The Facts Behind Gear Lubrication

When failure is not an option, you have to know more than flow.

Background

Gears are designed with an involute profile (fig. 1) to promote rolling contact during meshing. At the pitch line, which is the point of contact for correctly aligned gears, the velociry of the mating gears is identical. At this point, the gears transmit power without excessive heat generation.

Above and below the pitch line, the velocities of the mating gears are different as they make contact at different points on their diameters. Thus, gears slide in and out of contact above and below the pitch line, generating frictional heat as they transmit power. This heat is responsible for the most common cause of gear failure — overheating of lube film at the point of contact.

Effect of Lube Film Thickness

The purpose of a gear lubricant is to provide a protective barrier between contacting tooth surfaces and to dissipate the heat generated during contact. The lubrication flow to provide a protective film is relatively low. The flow required for heat removal is much higher and is proportional to the power being transmitted. Inadequate flow results in metal-to-metal contact which, in turn, begins the wear and failure process.

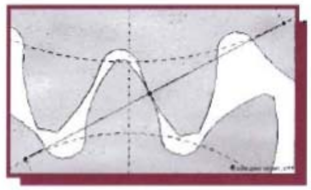


Figure 1

Adding to the problem, the wear particles created by poor lubrication typically remain suspended in the lubrication, become work hardened as they pass through successive gear nips, and ultimately act as abrasive particles. In theory, a perfect lubricating film provides an insulating layer between the gear teeth whereupon tooth surfaces are never in contact. However, this is rarely the case. For reasons that will be explored, the lubricating film in the gearing on most paper machines is inadequate by a significant degree.

There are three classifications of film thickness. In the case of Boundary Lubrication, the lube film thickness is almost nonexistent, resulting in contact across the full surfaces of the gear teeth. In these cases wear will be rapid. With Mixed Lubrication, the lube film is greater but asperities on the gear tooth surface will break through the lube film, creating a localized failure. When this happens, pitting, abrasive wear, and scoring can occur. Most paper machines have gearing operating in one of these two lubrication conditions. The third condition is elastohydrodynamic lubrication and is covered later in the article.

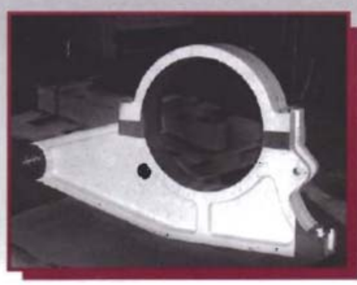
Wear Conditions Caused by Poor Lubrication

Abrasive Wear (fig. 2) is caused by overall inadequate lubrication and/or particulates in the lube. Here, gear teeth were not separated at the sliding points by the lube film. Wear has begun where the tooth surfaces contact. As the teeth wear, resulting metal particles remain suspended in the lube and act as abrasives. When not corrected, abrasive wear becomes destructive wear resulting in loss of tooth profile and ultimate failure of the gear (fig. 3).

Figure 2

Figure 3

What is It?



You can find the answer on page 3.

Scoring (fig. 4) is the instantaneous welding and tearing of contacting surfaces caused by localized overheating and breakdown of the lube film. Asperities on the tooth surfaces contact, weld together, and then tear out. As in abrasive wear, the particles generated during wear often remain suspended in the lube and act as abrasives. Consequently, it is common to see scoring and abrasive wear together.

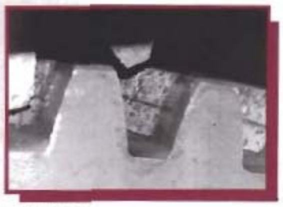


Figure 4

Pitting occurs when the load exceeds the capacity of the gear material, or the lube film is not thick enough to prevent contact between high points on tooth faces. The repetition of high stress over many cycles produces surface and subsurface stressers. As a result, the material fatigues and fails either at or below the surface. The crack(s) then propagates to the surface and a small piece breaks free forming a pit. If not corrected, many smaller pits join to create larger craters called spalls (fig. 5). Pitting is often the first indication of a lube film problem. As in abrasive wear and scoring, the broken particles tend to remain suspended in the lubricant and act as abrasives.

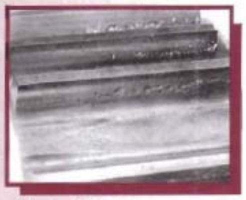


Figure 5

Proper Lube Film Thickness

Elastohydrodynamic Lubrication (EHL) is the overall best gear lubricating condition. In this condition, the lube flow is sufficient to dissipate the heat while providing an insulating film between the gear teeth. The lubricating oil's viscosity increases under pressure (as long is it does not break down) and behaves like a solid, providing an insulating layer between tooth surfaces. Thus, power is transmitted from one gear, through the lube film, to the mating gear without any contact between gear teeth.

