Since mill maintenance budgets must be reduced to remain competitive, gear spindle life can have a significant effect on mill maintenance costs and mill productivity. To help address this need, Ameridrives International has developed a new generation of advanced crowned gearing and its mating sleeve for longer life spindles (patent pending).

MILL SPINDLE ADVANCED GEAR DESIGN

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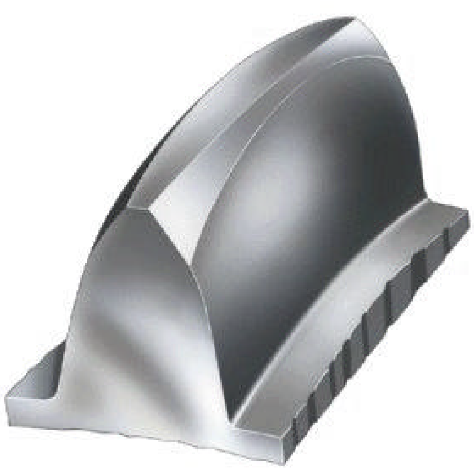
Through an intense "Advanced Gear Design" analysis (patent pending), Ameridrives International has optimized the geometry of the existing Fully-Crowned Gear Tooth (Fig. 1) to increase capacities by 20 to 300% greater than the existing conventionally designed tooth. This analysis was developed through years of finite element analysis, strain gage testing, dynamic testing and field testimonials from users.

Fig. 1 — Fully-Crowned Gear Tooth



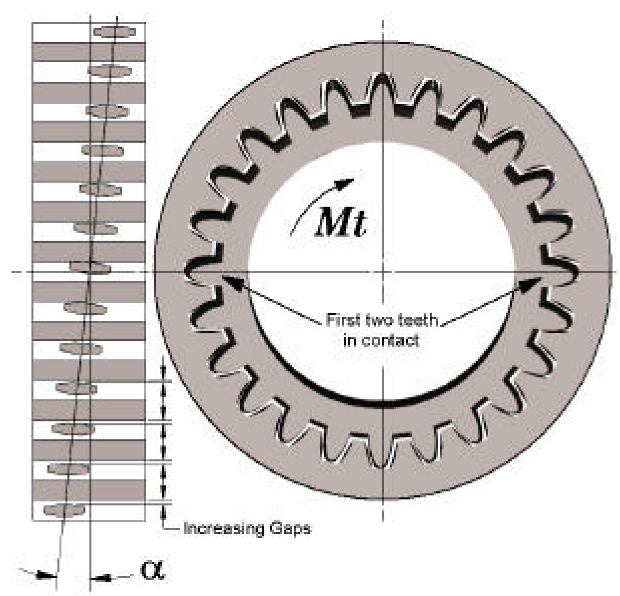
The Basics of "Advanced Gear Design"

The main concept of the "Advanced Gear Design" is optimization of the tooth geometry to obtain a higher percent of teeth in contact at the coupling operating conditions. In order to perform this optimization, one must first understand the variables that effect the actual percent of teeth in contact.

Misalignment Angle—
This is the only factor given consideration in the percent of teeth calculation of a conventional gear coupling analysis.

Theoretically, there are only two teeth in contact when misalignment (Fig. 2 - α) is present and no load is applied. The remainder have a gap between each tooth set.

Fig. 2 — Tooth spacing at misalignment



Applied Load—

There must be a load applied (Fig. 2 - *Mt*) to obtain contact of more than two teeth. The final results are non-linear based on the gear component stiffness and tooth spacing gaps. This torque is a function of horsepower (HP) and speed (RPM) as:

$$Mt = \frac{HP(63025)}{RPM}$$

Flank Curvature—

This is the main contributor besides the misalignment angle in determining the gap between each tooth set.

An optimized flank curvature will produce minimal gaps between each tooth set while maintaining an acceptable compressive stress.

