Comparison of Rating Trends in AGMA Versus ISO

Octave A. LaBath and Dennis Richter

Summary

As the international business community grows closer together, the need for understanding differences between national and international gear rating standards becomes increasingly important for U.S. gear manufacturers competing in the world market.

In the international gear business, the ISO 6336 rating standard is gaining more acceptance across many industries and markets. This is important to U.S. gear manufacturers as it can affect not only the ratings on existing designs that form the basis for a company's standard line of units, but can also dictate the basic design philosophy of sizing a new gear design.

Using an AGMA-developed software package to compare the ratings for gears by the ISO and AGMA methods shows how the AGMA and ISO standards differ as various parameters are changed.

The gear parameters studied include profile shift/addendum modification coefficient changes, helix angle changes and pressure angle changes. Since this comparison is for rating trends instead of actual ratings, they were normalized for each rating method. The article indicates how each rating standard could alter the design for the same gearbox.

This article is condensed from AGMA Paper 02FTM10, which was presented at the AGMA Fall Technical Meeting in St. Louis on October 22, 2002. Copies of the original paper are available from the American Gear Manufacturers Association, 500 Montgomery Street, Suite 350, Alexandria, VA 22314. Visit *www.agma.org*.

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currently the sole proprietor at Gear Consulting Services, has more than 40 years of experience in the gear industry. He was vice president of engineering at Cincinnati Gear Co. until 2001. He received an AGMA Technical Division award in 1982 and is now chairman of AGMA's epicyclic enclosed drives committee.

Many people have made comparisons of the differences in ratings between AGMA rating methods and ISO rating methods.

In 1977, G. Castellani (Ref. 1) was the first to point out that there was a difference in the rating trend on spur gears when you change from standard gears to those with a profile shift.

In an ASME paper (Ref. 2) presented in 1980 by Imwalle, LaBath, and Hutchenson, the comparisons of AGMA and ISO ratings for 54 different gear sets were studied. In some cases, large differences were calculated.

In an AGMA paper (Ref. 3) presented in 1981, LaBath compared the change in calculated stresses for three sample gear sets as a function of the profile shift and one sample as a function of the helix angle.

The above study on the difference in trends for corrected gears and different helix angles was included in another AGMA paper (Ref. 4) also presented in 1981, by Imwalle and LaBath along with a study on 156 gear sets.

In the latter two papers, Imwalle and LaBath showed that, with a positive profile shift, the strength rating increases in AGMA and ISO, but with different magnitudes. With a negative profile shift, the AGMA strength rating decreases and, depending on the gear geometry, the ISO strength rating can go down or sometimes remain almost constant. The durability ratings also had different trends for AGMA and ISO.

The comparisons in the three papers by Imwalle, LaBath, and Hutchenson were based on computer programs written at The Cincinnati Gear Co. for the then-current AGMA rating standards and the draft ISO standards. They were based on the interpretation of the various standards by the engineers at Cincinnati Gear.

In a 1989 AGMA paper (Ref. 5), Dr. Hosel also reported that the rating trends were different for AGMA and DIN (ISO) with respect to the effect of profile shift on the ratings.

In a 2002 paper prepared for NREL (Ref. 6), Robert Errichello compared the different rating trends for AGMA and ISO. The durability rating trend for AGMA and ISO with respect to profile shift was almost the same for a spur gear sample. The strength rating trend was significantly different for the spur gear example. Errichello showed that the trends for both the strength rating and the durability rating were different for a helical gear example. He also showed that there was a difference in trends from AGMA and ISO for variations in the pressure angle.

The comparisons made by Errichello were based on calculations made for AGMA by his Geartech AGMA 218 program package and for ISO by the ISO 6336 Gear Rating Program copyrighted by AGMA in 1997.

Calculation Method

The comparisons made in this paper will be based on calculations formulated from the AGMA copyrighted ISO 6336 program and the newly developed AGMA program for calculations per ANSI/AGMA 2001. These two programs are being released as "Gear Rating Suite by AGMA." Using these two programs to do the rating comparisons, the results are independent of any one individual's opinion or interpretation of either standard.

