Mechanical Drive System Uprating & Updating for Increased Production

981204
January, 1999

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Abstract
In the never ending quest for increased production, many times the limiting factor is the mechanical drive system for the driven equipment (pumps, grinding mills, conveyors). This paper provides a step-by-step approach to uprating existing mechanical drive systems for increased production. Advances in mechanical drive system design, manufacturing and material technologies allow existing equipment to be uprated or replaced with components of significantly higher power density.

I. Introduction

This paper provides a step-by-step approach to uprating existing mechanical drive systems. Within this paper, a mechanical drive system is defined as the mechanical components needed to transmit torque. The components involved include shaft couplings, gearboxes, and girth gearing.

In retrospect, the design methodologies and rating practices used for industrial mechanical drive systems were conservative. This statement could only be made after the introduction in the early 1980's of a new series of rating standards that more accurately model actual performance. The good news however, is that the conservatively designed vintage systems can be uprated or replaced with components of significantly higher power density, allowing increased production.

In addition to new methodologies and rating practices for drive systems, the manufacturing methods, materials employed, and the purchased components (bearings, seals, etc.) have also changed significantly. Therefore, the vintage designs are, by today's standards, much larger than required.

The following gear and pinion data are a baseline selection that are used for the rating examples within this paper.

TABLE 1 — Baseline Selection Information

Pinion Speed	240 rpm
Pinion Teeth	19
Gear Teeth	267
Face Width	660 mm (26 inches)
Tooth Form	20.3 Module (1.25 DP)
Pinion Hardness	265 HB minimum
Gear Hardness	180 HB minimum

II. Girth Gear Set — Pinion Replacement

One of the most conservatively designed components in any drive system is the girth gear set consisting of a girth gear and pinion. The girth gear rating practices developed by AGMA were purposely made more conservative than enclosed drive standards in an attempt to quantify issues such as the difficulty of manufacturing large gearing. Today, the differences between enclosed drive standards and girth gear standards are much less significant.

In addition to conservative design standards, the state of the art in material technology for steel castings could only produce gear blanks with a hardness of 180 HB (typical) or 225 HB (maximum). For the mating pinions, the typical hardness was 265 HB or 285 HB. Carburizing the mill pinion was not a commercially available option for large mill pinions.

The improved gear tooth accuracy produced by modern day machinery also allows an increase in rating. The gear tooth quality that 1950's or earlier vintage gear cutting equipment could produce is in the low to medium range (AGMA 6-8) by today's standards (AGMA 8-10). Finish grinding of the pinion teeth, which can produce AGMA quality 12, was not considered since it was not available. This combination of design, materials, and manufacturing capability resulted in very low power density mill drive packages.

To increase the power density of this vintage girth gearing, a higher hardness pinion can be installed. AGMA rating practices allow a rating increase by increasing only the hardness of the pinion. The reasoning for increased rating with a higher hardness pinion is the additional number of cycles a pinion experiences during service and the work hardening effect that a "hard" pinion has on a "soft" gear. Increasing the pinion hardness does not increase the minimum strength rating of the gearing since the gear typically rates the set. Strength rating is usually not a concern since mill gearing typically has a much higher strength service factor (2.50 minimum) than durability service factor (1.50 minimum).

The replacement pinion can be either through hardened or carburized depending on the rating increase desired. Table 2 shows the percentage rating increase when replacing a 265 HB through hardened pinion with a 365 HB through hardened pinion or a carburized pinion. For all of these examples the baseline gear hardness of 180 HB is used. Also listed is the approximate cost increase of the higher hardness options.

TABLE 2 — Rating Increase (%) Using Higher Hardness Pinion

	365 HB Pinion	Carburized Pinion
Pinion Durability Rating	67	172
Gear Durability Rating	5	15
Pinion Strength Rating	22	56
Gear Strength Rating	0	0
Approximate Cost	10	71

For the baseline example, the installation of a higher hardness through hardened pinion is the best value option resulting in a 5% increase in rating for a 10% increase in cost. For higher hardness girth gears (265 HB or greater), significant rating increases can only be gained by installing a carburized pinion.

It should be noted that the rating increase assumes the girth gear is in like new, as manufactured condition. This is typically not the case and therefore a rating decrease may be required. An exact value for derating the set due to gear wear or damage cannot be assessed without a thorough inspection of the gear.

Additional service life can be achieved through the use of tooth modifications designed to correct contact problems that occur under service conditions. The replacement higher hardness pinion can be ground with specific tooth modifications to increase load carrying capacity and operating contact. Figure 1 shows the different Hertzian stress levels of a pinion with various tooth modifications at different misalignment values.

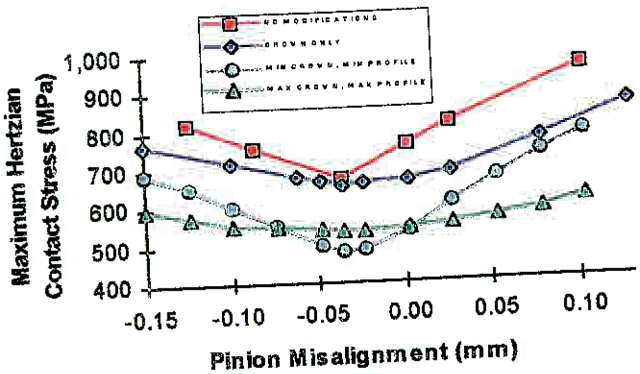

Figure 1 The effect of pinion tooth modifications on contact stress at different pinion misalignment conditions.

