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Monday, 01 August 2011 00:00

This article is the third in this ongoing series on the important components of lubrication certification examinations administered by the Society of Tribologists and Lubrication Engineers (STLE) and the International Council for Machinery Lubrication (ICML).

Click here for more information on STLE and ICML certifications.

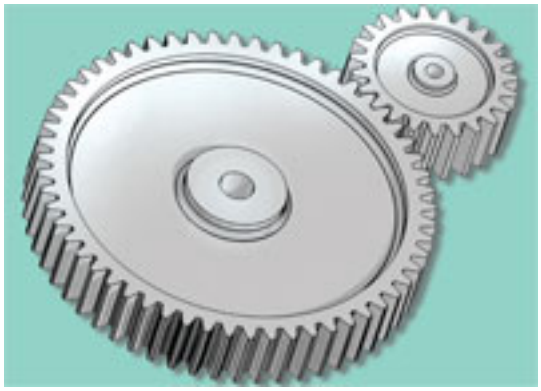

Fig. 1. The simplest gear is the spur type. In this unit, the smaller gear is the "pinion." The large one is the "bull."The simplest gear is the spur type. In this unit, the smaller gear is the "pinion." The large one is the "bull." A key component of all types of applications, gears are used to transmit speed and power (torque) from one revolving shaft to another. They can change speed, torque and direction of rotation. Their major advantages as drives include the fact that they don't slip, they're able to carry high loads and they are compact in size. Figure 1 shows the simplest type, the spur gear.

Referring to Fig. 1, note that the smaller gear in the spur unit is the pinion; the larger one is a bull gear (also known as a "driven gear"). Typically, gears are speed reducers. The amount of

speed reduction is based on the teeth ratio of the pinion and bull gears. For example, if the pinion has 15 teeth and the bull (driven) gear has 75, the reduction ratio is 5:1. A pinion rotating 3000 rpm would result in the shaft of the driven gear to be 600 rpm. The rotation of the bull gear is opposite the rotation of the pinion. To have the same rotation between the pinion and bull gear, an idler gear—*which has no effect on speed and torque*—is inserted between the pinion and bull gear. Several terms are used to describe the mating action of gear teeth:

1. Pitch is the distance between a point on one tooth and the corresponding point on an adjacent tooth. It is the point on the tooth where rolling motion and the greatest force occur. Pitch circle is the circle formed by the point on each tooth at which meshing action is pure rolling.
2. Sliding motion that occurs above and below the pitch point, called respectively the addendum and dedendum of the tooth, can result in high wear.
3. The pure rolling at the pitch point results in an elastohydrodynamic lubrication regime characterized by a small solid-like lubricant film one micron or less in thickness. This small film does not prevent asperities (rough surface edges) from coming in contact with the pitch point, and causes initial pitting along the pitch line of the mating teeth. This is perfectly normal unless the pitting spreads destructively to the dedendum and eventually throughout the tooth.
4. Clearance is the distance between the top of one tooth and the base of the tooth in the other gear.
5. Backlash is the distance between the back of one tooth and the front of the next mating tooth.

Gear types and properties

Gears are classified by shaft orientation. The most common type makes up the parallel shaft group, shown in Fig. 2.

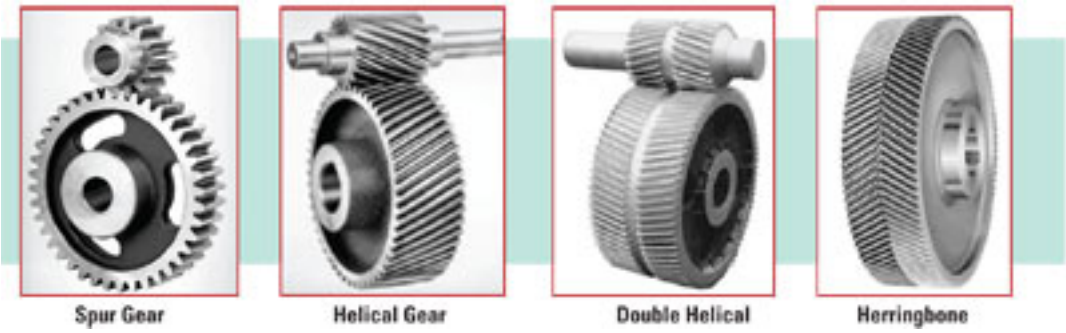

Fig. 2 The parallel shaft group is the most common gear type.

