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How To Extend Gear Life

LEONARD HAAS
Director of Engineering
Philadelphia Gear Corp.
King of Prussia, Pa.

No gear will last forever. But you can extend the life of a gear set many times over by following a few relatively simple guidelines. Some of them will cost you a few dollars more, but the potential payoff is big—many extra years of efficient, trouble-free operation.

SINCE INDUSTRIAL GEARS are usually custom-designed, premature failure can keep a machine out of commission for a long time. With money tight and profits being squeezed, such failures are becoming increasingly intolerable. Thus, there is a growing demand for gears designed specifically to operate continuously in rugged applications, for perhaps billions of cycles without failure.

Such "super-gears" are not distinguishable to the eye from average gears. Two gear drives, for example, each rated at 500 hp, may differ in overall size. It would be natural to assume that if both were to drive a 500-hp load, the larger one would last longer. But the smaller one could well have

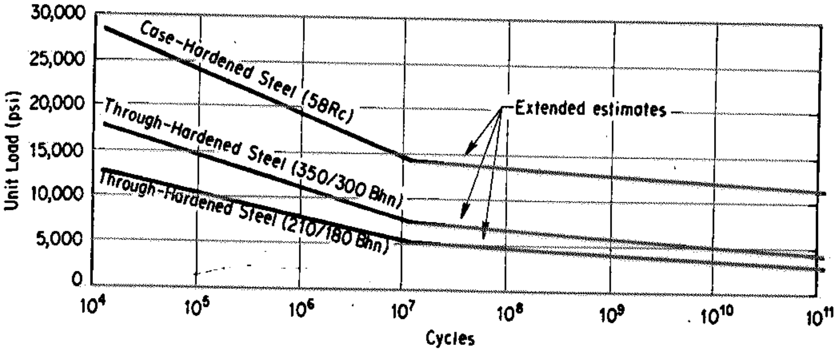

Fig. 1—Unit load curves, showing the gain in gear life obtained by reducing unit load. The curves are derived from estimates based on work by several well known gear analysts.

a longer operating life, simply because it has been designed specifically for that purpose, while the larger unit may have been designed for low cost—the least expensive unit possible that can handle the 500-hp load.

The proper analytical procedures for designing a gear set with long life are too lengthy and complex to discuss in a brief article. Computer programs make it feasible to bring into the calculations hundreds of factors and to make very precise analyses on any set of gears. The purpose of this article is to provide a checklist of factors that the user should keep in mind when designing or specifying a gear drive for long life.

Specify Extra-High Service Factors

Generally speaking, the factors that determine how big or strong a gear should be fall into two categories: design, and service (derating) factors.

Design factors consider loading and geometric qualities, such as tangential load, diametral pitch, pitch diameter, face width, geometric shape of the tooth, tooth ratio, materials, heat treatment, etc. If all these factors were optimized, and the gears properly manufactured, assembled, installed, and lubricated, the gear set would, theoretically, last indefinitely at maximum capacity.

But since perfection is unlikely, service factors are used to reduce permissible capacity of the gears. These service factors take into consideration the effect of speed and tooth tolerances, size and misalignment, and shock and roughness during operation, to name a few. Service factors also allow for transient loads and peaks.

The higher the service factor, the lower the permissible unit load on the gear teeth. As is the case with bearings, there is a definite load-life relationship in gears, although not enough research data exists to pin-point the exact relationship.

In general, doubling the capacity of the gearing, or running it at half the normally rated capacity, will increase life on the order of ten times. Thus, raising service factors is the best way to boost the operating life of the gears.

There are no AGMA long-life formulas or design curves. However, the unit load curves in Fig. 1 have proved useful. The curves were derived from estimates based on work by several well known gear analysts.

The unit load plotted in the curves is proportional to the tangential load on the gear teeth of the driving gear:

$$U = \frac{WP}{F} C$$

where: U = unit load, lb/in.; W = tangential driving load, lb; P = diametral pitch (normal diametral pitch in helical gears); F = face width, in.; C = modifying factor, which takes into account the many variables, such as misalignments, accuracy, speed, etc., that play a role in gear life. Theoretically, C can be unity, but in practice, $C > 1$. The curves clearly show the gain in gear life obtainable by reducing unit load. For example, for case-hardened gears, with a unit load of 25,000 lb/in., the gears may last only 80,000 cycles. (This, of course, is a rough statistical estimate.) Dropping the unit load to 12,500 psi boosts life to about 4 billion cycles.

Such astronomical life is not unrealistic. Most fatigue testing extends only to about 10 million cycles, yet a drive operating at 1,750 rpm for eight hours, 300 days per year, piles up over 1.5 billion cycles in six years. A high speed compressor operating at 10,000 rpm continuously 24 hours per day, 365 days per year, will go through 5.25 billion cycles per year. Yet if it is properly designed for long life, the drive will operate trouble-free for many years.

