Gearbox Field Performance From a Rebuilder's Perspective

Charles D. Schultz

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Introduction

The major focus of the American Gear Manufacturers Association standards activity has been the accurate determination of a gearbox's ability to transmit a specified amount of power for a given amount of time. The need for a "level playing field" in that critical arena was one of the reasons the association was formed in the first place. Over the past 85 years, AGMA committees have spent countless hours "discussing" the best ways to calculate the rating of a gear set, often arguing vigorously over factors that varied the resulting answers by fractions of a percentage point. While all that "science" was being debated in test labs and conference rooms all over the country, our industry's customers were conducting their own experiments through the daily operation of gear-driven equipment of all types.

Unfortunately, the results of those "test programs" are usually unavailable to the design engineer unless failure occurs during the relatively short warranty period offered on new equipment. My employer, the Pittsburgh Gear Co., has been engaged in the repair, rebuilding and field servicing of gearboxes for many years. The record of that activity provides some interesting insights into what happens to gearboxes long after their warranties run out. (See Appendix A.) While the majority of our customers are in the steel business, equipment from the chemical, mining and rock-quarrying industries has also been repaired. At one time or another, products from most domestic and foreign suppliers have been serviced. The gearboxes cover much of AGMA's history and include most of the designs popular today. One of the drives operated by a local customer was put on-line in 1921 and hasn't missed a day of work yet. That type of performance is exceptional, of course, but it certainly inspires respect for the designers who labored in our trade long before the advent of the computer.

It is in deference to those creative engineers that I encourage today's gear designers to avail themselves of any opportunity to study long-term performance. Having spent most of the last 25 years engaged in gearbox design and development, exposure to the far less glamorous side of the business has been extremely beneficial to my design work. In this paper, I'll try to share some of the things I've learned and how they've affected my design philosophy.

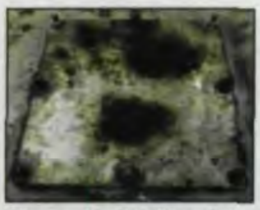

Figure 1—Traditional inspection cover.

Figure 2—Threaded pipe plug inspection port.

Failure Definition

Our customers have their own definition of "gear failure," and it has nothing to do with bending stress or durability rating. The average mill superintendent cares about only one thing: *Can the equipment work today?* If a little pitting or a small crack appears, the user couldn't care less if production can continue. While some of the more sophisticated plants are rapidly moving towards a "predictive maintenance" environment, the vast majority of mills react only to catastrophic breakdowns. We've seen some incredible performances by gearboxes run completely without oil for months or missing sizable tooth fragments due to bearing-related misalignment. We have seen very few "failures" caused by overrating or misapplication, although overloads due to process line "crashes" and field modifications remain a significant problem. AGMA's standards writers and the application engineers can be justifiably proud of their work.

The same pride cannot be shared by the plant maintenance crews, however. The most common causes of failure recorded in our database are lack of lubrication, poor lubricant quality and debris damage. Tooth breakage is rarely seen unless bearing damage, extreme tooth wear or debris is involved. Pitted teeth are usually left untreated until the drive becomes noisy enough to attract attention or someone becomes alarmed at the metal seen during an oil change. While there are certainly design deficiencies that contribute to those problems, most customers would enjoy lower overall operating costs if they did a better job of monitoring the equipment's oil quality. For the designer, knowing that even the most state-of-the-art gearbox will operate in an environment full of soot, sand, water, blunt instruments and mechanics struggling to keep everything moving can help reduce the anxiety of determining the contact stress to the third decimal place.

Design Practice Changes

Observing the maintenance problems first-hand has resulted in some changes to my design philosophy. For example, unless a customer insists, we no longer use the traditional bolt-on inspection covers. (See Figure 1.) We've found the thin plates almost impossible to seal against moisture and have noticed that many times the debris that inflicted the final damage to the gears was a small capscrew used to attach the plate. Our technicians have found an incredible amount of "stuff" inside gearboxes with large covers, including wrenches, screwdrivers, files and flashlights. We've often joked that the bigger the inspection cover, the bigger the debris. While handy for gear inspection, the covers ought to have a warning label affixed reading: "No user serviceable parts in here." We've switched to large threaded pipe plugs for inspection ports. (See Figure 2.) They seal tightly against water, permit quick inspection of tooth condition and are impossible to drop into the oil sump. The pipe wrenches required to remove them are too big to drop though the hole, although the tiny flashlights favored by some mechanics do present a continuing hazard.

