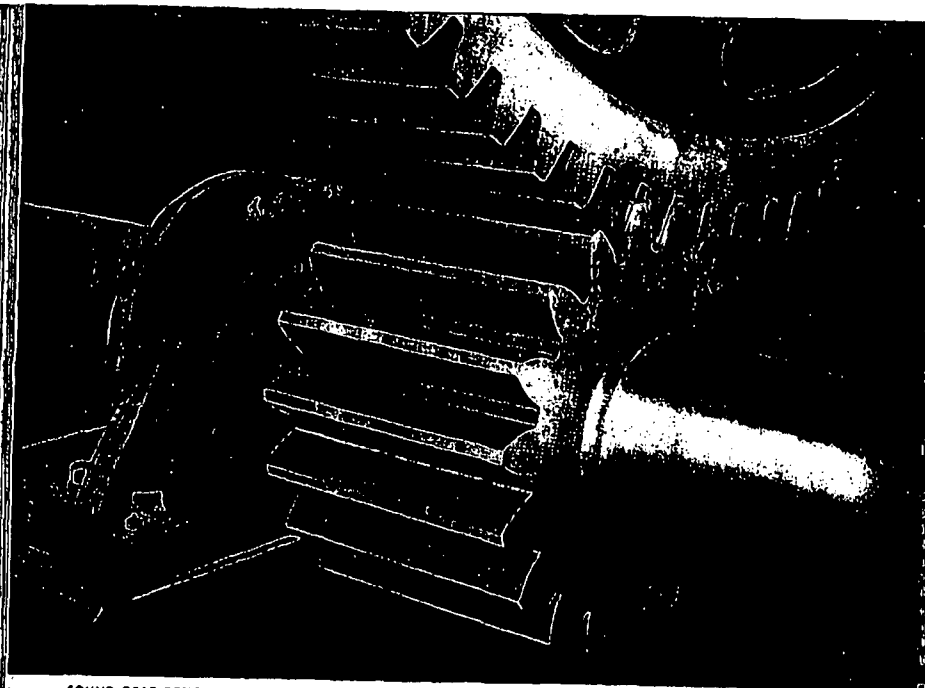


SOUND GEAR DESIGN, proper application and smart lubrication know-how are three essential ingredients for long gear life

Today's Thinking on Gear Failures

. . . points up the important fact that most troubles you meet are not the fault of the lubricant. Here are eight factors, including design and operating practices, that come into the picture

Tooth Spacing

When teeth of a high-speed gear are not accurately spaced their surfaces are subjected to dynamic loads that *limit the useful* power the teeth can transmit. For example, consider a high-speed gear train having high moments of inertia for both prime mover and load. If there are sizable errors in tooth spacing, instantaneous changes in angular velocity result. And when we consider teeth that are in contact for only one ten-thousandth of a second, the blow transmitted *from one tooth to another* pierces the oil film and damages both.

Many gear-design specifications indicate that as speed increases, useful power that *may be transmitted decreases.* Where such specifications are used, the theoretical power that the gears can carry is calculated, then derated by a "velocity factor" to determine the actual power. But where teeth are accurately spaced, recent tests prove velocity factors are unnecessary. As speed increases, the load carried can also be increased. Consider teeth accurately spaced where tooth-to-tooth error does not exceed 0.0002 in.

Tooth-Surface Finish

If surface finish is rough, teeth may be likened to two files in contact (POWER, Dec 1951, p 80). Hills on the tooth face may pierce the lube film allowing the two mating surfaces *contact. But if lube viscosity is high and load light, teeth* ride on the lube without *metal-to-metal* contact. As load increases *a point is reached* where the hills of mating surfaces contact, or hills on one surface fall into valleys opposite. Mechanical shearing *of metal* or bending of hills results in wear. This has been proven time and again.

Many engineers think that if tooth surface is too highly polished, *surfaces will not sustain a lube-oil film. This belief* needs qualification since speed enters the picture. It is possible that a hydrodynamic film will not be established with highly *polished* tooth surfaces and extremely low sliding velocity. But where sliding velocity is high, say 30,000 to 40,000 fpm, a fine surface finish is desirable. A hydrodynamic film is established and the teeth are satisfactorily lubricated. Gears under high velocities, have tooth-surface finish fine.

It has also been said that if surface finish is absolutely perfect (ideal case) no lubricant is required. This is true if load is kept at extremely low values. But as load is increased surfaces deflect. Plastic working of surfaces generates heat, which must be carried away by a lubricant.