By using these programs, the input data for the gear geometry is the same for both the AGMA and the ISO ratings. This allows for a consistent trend analysis by only changing one gear geometry parameter while holding all of the other items constant within the program.

The focus of this paper is to show the trends of the two rating systems by varying specific geometry parameters one at a time. This paper is not trying to establish a "rating constant" between the two rating standards and should not be used as such.

Examples similar to the three from the 1981 AGMA papers will be re-examined to determine the rating trends with respect to changes in the profile shift. An example similar to Reference 4 will also be re-examined to determine the rating trends with respect to changes in the helix angle. Two examples will be added to investigate the differences in rating trends with respect to pressure angle for a spur gear set and a helical gear set.

We will rate the gears as carburized and hardened gearing ground to AGMA Class Q11. This is approximately ISO Class 6. We will use the upper life factor curves and rate the gearing for a life of 10,000 hours. The pinion speed will be set at 1,750 rpm. An input power of 250 hp (186.3 kW) is being used and the programs can calculate the factors of safety.

In each example, the first calculated factor of safety becomes the reference factor of safety. The other calculated factors of safety are then divided by the reference factor of safety to get the factor of safety trend value. In the tables, we are calling the factor of safety trend "FST." This is repeated for each rating item: pinion bending, gear bending, pinion durability, and gear durability. FST is calculated independently for AGMA and ISO. The factor of safety trend value is then plotted versus the factor being varied for each example.

Running the Rating Program

The tooling was specified as not having protuberance. The tooling tip was specified to be a full root radius or as large as the geometry would allow. No grind stock was specified. The surface finish was specified as 32 RMS for both the flank and the root fillet.

The leads were specified as having an ideal crown/correction with favorable tooth alignment. The gears were specified as commercial. The gear was specified as being a solid blank design. The bearing span was specified as being twice the face width. The gearing was centered in the bearing span. The ISO load distribution factor, KHbe, was calculated per method C1.

The AGMA gear quality was specified as 11. The ISO quality was specified as Class 8 for the pinion and Class 7 for the gear. The ISO dynamic factor was specified per method B. The reliability was specified as 99%. The stresses were for industrial application, the upper curve. A 1.0 application factor was used.

In AGMA, the strength ratings were calculated for the load applied at the HPSTC for the spur gear meshes.