We've also become believers in "low oil level" sensors. (See Figure 3.) Originally wary of putting delicate electrical devices in the rough-and-tumble mill environment, observing a plant start-up where the only gearboxes run "dry" were the only ones without the sensors was convincing evidence of their value. We've also been increasing the "robustness" of the external lubrication plumbing used on both new designs and rebuilds. Lube lines apparently make excellent ladders for climbing, serve as emergency crane hooks and are easily snagged by passing loads. One of our customers now has us fitting his more susceptible gearboxes with guards made of 0.25-in. plate to protect them from damage. (See Figure 4.) For most pressure lines, we've switched to high-quality hydraulic hose after discovering that even the bravest mechanic won't use them for a step or a lift point. (See Figure 5.) So far, the customers have been very accepting of that change, especially when they realize it is much cheaper to make a new hose than it is to repair a damaged pipe.

Fast turnaround on repairs is increasingly important to the mills, many of which have greatly reduced both their maintenance staffs and their spares inventories. Among the most distressing problems we have to deal with on a regular basis is the housing bore damaged by a "spun bearing." (See Figure 6a.) Repairing a damaged housing is very time consuming and costly, especially on special units with multiple split lines or a divided power path. The AISE heavy-duty crane specification (see AISE Technical Report 6, June 1996) requires that bearings be mounted in replaceable cartridges (see Figure 6b) due to the difficulty in removing the housings from their lofty perches for re-machining. Superintendents faced with expensive in-place machining of gearbox housings grouted into the floor quickly make sure future purchase specifications follow the AISE's example. Except for bearings that must float axially, it might be worth studying the effects of tighter outside diameter fits on most housings. Where possible, anti-rotation pins (see Figures 7a and 7b) seem to be quite effective.

Some of the lubricant loss experienced in the mill can be traced to worn seal diameters. Many output shafts are made of material that has not been heat treated. Consequently, those shafts have soft seal diameters, which wear out rather quickly. After-market wear sleeves have proven to be quite effective in fixing that problem, although the units have to be removed from their mountings and stripped of their couplings to

Figure 4—Guarded lubrication system.

Figure 5—External lubrication system with hydraulic hose.

Figure 3—Oil level sensor.

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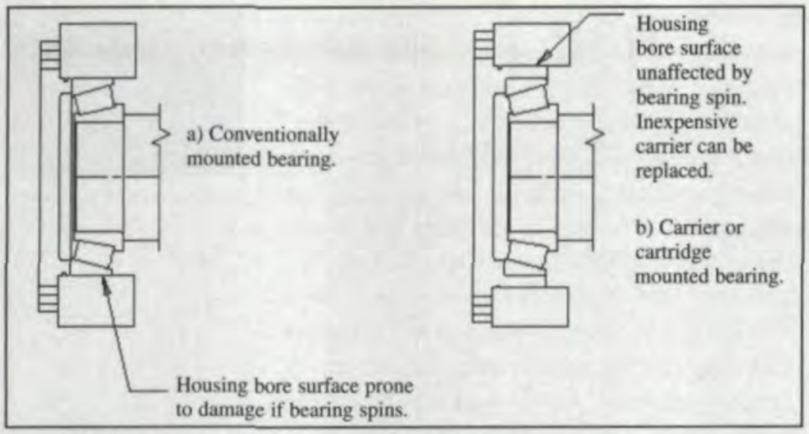

Figure 6—Bearing mounting for extended service life.

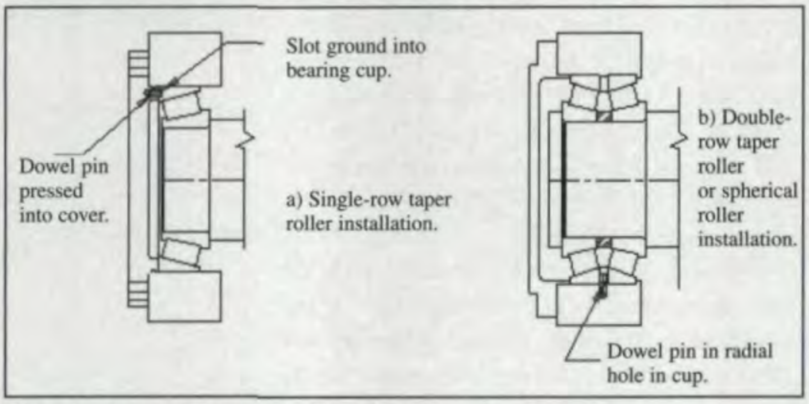

Figure 7—Common anti-rotation pin designs.