Hub and Sleeve Set Stiffness—

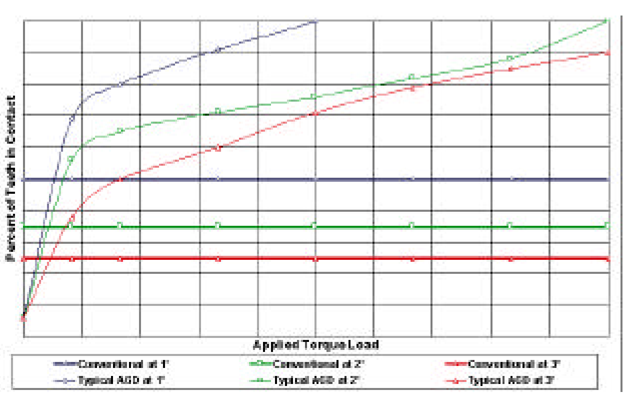
Tooth quantity, tooth size and sleeve barrel diameter are all important factors in determining the stiffness of the hub and sleeve set.

An optimized stiffness is soft and maintains a balanced deflection of the hub and sleeve set.

Result of Including all Contributing Factors—

In calculating the percent of teeth in contact, the Advanced Gear Design Method includes the effects of all the contributing factors discussed above. This method produces significant differences in analysis results for any gear configuration (Fig. 3).

Fig. 3 — Comparison of the method to calculate the percent of teeth in contact as a function of applied torque load



When compared to a conventionally designed gear, the physical appearance of the Advanced Gear is a narrower, larger tooth with a more radical flank curvature and fewer teeth per gear mesh (Fig. 4 and 5).

Fig. 4 — Gear mesh designed using the conventional method

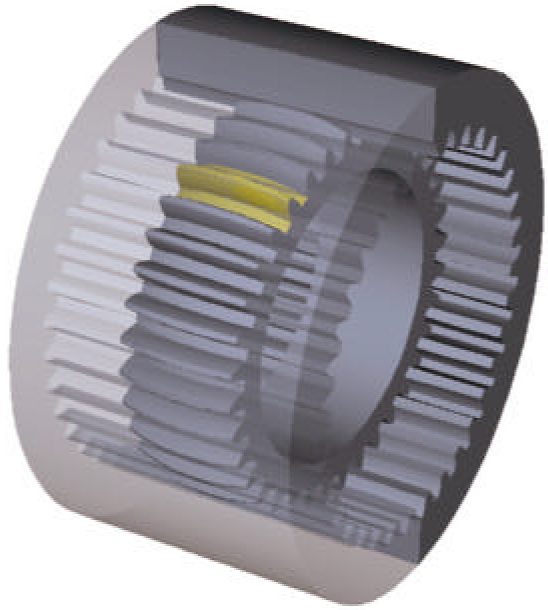
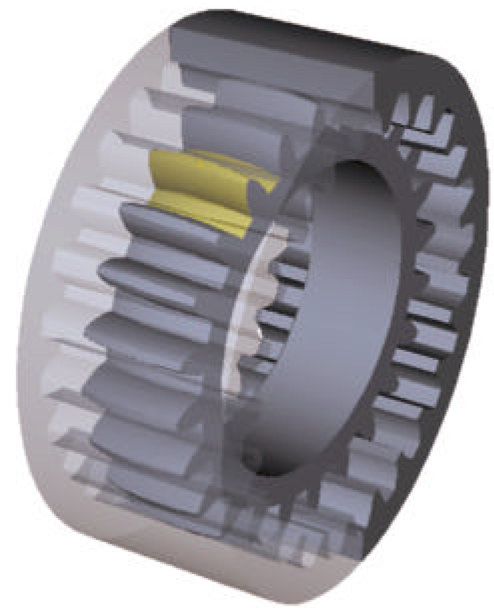


Fig. 5 — Optimized gear mesh using the Advanced Gear Design method



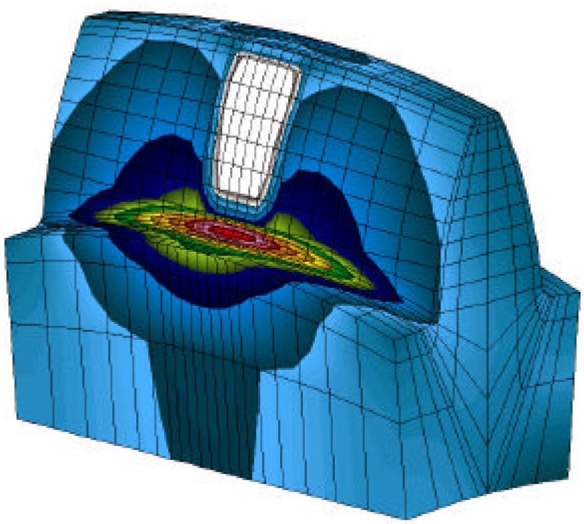
The Development of the "Advanced Gear Design" Procedures