Figure 1-1 Example #1 Pinion Bending

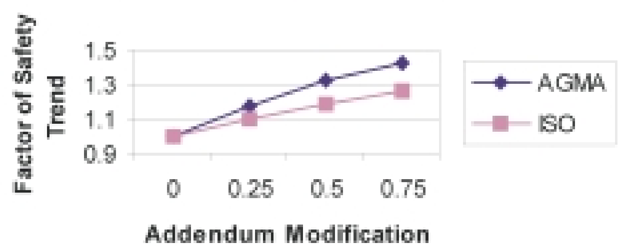


Figure 1-2 Example #1 Gear Bending

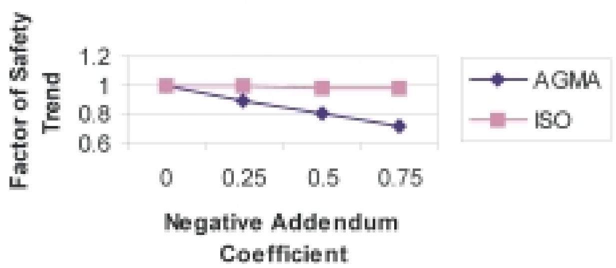


Figure 1-3 Example #1 Pinion Durability

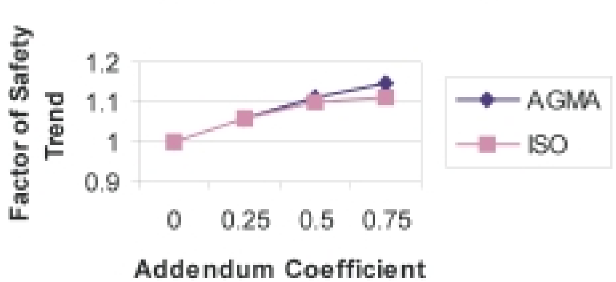
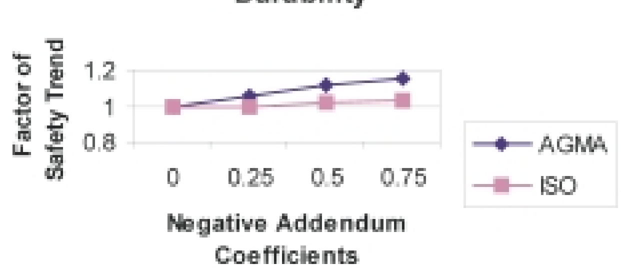


Figure 1-4 Example #1 Gear Durability



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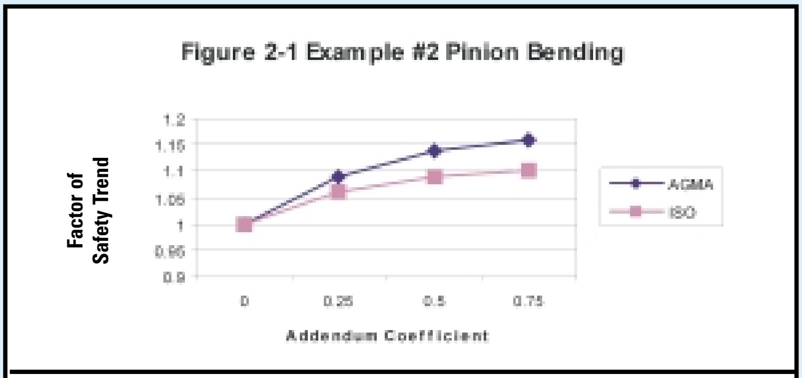
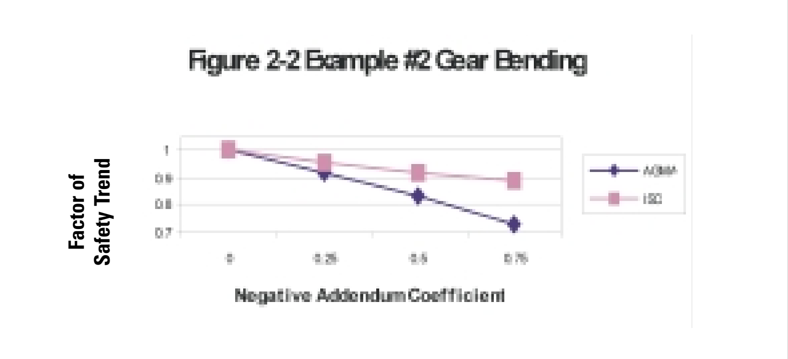
For ISO, a viscosity of 220 was specified.

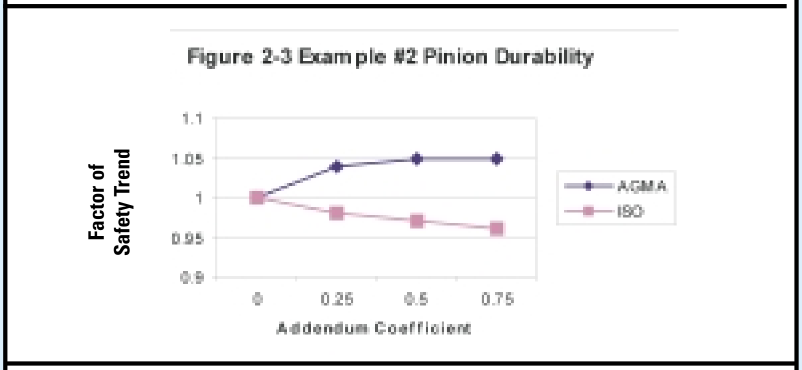
Again, the absolute ratings are not relevant to this study. The ratings calculated are consistent within the examples used, and the trend differences are real.