Some confusion can exist between double helical and herringbone gears: Most people consider them the same. In Fig. 2, though, notice that one of these gears has a strip in the middle and the other has continuous teeth. One definition holds that the double helical type has teeth slanting in opposite directions, while the teeth in the herringbone all slant in the same direction. Originally, that strip in the middle of the double helical was needed because of the manufacturing process. Eventually the process allowed all teeth to be continuous with no break in the middle. It should be noted that one of the major disadvantages of the helical gear is that it creates thrust along the shaft. This is eliminated by the use of herringbone (double helical) gears. Typical reduction ratios for parallel shaft gears do not exceed 10:1—*and are more like 5:1.* Table I summarizes the properties of parallel shaft gears.

Table I. Properties of Parallel Shaft Gears

	Spur	Helical	Herringbone
Load carried on	One tooth	Multiple teeth	Multiple teeth
Tooth length	Short	Longer	Longest
Sound	Noisy	Quieter	Quietest
Bearing thrust	No	Yes	No
Motion	Rolling/sliding	More sliding	Most sliding
Load capacity	Low	Moderate	High
Speed	Low	Moderate	High
Cost	Lowest	Higher	Highest

Table I. Properties of Parallel Shaft Gears (Click to enlarge)

As illustrated in Fig. 3, the next group of gears, which have shafts at right angles, are divided into intersecting and non-intersecting types.

Bevel Gear | Spiral Bevel Gear | Worm Gear | Hypoid Gear

Fig. 3. The right-angle shaft gear group is made up of intersecting and non-intersecting types.

Both bevel and spiral bevel gears have shafts that intersect at the centerline, whereas worm and hypoid gears have non-intersecting shafts with one below the centerline. The properties of right-angle shafts are illustrated in Table II.

Table II. Properties of Right-Angle Shaft Gears

Gear Type	Advantages	Disadvantages
Straight Bevel	Economical Low thrust	Low load-carrying ability Low speed Maximum reduction ratio 6:1
Spiral Bevel	Increased load-carrying ability	Axial thrust produced Maximum reduction ratio 6:1
Worm	Smooth and quiet High shock-loading capacity Reduction ratios as high as 100:1 Supporting shafts can pass each other	Low efficiency High thrust Run hot (typically 90 F over ambient) High price per horsepower
Hypoid	Compact Moderate load-carrying capacity Reduction ratios as high as 100:1 Supporting shafts can pass each other	Low efficiency Run hot (typically 90 F over ambient) Require strong EP additives Lower speed than spiral bevel

Table II. Properties of Right-Angle Shaft Gears (click to enlarge)

It should be noted that hypoid gears are used primarily in automotive applications: They've replaced spiral bevel gears in differentials, which results in a much more compact arrangement since the shafts can pass each other. They also produce high torque.

Lubrication delivery systems

Most gears are lubricated by splashing oil from a sump onto the gear teeth and bearings. Achieving the right level/delivering the correct amount of lubricant is crucial. If the level is too low, you'll find yourself dealing with lubricant starvation, increased wear, inadequate heat dissipation and foaming. Too much lubricant, on the other hand, may lead to churning, resulting in higher operating temperatures, a decrease in efficiency and greater foaming tendency. Typically, for parallel shaft and bevel gears at normal speed (1000 fpm- 4000 fpm), the oil level ranges from completely covering the bottom teeth up to three times the depth of the bottom teeth—*the most common being twice the depth of the bottom teeth.* At very low speeds (< 1000 fpm), the level of immersion can be 3-5 times the tooth depth. Lubrication of worm gears is

different. Worm gears come in three designs, each with its own lubrication approach:

- *Worm on top…* the oil level is typically one-third of the wheel diameter.
- *Worm on the bottom…* the oil level is up to 50% of the worm, which is the center of the meshing zone.
- *Worm at the side…* half the wheel is immersed to at least the worm height.