The Advanced Gear Design procedures were developed using Pro-Engineer's™ 3-D modeling system and NISA Finite Element Analysis (FEA) software. The following process shows the basic steps involved in this development program.

Develop Finite Element Models—

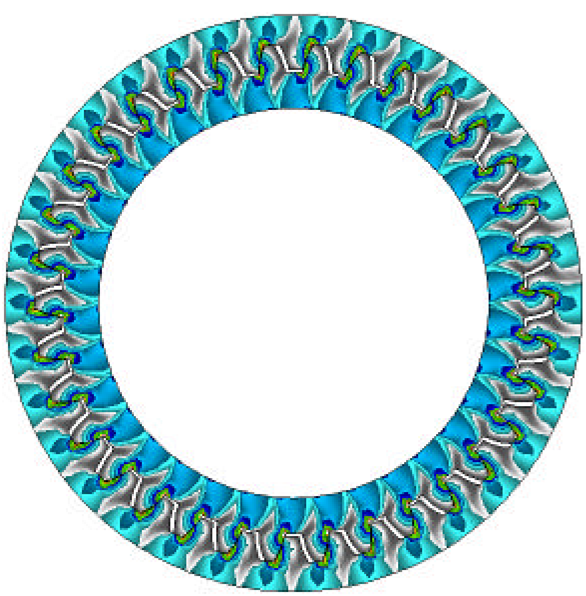
A single tooth 3-D model (Fig. 6) is correlated to both conventional equations and strain gage results. Linear FEA runs were used assuming 100% of the teeth in contact or a 0° misalignment angle.

Fig. 6 — Single tooth 3-D FEA model



Next, a 360°, 2-D model (Fig. 7) using non-linear FEA runs with zero gap elements between each tooth set to simulate the 100% teeth in contact condition at 0° misalignment is correlated.

Fig. 7 — 360°, 2-D FEA model at 0° misalignment

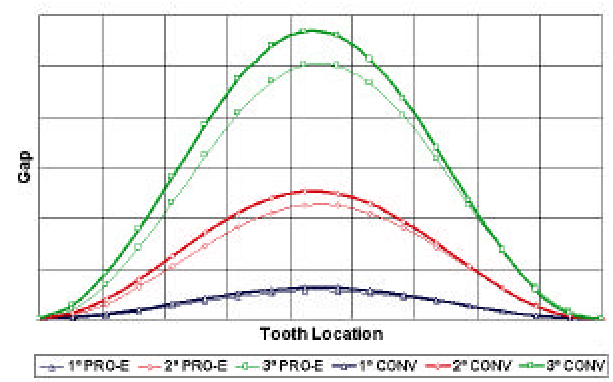


Calculate the Physical Gap Between Each Hub and Sleeve Tooth—

The gap between every hub and sleeve tooth was calculated using Pro-Engineer's™ 3-D modeling and gap calculation capabilities. This was performed at various misalignments.

A conventional equation was derived to achieve the gaps produced by the Pro-Engineer models (Fig 8).