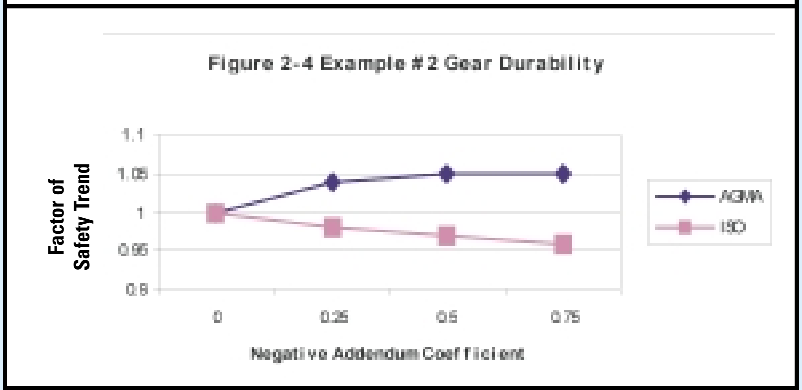
Example #1—Spur Gearing With Varying Profile Shift Coefficients

This example is a spur gear set operating on the standard center distance. The gear geometry is as follows:









21 teeth on the pinion
84 teeth on the gear
5 module (5.08 normal diametral pitch)
20° pressure angle
100 mm (3.939") face width
Standard hob proportions are being used
Center Distance = 262.5 mm (10.3346")

For this example, we will rate the gear set as a standard gear set and then rate it for increasing profile shifts or addendum modification coefficients on the pinion. The profile shift coefficient is as it is defined in the MAAG Handbook (Ref. 7).

Since the center distance is being maintained at the standard center distance, the rack shift coefficient for the gear has the same value as the rack shift coefficient for the pinion, but is positive on the pinion and negative on the gear.

The factors of safety have been normalized around the factors of safety for standard gearing and are plotted in Figures 1-1, 1-2, 1-3 and 1-4. As you can see, for this spur gear, both AGMA and ISO give an increased factor of safety for bending stress on the pinion when the addendum modification coefficient is increased. This is what would be expected since the tooth thickness increases as the addendum coefficient is increased. As the value of the positive addendum modification is increased, AGMA gives more of an increase in the factor of safety than does ISO.

In Figure 1–2, the addendum modification coefficient is negative. On this spur gear, AGMA gives a reduction in the factor of safety for bending when there is a negative addendum modification coefficient. As the value of the negative addendum modification coefficient is increased, AGMA gives a corresponding higher reduction in the factors of safety. This is what would be expected since the tooth thickness is reduced as the amount of the negative addendum modification is increased.

In ISO, for this spur gear, the factors of safety for bending are almost independent of the increasing negative addendum modification coefficient and the decreasing tooth thickness.

It is the goal of this paper to present the differences in the trends, not to explain the differences.

When there is a positive addendum modification coefficient, both AGMA and ISO calculate a higher factor of safety for durability on this spur pinion. As the value of the positive addendum coefficient is increased, the calculated factor of safety increases for both AGMA and ISO. With an almost extreme value of positive addendum modification coefficient, $x = 0.75$, AGMA gives a slightly higher increase than ISO.

Even though there is a negative addendum modification on the gear, both AGMA and ISO give an increase in the factors of safety for durability on this spur gear. The factor of safety is increasing with the growing value of negative addendum modification coefficient. The increases in the factors of safety are higher in AGMA than they are in ISO.

Example #2—Helical Gearing with Varying Rack Shift Coefficients

This example is a helical gear set operating on the standard center distance. The gear geometry is the same as that used in Example #1. The only difference is the helix angle. Due to the helix angle, the standard center distance is a little larger than that used with the spur gearing in Example #1. Center Distance = 271.76 mm (10.6992").

Again, we will rate the gear set as a standard model and then for increasing profile shift coefficients on the pinion and decreasing negative profile shifts on the gear.