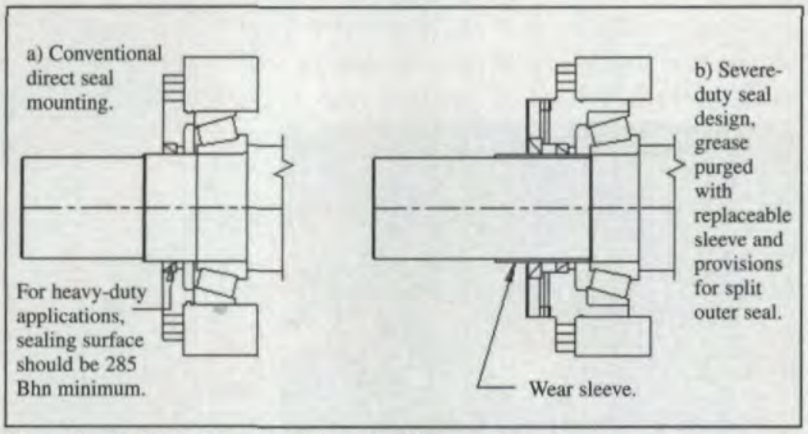

Figure 8—Seal designs for extended service life.

Figure 9—Example of miscellaneous damage.

install them. Coupling removal occasionally causes enough additional damage to the shafts to necessitate their replacement anyway. We recommend that seal diameters be at least 285 Bhn on all shafts unless wear sleeves are fitted. (See Figures 8a and 8b.) Chrome plating or induction hardening is preferred by some customers, although those processes add to the turnaround time. For severe-duty "wash down" environments, special seals, such as packing glands, are well worth the extra expense.

We are still trying to develop better ways to keep water out of the sump. Continuous caster gearboxes are particularly prone to water contamination, even when fitted with expansion chambers rather than breathers. As a result of that problem, the mills have reluctantly gone to strict preventive maintenance programs on those critical drives. Through careful attention to details, such as chrome plating, seal diameters and regularly repainting the interior surfaces of the housing, we have been able to lengthen the time between rebuilds by 50%. The most amazing thing to me is how well the carburized bevel gears have held up after being lubricated with watered-down oil. In similar situations, through-hardened helical gears destroy themselves in a matter of weeks.

Wear is a much more common "gear failure" mode than tooth breakage on the drives that we repair. As noted earlier, customers seldom react to the appearance of pitting, even on carburized gears. Severe wear frequently produces a noticeable change in how the gearbox sounds and draws the interest of the mechanics. Carburized gears typically outlast several sets of bearings, unless the bearings are allowed to deteriorate so far that misalignment results in severe pitting or tooth breakage. In similar applications, through-hardened gears do not seem to hold up as well and are more frequently replaced at the same time as the bearings. The longevity of through-hardened gear sets is adversely affected by the high face-to-diameter ratios used in some designs, which makes the sets prone to deflection-related load distribution problems. In redesigning those gear sets, we often use the additional capacity afforded by changing to carburized gearing to reduce the face width, thereby reducing the face/diameter ratio to more conservative levels.

Basic design problems are relatively rare, but when they occur, the customer has to live with the results for years. One installation we service has a 49:1 ratio, double-reduction gearbox in a very tight location. The 7:1 gear sets have face-to-diameter ratios of over 2.0 and require replacement every 18 to 24 months. We have other "frequent visitors" with multiple input-multiple output configurations that suffer from recirculating power problems. Improved part quality or increased hardness has lengthened the time between rebuilds, but the lack of redesign options prevents effective, long-term resolution. When designing our own "specials," we try to give ourselves room for future upgrades by taking a conservative approach to ratio selection, face-to-diameter proportions and internal housing clearance.