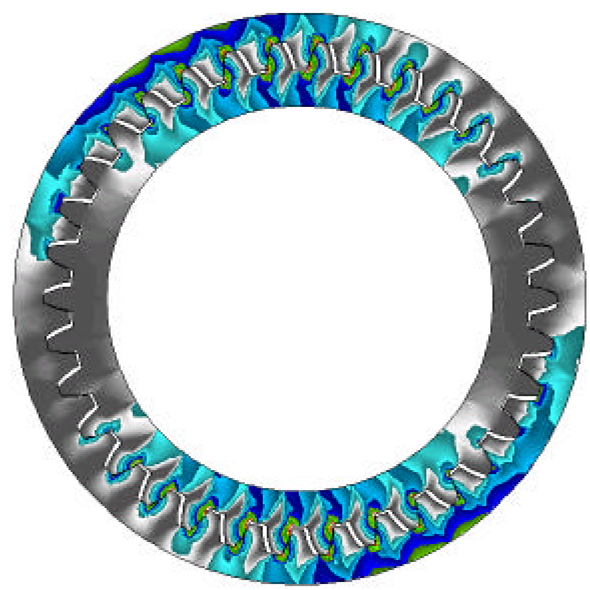
Fig. 8 — Graph showing correlation of Pro-Engineer and conventional equation tooth gaps



Obtain Stresses and Percent of Teeth in Contact for Operating Conditions—

The gaps obtained from Pro-Engineer™ were applied to the 360°, 2-D model providing both bending stress and percent of teeth in contact (Fig. 9).

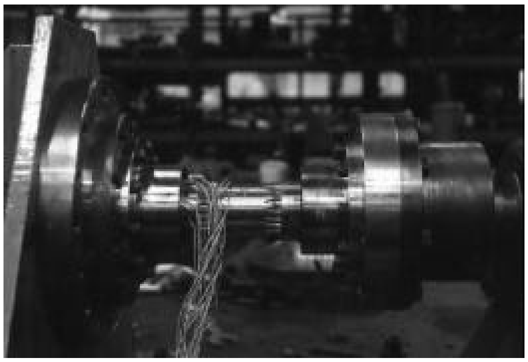
Fig. 9 — 360°, 2-D FEA model at 2° misalignment



Verify the Design Process

In House Testing—
The verification process consisted of numerous in house strain gage (Fig. 10) and dynamic tests on both new and old crown gear tooth design configurations.

Fig. 10 — Strain gage test setup



The correlation of stresses, percent of teeth in contact (Fig. 11 and 12) and heat generation characteristics were all excellent.

Fig. 11 — Graph showing tooth bending stress at various misalignment angles

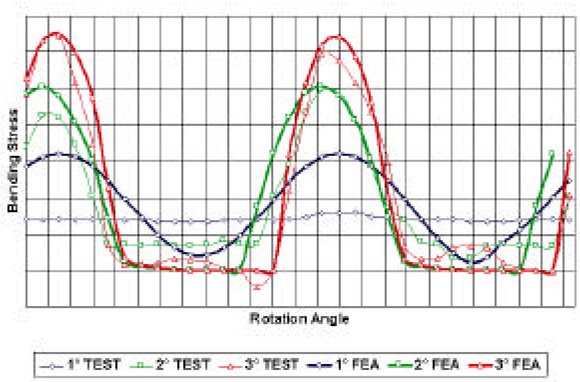
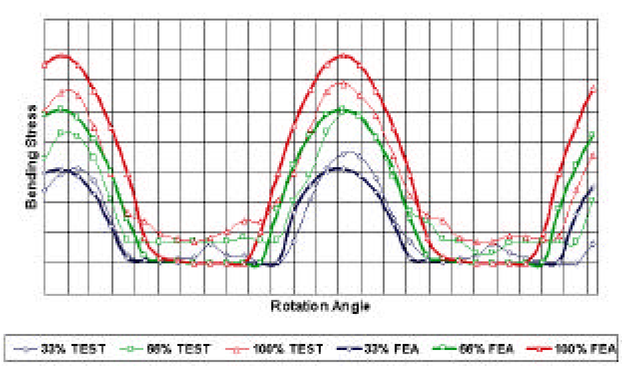


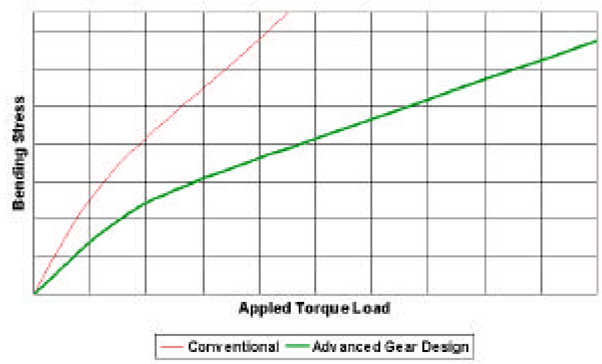
Fig. 12 — Graph showing tooth bending stress at various torque loads



In reviewing Figures 11 and 12, notice that the curves exhibit the same pattern, confirming the percent of teeth in contact method. In addition to this, the actual stress values are also within 15% with the design (FEA) values on the high or conservative side.