For a typical grinding mill, a significant production increase may be possible by increasing the number of pinion teeth. This results in a lower total gear ratio which increases the mill's speed. For the baseline gear set, increasing the number of pinion teeth from 19 to 20 teeth increases the mill speed by 5.3%. A 4.5% to 6.25% increase in mill speed is possible when increasing the number of pinion teeth by one. The exact speed increase depends on the original number of pinion teeth. An increase in mill speed can result in a significant increase in production. However, the mill will operate closer to the critical speed, so the mill OEM should be consulted when making this change.

Increasing the number of pinion teeth may require increasing the girth gear set's center distance. For the baseline gear set a center distance increase of 10 mm (0.4 inches) is required to maintain the same gear geometry. Allowance for this is usually available in the pillow block foundation bolt holes. If not, the bolt holes can be slotted to accommodate the increased center distance.

The motor must also be capable of providing the extra power required to drive the mill at the increased speed. This is typically not a problem as most mills draw less than full motor power. If the mill is operating at motor nameplate power, the motor power can usually be increased by adding additional cooling to the motor.

III. GIRTH GEAR SET – REPLACE PINION AND RE-CUT GIRTH GEAR

As mentioned in Section II, a worn gear should be derated based on its condition when uprating an existing girth gear set by replacing the pinion. This derating factor can be eliminated if the girth gear is re-cut. Please note that it has been assumed that both flanks of the gear have already been used.

Used Gear

Tooth Damage

Re-cutting the teeth of a girth gear restores the original tooth form and makes it possible to take full advantage of a new pinion. In addition, the gear structure is

NDT Results

inspected and any defects repaired. This provides the structural integrity required to transmit the increased torque.

Defect Excavation

Defects in the gear structure are identified by non-destructive testing (NDT) methods and then weld repaired. The NDT methods employed include magnetic particle inspection and ultrasonic inspection. Defects are identified, excavated, and weld repaired. After weld

Completed Weld Repair

repairing, the girth gear is completely stress relieved and re-heat treated to ensure proper integration of the repair with the base metal. All machined surfaces are re-machined to ensure dimensional accuracy and that geometric tolerances meet or exceed the original design.

Remachined Gear

A complete design review is undertaken that validates all aspects of the gear and pinion design and manufacture. This updates the design with current design methodologies and rating practices.

Restored Tooth Surface

The new tooth surfaces also yield the benefit of increased efficiency. A worn or pitted gear tooth surface dramatically affects efficiency. A re-cut gear operating with a new pinion restores the original 99%+ efficiency to the gear set. This can translate into significant operating cost savings. A 1% increase in efficiency for a 1000 kW (1341 hp) mill results in savings of $3500/year using an electricity cost of $0.04 per kW/hour.

The cost of the pinion is the same as discussed in Section II. The cost of re-furbishing the gear varies depending on the amount of repair that is required. Typically, re-cutting the teeth of an existing girth gear is 30 to 50% of the cost of a new girth gear. The exact final cost is heavily dependent on the amount of weld repair required to the gear structure.

IV. GIRTH GEAR – REPLACE BOTH PINION & GIRTH GEAR

The next step is to replace both the pinion and girth gear. This allows the use of the latest design methodologies and rating practices. Also, advantage can be taken of the many improvements in manufacturing and materials technology. Dimensionally interchangeable components can be furnished that have significantly more rating.

Table 3 shows the rating increases possible when replacing the baseline 180 HB girth gear and 265 HB pinion with a 310 HB girth gear and carburized pinion. The cost increase is also listed.

TABLE 3 — Modern Girth Gear Design Rating Increase (%)

Pinion Durability	172
Gear Durability	130
Pinion Strength	56
Gear Strength	47
Cost	12

The rating increase achieved by updating to a modern design is dramatic. An important item to note is the percentage increase in rating (47) compared to the percentage increase in cost (12). The relationship between rating increase and cost increase is not linear when updating a girth gear design. This results in significantly more value to the customer when replacing vintage designs with modern designs.

V. Gearboxes & Couplings

Uprating the girth gear and pinion only is useless if the main gearbox and/or couplings cannot transmit the increased torque.

The through hardened gearing in most gearboxes can be uprated in the same manner as the girth gear set. A higher hardness pinion (through hardened or carburized) can be used or the pinions and gears can be carburized. The typical uprate achievable using just carburized pinions is 15% and using all carburized elements is 50%.

At the same time the gearing is replaced, new bearings employing the latest material and manufacturing technology can be installed. Bearing manufacturers have released E type spherical roller bearings that have significantly more load carrying capacity for the same size. The typical uprate using E type bearings in place of standard bearings is 15%. Also, the rating practices for bearings have evolved to include adjustment factors for lubrication, cleanliness, and load zone. The use of these factors can either increase or decrease the calculated life of a bearing. The result is a much better understanding of the actual operating life that the bearing can be expected to achieve.

In addition, new seals with higher allowable operating temperatures (Viton™) can be installed. New seal design technology (Taconite, Magnum™, or non-contact) can be installed to provide better leak protection, reduced operating temperatures, or longer seal life.

Shaft couplings have experienced a similar uprate in the last 30 years. New materials and manufacturing processes have increased shaft coupling power density 70% for grid type couplings (size for size). The rating of gear type couplings has increased at least 55% (size for size).

This means a dimensionally interchangeable coupling with a much higher rating can be used. Or, a smaller coupling with the same rating can be installed, significantly reducing cost.

VI. Conclusion

There are many ways to increase the power density of existing drive systems to increase production. They include, replacing pinions, re-cutting girth gears, replacing vintage designs with new designs, and uprating gearboxes and couplings. In the quest for increased production and reliability the drive system need not be the limiting factor.

This paper was originally prepared for and presented at the IEEE/PCA 40th Cement Industry Technical Conference, Rapid City, SD, May 17-21, 1998