Tooth Modification

Gear teeth may check out as perfectly spaced with instruments and yet run into trouble during operation. Consider two perfectly spaced gears in mesh giving a smooth engagement under no load. *As load increases, teeth sharing load begin to deflect.* This, in effect, displaces teeth somewhat. What may actually happen is that the corner of a tooth strikes its mating tooth, scraping off the oil film. Tooth modification prevents this by increasing by a certain amount both the radius of curvature and the depth. The effect is that of the upturned ends of a pair of water ski when pulled through water at high speed. This modification has worked well for gears that ran into trouble at high speeds and heavy loads.

Sliding Velocity: Pitting

Engaged teeth slide between *both surfaces* except for the instant when rolling takes place at pitch line. Maximum *sliding velocity is a function* of tooth proportions. If extremely long *addendum* teeth are used, sliding velocity at tip of tooth is high. And unless teeth are modified and surface finish highly refined, their tips may burn. So length of *teeth* and sliding velocity should be considered wherever tip burning is met.

Since pitting may occur on teeth carrying a normal load, we can assume slight imperfections give in localized points of high pressure.

In general, if speed and load are held constant, pitting ceases with time. Areas between pits become polished and no further pitting results.

Abrasive Wear

Foreign material in lube oil generally causes abrasive wear. The tooth appears to have been rubbed with emery cloth or sandpaper. Abraded surfaces show scratches at right angles to the tooth axis.

Scoring generally results from small particles becoming welded to the mating elements, producing scratches that extend radially along tooth flank. They could also be caused by a high point becoming so warm it adhered to mating element. A scratch is produced since high point is trapped between two loaded surfaces moving in opposite directions.

Burning, Rolling

As mentioned above under sliding velocity, burning can take place in meshing gears. It results in discoloration of tooth surfaces indicating: (1) Lube oil did not carry away heat generated between two surfaces. (2) Load was too high. (3) Coefficient of friction between surfaces was excessive.

Some teeth under load form a little burr along tip, which indicates metal is being displaced from surface. Where teeth are not discolored any heat formed is being carried away. Rolling appears to stem from a plastic flow of material and has been observed on moderately loaded teeth.

Analyzing the Fault

Pitting, abrasive wear, scoring and burning on the surface might be considered as lubrication failures. Since pitting points to localized stress concentration, it is highly improbable that a lubricant could be applied that would prevent it. Assume tooth-surface load is distributed across the face giving a stress of 90,000 psi. *But if* a number of bumps are present equal to 10% of total tooth area, unit pressure becomes 900,000 psi, resulting in pitting.

If enough lubricant is present to keep temperature of high points below temperature at which they adhere to mating members, particles pitted out go into lube oil and are picked up by a magnetic strainer. But if temperature increases to point of seizing, material adheres to mating member and score marks are produced on mating-tooth surface. When you note signs of abrasion, clean lube system and filter oil.

Typical Gear Failures

Following are four cases of gear failure, a logical analysis and remedy:

1. Marine gear becomes noisy and indicates wear through metal particles picked up in magnetic strainer. Close check shows a nut or bolt has gone through the mesh. Teeth had been corrected by filing. But because of filing, tooth surfaces *have been roughened and wear started. Small steel* particles given off from this wear contaminate the oil and induce wear in other parts of tooth surfaces.

System should be flushed and oil filtered. It may be best to put in a heavier oil till teeth have again obtained a polish.

2. Marine gear has operated for 10 years but during last year has started showing undercutting and metal particles in lube oil. Careful examination will probably show up dirty oil. If condition is noted early enough and corrected, gears will often polish up. If wear *has progressed,* it may be best to use a heavier oil till teeth again take on a polish.

3. Heavily loaded new gear starts pitting after operating one week. Pitting on a new gear points to presence of slight bumps on tooth surface causing stress concentration. Since gear is heavily loaded, best solution is to use an oil with anti-welding properties or an extreme-pressure oil. Teeth should then polish up with time.

4. Gear unit driving an induced-draft fan becomes noisy yet tooth surfaces appear OK. You will probably find that while the pinion teeth look good they have worn unevenly. Their pitch line is no longer concentric with axis of rotation. Further examination may show load is far from constant and torque varies. The oil is contaminated with flyash, and cyclic wear has taken place.

Solution: Recut gear, pinion; clean system; if possible, eliminate load variation, or at least reduce its magnitude.

Many cases have been found where a tooth has broken out under heavy loads and the lubricant has proven "stronger" than the tooth. Study showed the tooth surface highly polished, free from pits, abrasion, rolling or galling.

EDITOR'S NOTE: This article is a free adaptation from the paper, *Lubrication Requirements of Gears as Seen by a Gear Engineer,* by L J Collins, General Electric Co, presented at ASLE *annual meeting, Boston, April* 13, 1953.