Keep Gear Size Down

Reducing unit loading on the gear teeth by selecting a higher service factor normally results in larger gear sizes. This is undesirable for a number of reasons. For one thing, large parts are not as strong on a unit basis as small parts. Also, the larger gear sizes. This is undesirable for a number and moments of inertia. And a larger gear set

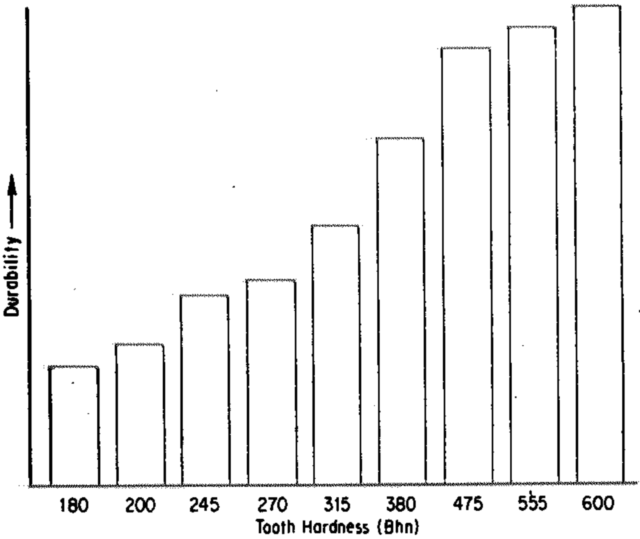

Fig. 2—Effect of tooth hardness on gear durability.

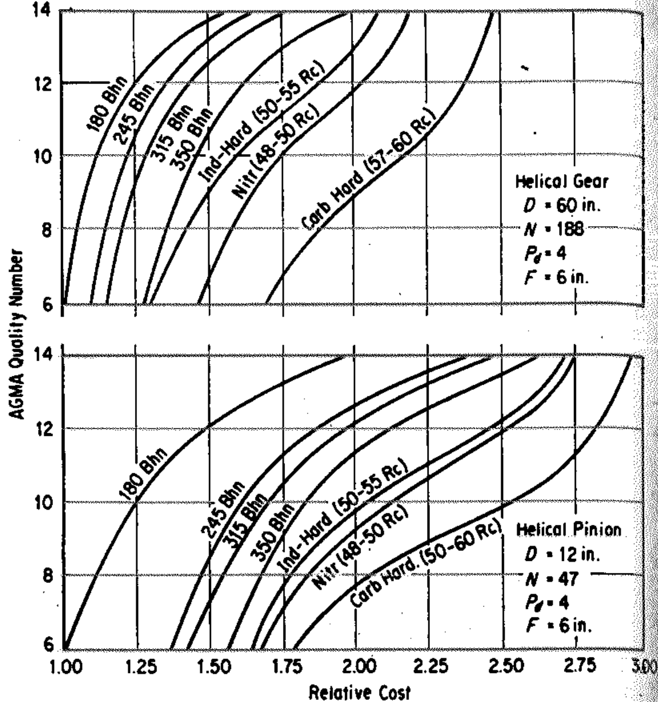

Fig. 3—Representative curves showing relative cost of different hardnesses and heat-treats for various AGMA Quality Numbers. In these figures, D = pitch diam; N = no. of teeth; P_d = diametral pitch; F = face width.

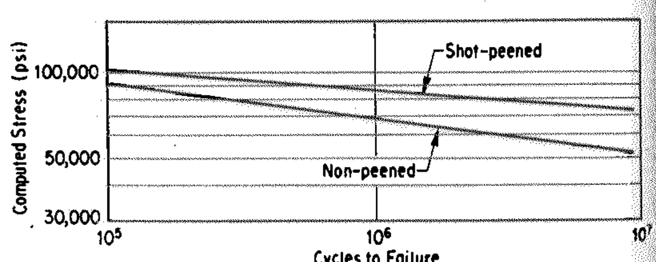

Fig. 4—S-N diagram showing the effect of shot-peening on cycles to failure. In this case, there is an increase of 25% in fatigue strength.

means a substantial increase in material, storage, and shipping costs.

One way to keep gear sizes to a minimum is to specify alloy steels with extra-hard teeth. It is often possible to reduce by one-third, or even one-half, the length, width, and height of a gear box by changing from medium-hardened gears (usually around 350 Bhn) to full-hardened gears (approximately 58 Rc). The durability (wear life) of gears climbs in accordance with increase in tooth hardness, as shown in Fig. 2.

Obviously, harder teeth mean higher cost. But the increase is less than might be expected, considering the savings in size, weight, and cost of the gear box, as well as the added life resulting from the lower surface speeds. An idea of the cost differential can be seen from the curves in Fig. 3.

Select a Balanced Design

The capability of a gear to transmit a steady load is based primarily on the surface durability of the teeth rather than on their beam strength. Beam strength, the resistance of the tooth to breakage, can be controlled by selecting the proper tooth size. Surface durability is a measure of the resistance of the tooth profile to pitting, which can cause fatigue failure. If the load is too high, the surface of the pinion will eventually deteriorate by pitting, leading to noise and vibration and, ultimately, tooth breakage. Resistance to pitting increases with higher surface hardness. Maximum hardness is achieved with deep-case carburizing.