The factors of safety have been normalized around the factors of safety for standard gearing and are plotted in Figures 2-1, 2-2, 2-3 and 2-4.

For this helical pinion, both AGMA and ISO give an increased factor of safety for bending stress on the pinion when the addendum modification coefficient is increased. Similar to the spur pinion example, as the value of the positive addendum modification is increased, AGMA gives more of an increase in the factor of safety than ISO.

On the gear, the addendum modification coefficient is negative. On this helical gear, both AGMA and ISO give a reduction in the factor of safety for bending when there is a negative addendum modification coefficient. As the value of the negative addendum modification coefficient is increased, both AGMA and ISO give a corresponding higher reduction in the factors of safety. The reduction in the factors of safety for bending by ISO is less than that from AGMA.

When there is a positive addendum modification coefficient on the pinion, AGMA calculates a higher factor of safety for durability on this helical pinion. As the value of the positive addendum coefficient is increased, the factor of safety calculated increases for AGMA. Here, ISO is calculating a reduction in the factor of safety for durability on this helical pinion. As the addendum modification coefficient is increased, the ISO calculated factor of safety actually reduces. Even for $x = 0.75$, the differences in the factors of safety are less than 5% for both rating systems compared to a standard pinion.

Figure 3-1 Example #3 Pinion Bending

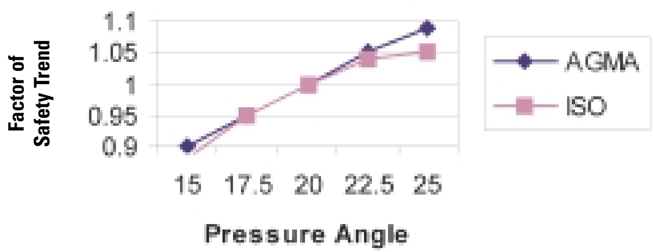


Figure 3-2 Example #3 Gear Bending

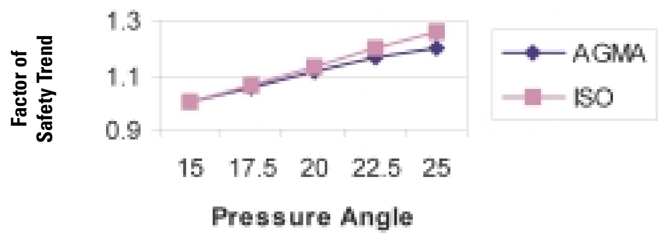


Figure 3-3 Example #3 Pinion Durability

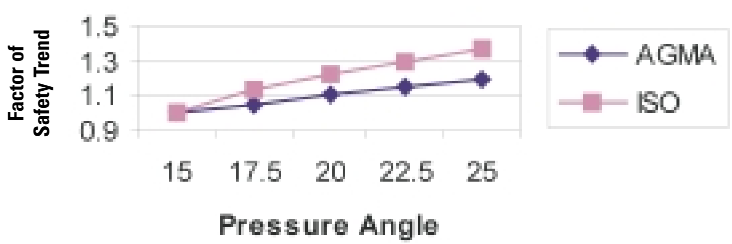


Figure 3-4 Example #3 Gear Durability

Similar to the spur gear example, even though there is a negative addendum modification on the gear, AGMA gives an increase in the factors of safety for durability on this helical gear. The factor of safety is increasing as is the increasing value of the negative addendum modification coefficient. In ISO, there is a decrease in the factor of safety for this helical gear when there is a negative addendum modification coefficient. As the value of the negative addendum coefficient is increased, there is a corresponding decrease in the factor of safety. Again, the differences are less than 5% compared to a standard gear.

Example #3—Spur Gearing With Varying Pressure Angle

This example is a spur gear set. The gear set is a standard gear set. With the exception of the pressure angle, everything else is the same as in Example #1 when the profile shift coefficient was 0.

Here, we will rate the gear set using pressure angles that vary from 15–25°. All other gear geometry is being kept constant.