The best method to achieve EHL, is to deliver the lubricating oil via a nozzle directed perpendicular to the tips of the gear teeth (fig. 6). For the oil to lubricate the working area of the tooth face, it must be delivered at a velocity equal to the gear tooth pitch line velocity. This ensures that the lube will fill the void as the space between gear teeth passes under the nozzle. If the lube velocity is not sufficient, it is analogous to dripping oil onto the blades of a fan — the oil will be flung away and little or no oil will reach the inner surfaces.

The standard used in the paper industry for lube delivery to dryer gearing is 2 pints/minute (TAPPI tip #0420-08), which is 0.25 gallons per minute and very close to the calculated value of our case study (this is coincidental, however, as flow requirements are dependent upon individual paper machine characteristics). The industry standard also specifies that this flow be delivered through 1/2" NPT ports. Based on this specification, with 30 psig lube pressure, the lube velocity will be 0.2 feet/second compared to the 35 feet/second required per our calculations. Using the industry standard results in a lube system where little or no oil reaches the

Lube Facts — A Case Study

The following simplified case study of a fine paper machine illustrates the data and calculations used to determine proper lube flows and velocity:

Paper machine speed:	3600 FPM
Paper machine trim:	242"
Dryer section NRL:	185 HP
Gear pitch diameter:	35"
Gear speed:	229.2 RPM
Oil pressure available:	30 psig
Oil temp rise desired:	10 degrees F
Gear inefficiency:	0.25%
Pinion location:	center of section

In this case, the pinion is located in the center of the section. Theoretically, then, the gears mating to the pinion on either side of it should receive 50% of the NRL. For our purposes of illustration, we'll use this 50% value when calculating the heat load.

Gear Velocity: (Sheet FPM x Pitch Dia) / (Dryer Dia x 60 sec) = feet/second

$$\frac{3600\ \text{FPM} \times 35"}{60" \times 60\ \text{seconds}} = 35\ \text{feet/sec}$$

Heat generated: 50% x NRL x gear inefficiency x 42.44 Btu/min (constant)

$$0.5 \times 185 \times 0.0025 \times 42.44 = 9.8\ \text{Btu/min}$$

Oil Needed:

$$\text{Oil wt} = \frac{\text{Btu/min}}{C_p \times T} = \frac{9.8}{5 \times 10} = 1.96\ \text{lb/min}$$

Note: C_p is the specific heat of oil. T is the delta oil temperature increase.

Oil Flow Needed:

$$\frac{1.96\ \text{lb.}}{(.032\ \text{lb/in}^3 \times 231\ \text{in}^3\text{/gal})} = 0.27\ \text{gpm/set}$$

Oil Pressure: Gear Pitch Line Velocity² divided by 169 (constant)

$$\frac{35\ \text{FPS}^2}{169} = 7.25\ \text{psig}$$

In this case, the gear mesh requires 0.27 gallons per minute delivered at a pressure of 7.25 psig. The flow rate meets the requirement for heat dissipation and the pressure accelerates the lube flow to the pitch line velocity of the gear. With this delivery system, the gear mesh should achieve an EHL condition resulting in thorough lubrication and increased longevity of the components. (Note: the proper orifice size is required to achieve the specified velocity at the available pressure. Oil viscosity at operating temperature must also be factored in.)

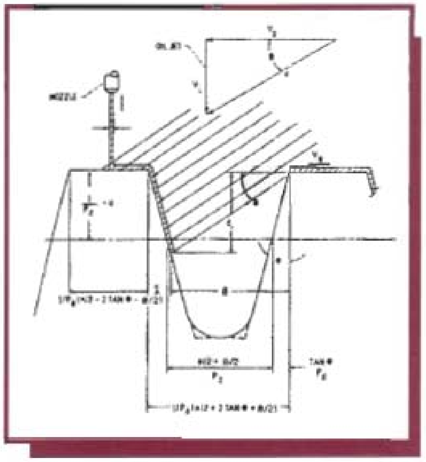


Figure 6

tooth surfaces because of low velocity. The flow is good, but the velocity is well below what is required.

Looking at it this way explains why many paper machines are operating with inadequate lubrication in the dryer section gearing.

For example, a cascading lube delivery system is employed in many paper machines. In these gear cases, oil is delivered to the top of the gear case(s). A series of ports and channels then direct the lube to the gears and bearings. Typically these systems were designed to deliver the industry standard 2 pints/minute of lube. But the lube velocity is extremely low as lube pressure is generated only by the head pressure created by the distance from the top of the gear case to the gear nip. It is obvious, then, that this type of delivery system does not provide good gear lubrication.

Conclusions & Recommendations

- A majority of paper machine gear problems are created by poor lubrication and contaminants in the lube.
- Existing recommendations for lubrication are based on generalized flow specifications, and do not address the critical lube velocity requirement.
- The easiest change to make at the mill level is to improve lube filtering to remove wear particles. Use filters as low as 3 microns. If the filters plug, it means they were needed and are doing their job. Filters are considerably less expensive than a gear failure.
- Determine the appropriate lube flow and velocity based on your specific paper machine and install the systems to deliver it. This typically involves installing new oil nozzles in the dryer section gearcases to deliver the lube in the proper orientation and at the optimum velocity.

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