Design for Extended Life

While recognizing the commercial limitations imposed upon us by the global marketplace, I believe that we can "design for extended life" by considering the problems likely to be encountered during the 15- to 25-year operating life of the typical process line and addressing them at the original equipment level. Not every gearbox needs "cartridge bearings," but all deserve a water-free sump. Following the AISE's example of graduated service classes to account for duty cycle, reliability expectations and life requirement would go a long way towards improving customer satisfaction with our industry. Within the context of those service classes, it would be possible to address detail design issues in a way that provides a consistent, level playing field for all competitors without forcing customers to develop their own in-house specifications. I realize the difficulty of changing from a catalog selection system based upon a list of applications and service factors to a system that includes non-gear related factors, such as housing design. It was just a few years ago, however, that we considered 10,000,000 cycles to be "infinite life" despite knowing that that was less than 100 hours of use for the typical high-speed pinion. A proposal for service classes is shown in Appendix B.

Acknowledgments

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Appendix A—Cause of repair summary.

Cause of Repair	Description	# of Orders	% Total
Inadequate Lubricant	Contaminated oil	353	16.1
Low Oil Level	Insufficient oil	449	20.5
Bearings	Worn or failed bearings	211	9.64
Miscellaneous	Non-Gear, Bearing, Lube	198	9.05
Overload	Gear or bearing damage	381	17.4
Preventive Maintenance/ Precautionary Repairs		596	27.2
Total		2,188	

Comments

1. Bearings and seals were changed on all gearboxes unless the customer specifically requested their re-use.
2. Worn or pitted gears were not changed unless authorized by the customer.
3. The "Overload" category includes all tooth breakage and indications of plastic flow. Frequently, the problem occurs when the process line "crashes," putting unforeseen loads on the gears, bearings and shafts.
4. The "Inadequate Lube" category includes units with evidence of contamination and general bearing/gear wear. The "Low Oil Level" category was reserved for cases of relatively sudden failure due to temporary lack of oil rather than long-term damage.
5. The "Miscellaneous" category includes physical damage to the gearbox by external sources, leaks not related to seals, hand-of-assembly changes, coupling changes and modification requests (See Figure 9).
6. The "Preventive Maintenance" repairs are made based upon previous experience that failure to do so on a regular basis will result in unplanned shutdowns.

Appendix B—Design for extended service life classes.

Class	1	2	3	4
Description	Regular Duty	Heavy Duty	Severe Duty	Critical Duty
Abbreviation	RD	HD	SD	CD
Minimum Gear Strength SF	1.25	1.75	2.50	3.00
Lube System	Splash	Splash	Pressure with filter	Pressure with filter
Min. Gear Design Life	10,000 hrs.	15,000 hrs.	20,000 hrs.	30,000 hrs.
Min. Bearing L-10 Life	10,000 hrs.	20,000 hrs.	40,000 hrs.	60,000 hrs.
Bearing Mounting	Conventional	Conventional	Cartridge	Cartridge
Seal Type	Single Lip	Single Lip	Grease purged with provisions for split replacements	Grease purged with provisions for split replacements
Shaft Surface	220 Bhn min.	285 Bhn min.	Replaceable sleeve required	Replaceable sleeve required

Gearboxes repaired included:	Alten Engineering Division, Westerman Companies Amarillo Gear Co. Browning, a division of Emerson Power Transmission Chicago Gear-D.O. James Corp. Cleveland Gear Co. Cone Drive, a division of Textron Power Transmission David Brown, a division of Textron Power Transmission Delroyd Worm Gear Products, a division of Nuttall Gear L.L.C. Dodge, a division of Rockwell Automation Dorris Co. Falk Corp. Fessler Machine Co. Flender Corp. Foote-Jones/Illinois Gear, a division of Regal-Beloit Corp. Hansen Corp., a Minebea Group company Harnischfeger Industries Inc. Hitachi Zosen Corp. Horsburgh & Scott Co. Lohmann + Stolterfoht GmbH Morse, a division of Emerson Power Transmission Nord Gear Nuttall Gear L.L.C. Philadelphia Gear Prager Inc. Renold plc Santasalo Gears (now Metso Drives) SEW Eurodrive Sumitomo Machinery Corporation of America Xtek Inc.