It is interesting to note that we were able to run both rating programs for the 15° and 17.5° pressure angles even though a simple calculation indicates that the 21-tooth pinion will have undercut for these two conditions. The AGMA rating program does print out a warning that the pinion may have undercut for both of these pressure angles. The bending ratings below 20° pressure angles are probably not correct. For this reason, we are making the 20° pressure angle rating the reference rating in bending.

For durability, the 15° pressure angle rating is the reference rating.

The factors of safety have been normalized and are plotted in Figures 3-1, 3-2, 3-3 and 3-4.

The trends of the factors of safety in bending with respect to pressure angle are very close to being the same for AGMA and ISO on this spur pinion and the spur gear. AGMA does give a slightly higher factor of safety than ISO as the pressure angle is increased above 20°.

The trends of the factors of safety in durability with respect to pressure angle are the same for AGMA and ISO on this spur pinion. The increase in factor of safety is slightly higher in ISO than in AGMA.

The trends of the factors of safety in durability with respect to pressure angle are in the same direction for AGMA and ISO on this spur gear. The increase in factor of safety is significantly more in ISO than in AGMA.

Figure 4-1 Example #4 Pinion Bending

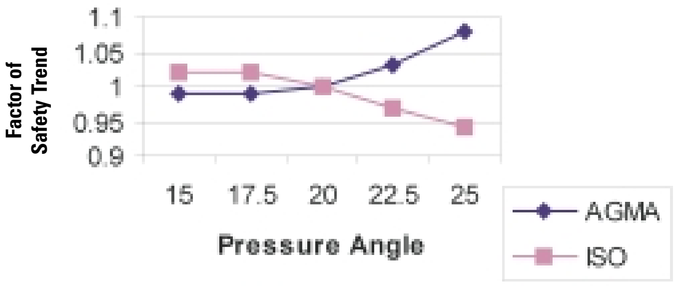


Figure 4-2 Example #4 Gear Bending

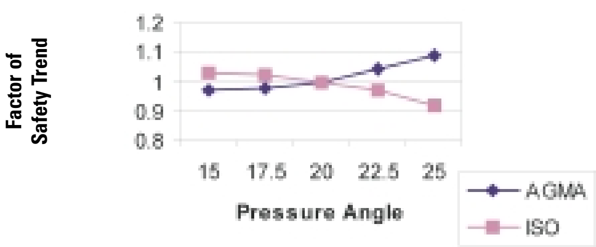


Figure 4-3 Example #4 Pinion Durability

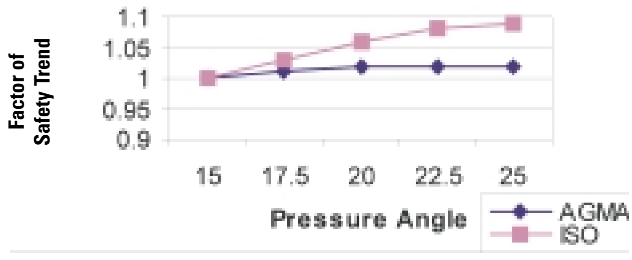
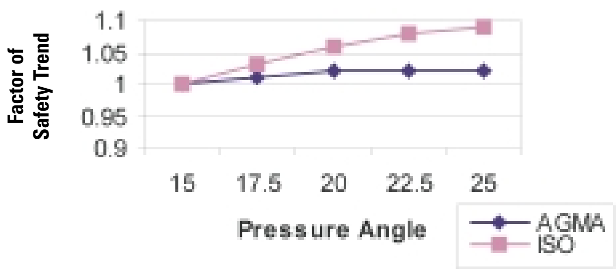


Figure 4-4 Example #4 Gear Durability



Example #4—Helical Gearing With Varying Pressure Angle

This example is a helical gear set. The gear set is a standard gear set. With the exception of the pressure angle, everything else is the same as that in Example #2 when the profile shift coefficient was 0.

Again, we will rate the gear set using pressures angles that vary from 15–25°. All other gear geometry is being kept constant.