The deep-case carburized pinion running with a deep-case carburized gear is the toughest, most durable combination. To eliminate distortions induced by heat treating, the gears are ground after case hardening.

If gear speeds are high, or if the gear set must be made very large because of high power requirements, the carburized and ground pinion meshing with a through-hardened gear offers the best combination. Such a pair is much more forgiving of manufacturing imperfections, while retaining the advantages of high hardness.

There are many potential causes of maldistribution of load in a large gear set. The set might be made to very close tolerances; but if the foundation is a little off, it could cause stresses during operation. These stresses can cause localized contact between the meshing gears which, over a long time, could result in pitting. The through-hardened gear yields slightly in such cases and tends to wear itself in to suit operating conditions. Furthermore, since the AGMA is more conservative in rating a case-hardened, through-hardened combination than in rating other types, any given service factor would also be more conservative.

Use Shot Peening

Shot peening has been used extensively to increase the fatigue strength of springs and torsion bars and is coming into wider use on gears.

This treatment is applied generally to the tooth fillets only, although sometimes the entire tooth profile is shot-peened. In the latter case, the resulting dimpling provides, in addition to improved stress characteristics, a beneficial effect on lubrication. The dimples act as lubricant pockets that aid in maintaining a full film thickness between meshing teeth.

Although it is difficult to pin a fixed value on the amount of operating life gained from shot peening, tests on specific gears have shown definite improvement. For example, in the SN (stress/cycles to failure) diagram for carburized and hardened gears, shot peened and non-peened (Fig. 4) the gears that were shot-peened show an increase in fatigue strength of about 25%, as measured in stress capacity.

In terms of operating life, this gain may result in even more dramatic results. For example, non-peened gears loaded to about 80,000 psi operated 300,000 cycles before the gear teeth cracked and failed. The same type of gears, when shot-peened and loaded to the same 80,000 psi, operated 3 million cycles. Other tests on shot-peened gears have reportedly shown an even greater increase in cycles to failure than that indicated in the chart.

Gear manufacturers generally prefer not to uprate gears that have been shot-peened. They look on shot peening, which is fairly inexpensive, as added insurance in getting maximum operating life.

Specify a Dual Lube System

All gear units can gain in life expectancy through proper lubrication. Therefore, provision for lubrication should be as much a part of gear design as load and geometry factors.

High-powered industrial drives are usually best lubricated by forced-feed systems. Most reliable is the dual-pressure system, in which one of the oil-pressure pumps is coupled directly to the gear shaft and driven by the gear drive; a second pump operates off an independent power source, usually an electric motor.

With such a dual system, the electric-motor pump is turned on prior to startup of the drive to provide forced lubrication to the gears. When the drive comes up to speed, the shaft-driven pump also comes up to speed to build up oil pressure. At a given pressure, the electric pump is automatically turned off.

During normal operation, the electric pump acts as a standby unit. Should there be a pressure drop for any reason—a failure in the shaft driven pump, for instance—the electric pump is switched back on automatically.

A dual filter system is also a good idea. One of the filters can be cleaned or replaced while the oil is routed through the second filter. Also, oil samples can be checked for acidity and wear particles at regular intervals.

Select High-Viscosity EP Oils

In general, the higher the viscosity of the oil the more effective it will be in preventing scuffing and wear in the gear teeth. There is, of course, a limit to how high viscosity can be. The higher the viscosity, the greater the frictional drag and power losses. And at high speed, the more viscous oils can cause heating, requiring a larger oil cooler. Also, the oil pump and filter must be of larger capacity.

Oil temperatures increase during operation, which drops the effective viscosity of the oil, and it is important to make sure the oil selected has the required viscosity at operating temperature.

Three types of lubricants are generally used for spur and helical gear drives: mineral oils with rust and oxidation inhibitors; mineral oils fortified with elements such as sulfur, phosphorus, chlorine and lead, and generally referred to as extreme pressure (EP) lubricants; synthetic fluids, including the polyglycols and the synthesized hydrocarbons.

For highly loaded gear drives operating at low to medium speeds, EP oils are recommended because they can extend gear life significantly. However, for high-speed applications—speeds over 3,600 rpm or pitch-line velocities over 5,000 ft/min—the mineral oils are preferred. Such drives ordinarily use hydrodynamic journal bearings; the required fine filtration actually will filter out the EP additives, leaving a substandard oil. Further, EP additives do not hold up very well at the higher temperatures normally associated with high-speed operation.

The synthetic lubricants are frequently employed where extended operation at high operating temperatures is anticipated. However, these are expensive and will attack paints and elastomers.

Include Monitoring Instrumentation

The use of instruments to keep track of temperature and of vibrations in the gear drive can help spot the beginning of any operating problems.

Vibration instrumentation usually consists of a proximity pickup next to the bearing journals to monitor the motion of the gear shafts relative to the housing. A warning light or a buzzer can be installed to bring attention to any increase in vibrations.

Bearing temperatures can be measured by means of pickups embedded into the babbitt material. Another good place to take temperature readings is at the oil sump.