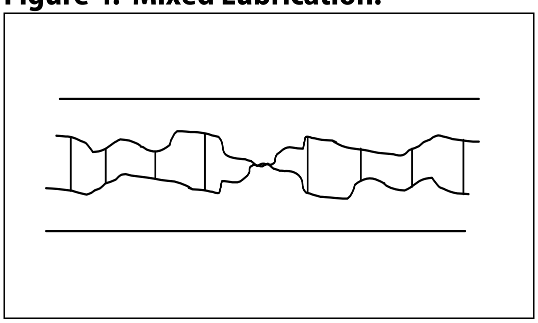
Anti-wear (AW) or extreme pressure (EP) additives can reduce friction and wear to acceptable levels by forming sacrificial solid-film barriers.

Figure 3. Hydrodynamic Lubrication.



A lubrication film completely separates two load-bearing surfaces. With no metal-to-metal contact, machine life depends on oil cleanliness. Friction increases with increasing film thickness.

Figure 4. Mixed Lubrication.



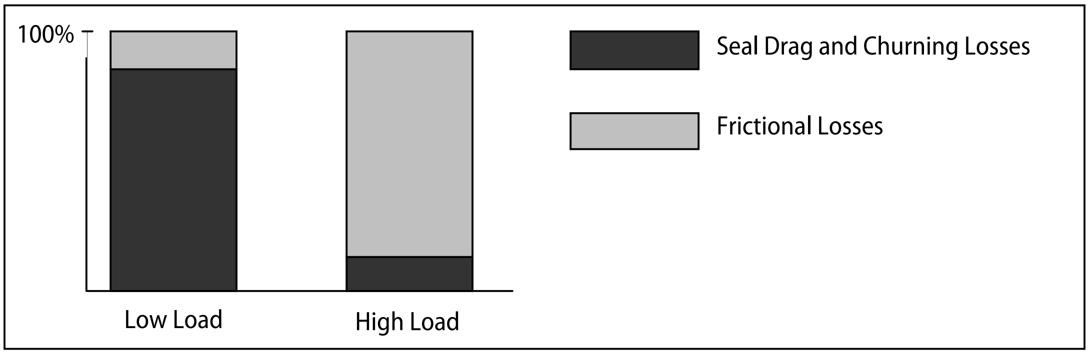
Mixed film lubrication describes the condition where the asperities (peaks) of two surfaces come into contact though a lubricating film is present. The lubrication film is thicker than in boundary lubrication, and it is a combination of hydrodynamic and boundary lubrication.

Friction can be lower than thick film hydrodynamic lubrication, but mixed film lubrication requires AW additives to reduce wear.

The traction coefficient is up to 30% lower for synthetic oils than for mineral based, possibly due to the synthetic's uniform molecular structure. In contrast, mineral oils are a mixture of hydrocarbons of various chain lengths. In conventional gear trains, synthetic oils can reduce frictional losses 0.5% per stage for conventional gears, and up to 8% for high reduction worm gears. (Choosing Between Synthetic Lubricants and Conventional Oils)

Churning losses are a function of viscosity. Thicker oil requires more energy to move gears and bearing rollers through the oil. When changing from an ISO 150 oil to an ISO 220, film thickness and viscosity will increase 50%. Seal drag depends on seal material, seal design, and the force imparted onto the shafting by the seal itself. For a gearbox not experiencing shaft deflection, seal drag is independent of load. Seal drag and churning losses are independent of load and as load is increased, these fixed losses make up a smaller portion of losses. Figure 5 visually shows the relationship.

Figure 5. Proportional Relationship of Frictional Losses vs. Seal Drag and Churning Losses.