As in the spur gear example, we were able to run both rating programs for the 15° and 17.5° pressure angles, even though a simple calculation indicates that the 21-tooth pinion will have undercut for these two conditions. The AGMA rating program did print out a warning that the pinion may have undercut for 15°. Again, the bending ratings below 20° pressure angles are probably not correct. Here, we are again making the 20° pressure angle rating the reference rating for bending.

For durability, the 15° pressure angle rating is the reference rating.

The factors of safety have been normalized and are plotted in Figures 4-1, 4-2, 4-3, and 4-4.

With an increase in the pressure angle, AGMA gives an increase in the factors of safety for bending on this helical pinion while ISO gives a decrease in the factors of safety for bending on this helical pinion.

In addition, with an increase in the pressure angle, AGMA gives an increase in the factors of safety for bending on this helical gear while ISO actually gives a reduction in the factors of safety.

For both the pinion and the gear in this helical gear set, as the pressure angle is increased, both AGMA and ISO give an increase in the factors of safety for durability. The increase in ISO is greater than the increase in AGMA.

Example #5—Helical Gearing With Varying Helix Angles

This example is a helical gear set. The numbers of teeth, module/pitch, pressure angle, and face width are the same as in Example #2. The only difference is that the helix angle will be varied from a spur gear (0° helix angle) to a helix angle of 30°. Due to the helix angle variation, the standard center distance for each gear set will be different.

We will rate the gearing for each of the different helix angles and the corresponding standard center distance. All other gear geometry is kept constant.

Below 9.0°, the helical gear sets have a helical overlap or face contact ratio less than 1.0. At 9.5° or higher the face contact ratio is greater than 1.05.

Note that as the helix angle increases, the standard center distance increases. At the higher helix angles, the center distance increases become more significant. From 0–5°, the center distance changes only 0.28%. From 25–30°, the center distance changes 4.65%.

The factors of safety have been normalized and have been plotted in Figures 5-1, 5-2, 5-3, and 5-4.

AGMA has two curves for the factor of safety with respect to the helix angle. Below the value where the helix angle is large enough to have a helical overlap or face contact ratio greater than 1.0, AGMA calculates a progressively higher factor of safety for bending as the helix angle is increased on both the pinion and the gear in this helical gear set. ISO also has two curves, but the distinction is very small. In ISO, the factors of safety for both the pinion and the gear are lower for a helical gear than for a spur gear until the helix angle reaches 15° on this sample gear set. In AGMA, the factors of safety for bending on both the pinion and the gear in this gear set are lower between the value for the helix angle that has a helical overlap greater than 1.0 and a helix angle of 15°.

Similar to the bending study, AGMA has two curves for the factor of safety with respect to the