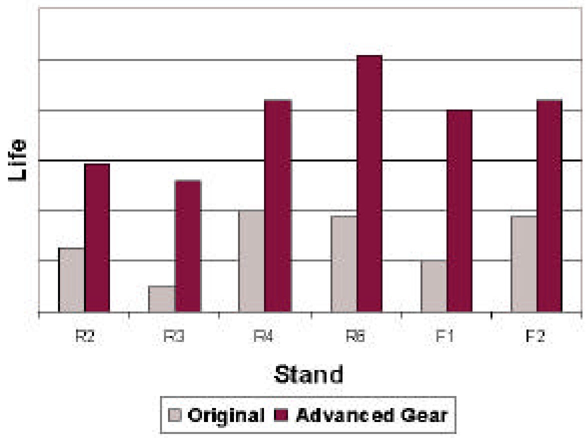
An optimization process consisting of flank curvature, diametral pitch, face width and sleeve barrel was performed on both actual and test configurations. The results were outstanding, decreasing the stress (Fig. 13) and increasing both load carrying capabilities and coupling life by magnitudes in the same diameter gear spindle.

Fig. 13 — Graph showing tooth bending stress as a function of applied torque



Testimonials—
In conjunction with the in-house testing, selected high maintenance, short life mill applications were used for field-testing.
In one case, a large steel manufacturer began having spindle failures on the roughing stands of their 84" hot strip mill after operational changes where made to increase the overall output of the mill. The spindle gearing began failing in as little as three to four months. Ameridrives provided prototype Advanced Gear Design Spindles to increase the life and allow the mill to produce at the new desired output. six months after installation of the prototypes, the spindles were removed for inspection and the gears were in near perfect condition. Since that time, failures have been eliminated and the spindle gears on this mill have now lasted in excess of two years (Fig. 14).

Fig. 14 — Graph showing Spindle life of the original and Advanced Gear Designs on various roughing and finishing stands on a hot strip mill



Ameridrives has applied the new design to all mill applications from 3½ inch leveler spindles, 21 inch high speed cold mill spindles to 38 inch hot mill spindles with significant life increases for all applications.

Inherent Design Features

A Mill Spindle designed using the Advanced Gear Design method also exhibits some additional operational advantages.

Reduced Vibration Characteristics—
The amount of backlash required to achieve the misalignment angle is much less than a conventionally designed gear mesh. This results in less vibration on the system, providing smoother roll operation, lower shock loads and a more stable system. This improves product quality with less chatter and enables cold mills to increase output by running at a higher speed.

Lower Temperature—
Actual field measurements have demonstrated cooler operating temperatures at the gear mesh. This is attributed to having more teeth in contact, reducing hot spots in the gear mesh and a tooth geometry that produces more of a rolling motion than a sliding action. This extends lubricant and spindle life.

Lower Cost—
Producing Mill Spindles with smaller diameters for given load conditions results in an overall cost savings for the initial product beyond that acquired from the lower maintenance and downtime savings.

Conclusion

The Advanced Gear Design Analysis enables Ameridrives to optimize Mill Spindles for the specific application's operating conditions. The high angle, largely loaded steel mills benefit with less maintenance, lower cost, increased productivity and minimal failures.

Summary

This article discusses the methods and advantages of the Mill Spindle Advanced Gear Design. There are many other factors not discussed, such as material, lubrication and tooth distortion from hardening processes that effect the operation and life of Mill Spindles and gear type couplings in general. However, due to the increased accuracy and inherent features of this design method, Ameridrives International is currently incorporating its use on any high angle gear type coupling it produces.