Tests

Sumitomo Drive Technologies tested several oils in a model CHH-6145Y-51. The oils were ExxonMobil's Mobilgear XP 150, Mobilgear SHC XMP 150, and a blend of Mobilgear SHC XMP 320 and 150 that has a viscosity equivalent to XMP 220. The Mobilgear XP series is a mineral base-stock, EP-type oil intended for use in heavily loaded gear trains. Mobilgear SHC XMP is a polyalphaolefin (PAO) base synthetic oil developed for gearboxes in wind turbine applications. ExxonMobil touts the XMP's low traction coefficient and advanced anti-micropitting protection. 150, 220, and 320 indicate the oil's viscosity at 40°C.

The equipment required to simultaneously input and output torque was not available. A method to set output torque with reasonable repeatability was devised while measuring input torque dynamically. Table 1 shows the results.

Table 1. Efficiency and Loss Results

	Mobilgear XP 150		Mobilgear SHC XMP 150		Mobilgear SHC XMP Blend	
Input Torque (in-lb)	212	264	208	260	228	284
Efficiency (%)	92.7	92.7	94.6	95.5	86.7	87.3
Losses (W)	319	395	233	241	636	740

As expected, the mineral based Mobilgear XP 150 posted lowest efficiency. Increasing the load 25% increased the efficiency less than 0.1 percent. Seal drag and churning losses are a small part of gearbox losses and that proportion decreases with increasing load. The magnitude of the efficiency increase was so slight that it was overwhelmed by the errors in not simultaneously measuring both input and output torque.

Changing to Mobilgear SHC XMP 150 increased the efficiency 1.86 points. Increased load increased the efficiency slightly. The lower fluid friction helped increase efficiency. Cyclo reducers have a variety of loading conditions – rolling between roller and race and sliding between pin and roller for example. It is difficult to say with certainty whether elements were in mixed- or hydrodynamic-regime. If some of the rolling elements were in a hydrodynamic regime, than changing to the lower viscosity caused a shift from hydrodynamic to mixed, lowering the internal fluid friction losses. Since 150-viscosity oil is the recommended grade for this gearbox under the ambient temperature test conditions, it is unlikely that any parts were in boundary lubrication, except perhaps at start-up.

The SHC XMP Blend posted a very good efficiency at lower load that declined slightly at the higher load. The difference in churning losses between a 150 grade and 220 grade is not that great compared to power required to drive the load. It appears that the combination of synthetic molecules and higher viscosity increased the efficiency compared to the mineral oil. The decrease in efficiency at higher load may have been due to measurement error.

Conclusion
It is apparent that thicker oil reduces surface contact of load-bearing surfaces. If the oil is much thicker than required, friction and losses will increase. Thicker oil increases losses through internal fluid friction and churning losses. A good anti-wear or extreme-pressure additive package is required for applications involving reversing, high shock loads, and during extended starts. Under these conditions, the load-bearing surfaces have not built up an oil film sufficient to maintain surface separation. Anti-wear and extreme pressure additive packages will reduce friction and wear in boundary or mixed film lubrication.

Except for polishing, most wear tends to increase surface roughness. Rough surfaces require thick oil films in order to prevent metal-to-metal contact. As wear progresses, rougher surfaces may move the lubrication regime from hydrodynamic to mixed or boundary and thus reduce gearbox efficiency.

Not addressed in this paper is the effect of efficiency improvements on lubricant life. Efficiency increases result in lower operating temperatures. For every 10^{o}C (20^{o}) decrease in temperature lubricant life doubles.

Recommendations
In order to increase gearbox efficiency, by only changing lubrication, one must use the thinnest oil that provides adequate film thickness and contains a good Anti-Wear or Extreme Pressure additive package that provides protection when transient conditions do not provide an adequate oil film. Synthetic oils and oils that have an exceptionally low traction coefficient will reduce internal friction losses.

***Note:**

MobilGear and ExxonMobil are registered trademarks of Exxon Mobil Corporation. The testing described in this paper was neither paid for nor sponsored by Exxon Mobil Corporation.

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Lee is a graduate of Virginia Tech and has over 14 years experience in the power transmission industry ranging from motors to cycloidal and hypoid type gear reducers.