It's best to adhere to what the OEM recommends for oil level during splash lubrication. The above levels are merely general guidelines.

Be aware that there is a speed limitation on the use of splash lubrication. Speed is measured in meter/second or feet/minute (fpm) and calculated by multiplying the circumference of the gear (π x diameter). For example, a 12" diameter gear, running at 1000 rpm, will have a speed of 3140 fpm (3.14 x 1 ft x 1000 rpm). With no design changes, a splash-lubrication system can usually operate up to 4000 fpm. By installing baffle plates and oil pockets, the speed can reach 11,000 fpm. At higher speeds, a pressure-circulation system is used. The two major types are dry sump (where the oil is stored outside the gearbox), or wet sump (where the oil is in the gearbox). In a pressure-circulation system, oil is sprayed directly at the teeth contact points.

Lubricant selection

The most important property for an oil used to lubricate enclosed gears is correct viscosity. The major variable in viscosity selection is the speed of the gears expressed in pitch line velocity, which is defined as speed of the gear in rpm times the circular pitch diameter in inches. The American Gear Manufacturers Association (AGMA) publishes viscosity recommendations based on pitch line velocity. Robert Errichello, a world-renowned expert on gear failure analysis, has developed the following simplified formula for determining the correct viscosity to use on enclosed gears:

$$Viscosity_{40} = \frac{7000}{\sqrt{V_1}}$$

V_1 = pitchline velocity of the lowest speed pinion in feet/minute (fpm)

fpm = 0.262 x speed (pinion rpm) x pinion diameter (inches)

Ambient temperature adjustments:

95 F increase ISO grade by one

122 F increase ISO grade by two

Table III notes the most common viscosities and gear oil types for enclosed gearboxes.

Table III. AGMA Gear Oil Viscosity Classification System

R&O	Compounded	Extreme Pressure (EP)	Synthetic	AGMA #
32			32 S	0
46			46 S	1
68		68 EP	68 S	2
100		100 EP	100 S	3
150		150 EP	150 S	4
220		220 EP	220 S	5
320		320 EP	320 S	6
460	460 Comp	460 EP	460 S	7
680	680 Comp	680 EP	680 S	8
1000	1000 Comp	1000 EP	1000 S	9

Source: American Gear Manufacturers Association (AGMA)

Table IV.
The Most Common Gear Oils for Enclosed Reducer Gearboxes

Gear Type	ISO Viscosity Range	Oil Type
Spur, Helical, Herringbone	150-320	EP PAO, PAG
Bevel, Spiral Bevel	150-320	EP PAO, PAG
Worm	460-1000	Compounded PAO PAG
Hypoid	460	EP

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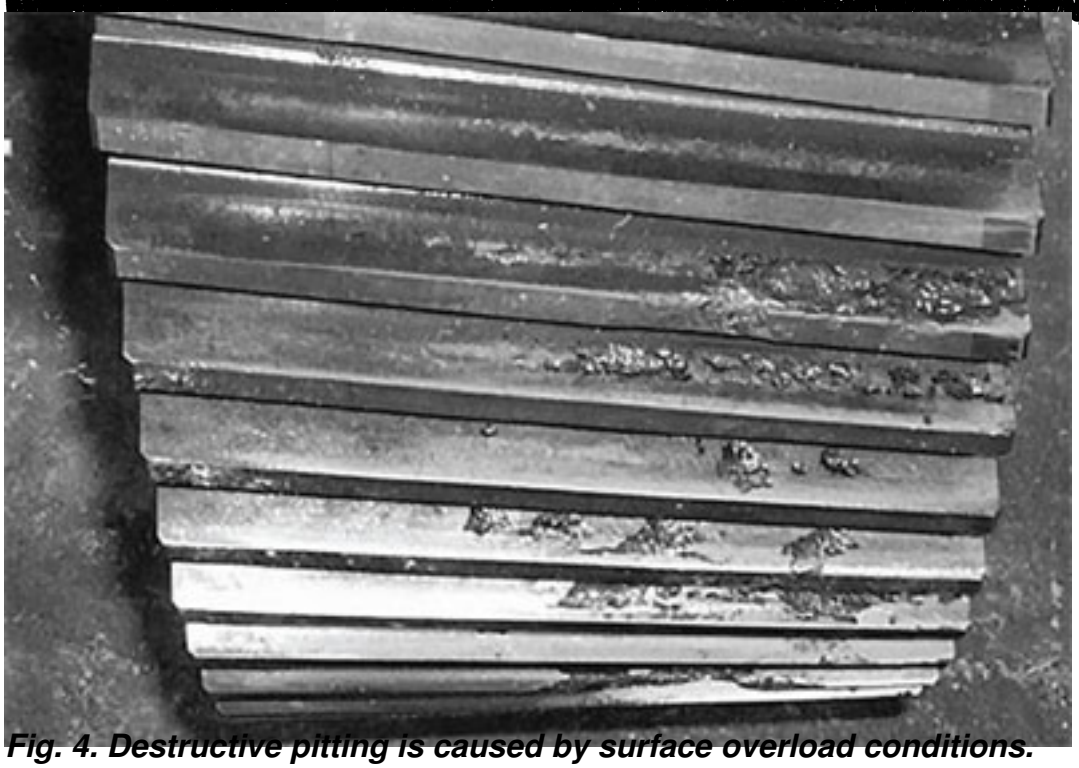
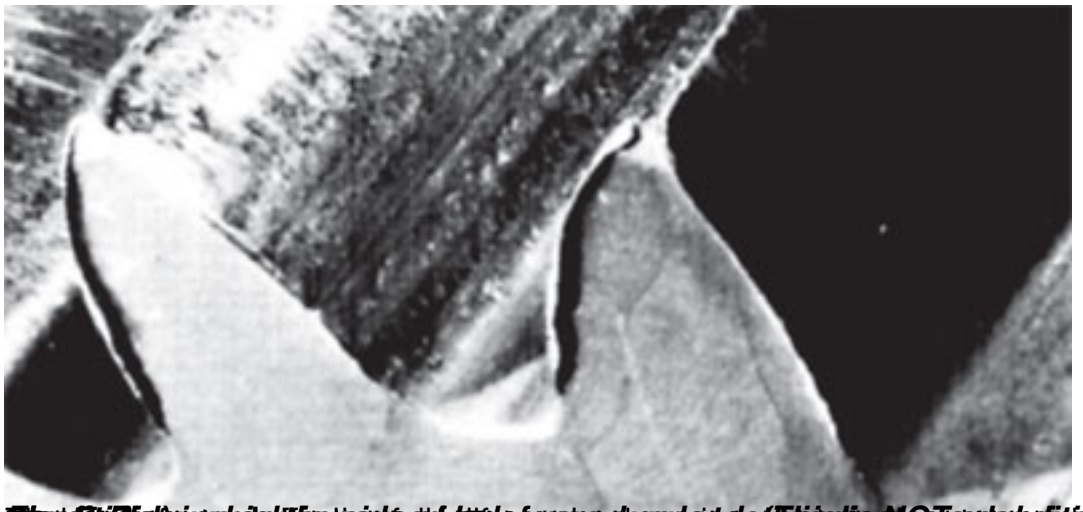


Fig. 4. Destructive pitting is caused by surface overload conditions.



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