Figure 5-1 Example #5 Pinion Bending

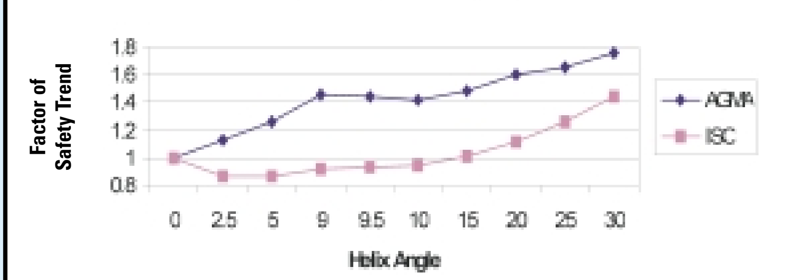


Figure 5-2 Example #5 Gear Bending

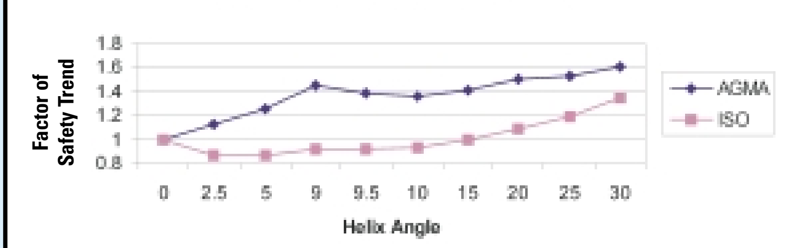


Figure 5-3 Example #5 Pinion Durability

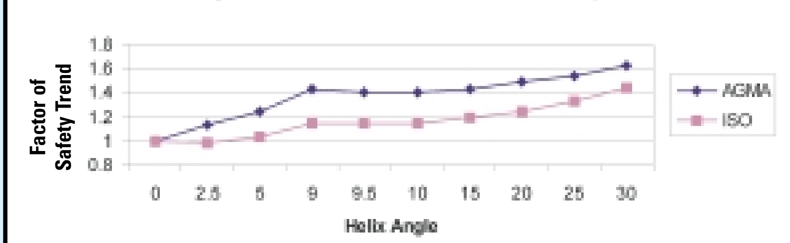
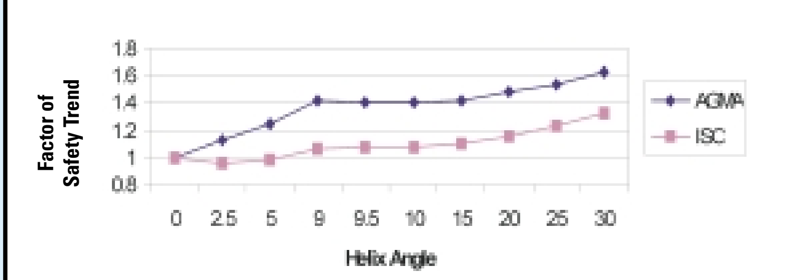


Figure 5-4 Example #5 Gear Durability



helix angle for durability. Below the value where the helix angle is large enough to have a helical overlap or face contact ratio greater than 1.0, AGMA calculates a progressively higher factor of safety for durability as the helix angle is increased on both the pinion and the gear in this helical gear set. ISO also has two curves, but the distinction is very small. In ISO, the factor of safety for both the pinion and the gear is again lower for a helical gear than for a spur gear until the helix angle reaches about 5°, which is about half of the value where the helical overlap ratio is greater than 1.0. In AGMA, the factor of safety for durability on both the pinion and the gear in this set is lower between the value for the helix angle that has a helical overlap greater than 1.0 and a helix angle of 15°.

Because the center distance increases when the helix angle increases, the rating differences are influenced by both the helix angle changes and the increases in sizes for the gearing. For this reason, a new example was developed where the center distance was held constant when the helix angle was changed. This required that the transverse pitch/module be kept constant. This requires that the normal pitch/module be changed when the pressure angle changes.

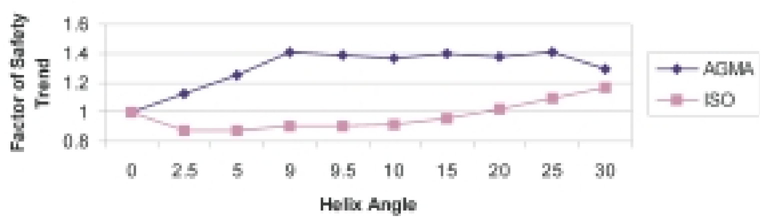


Figure 6-1 Example #6 Pinion Bending

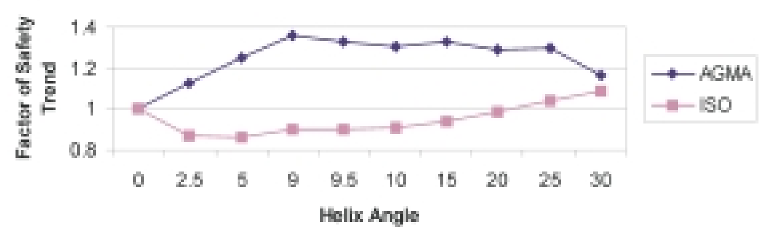


Figure 6-2 Example #6 Gear Bending

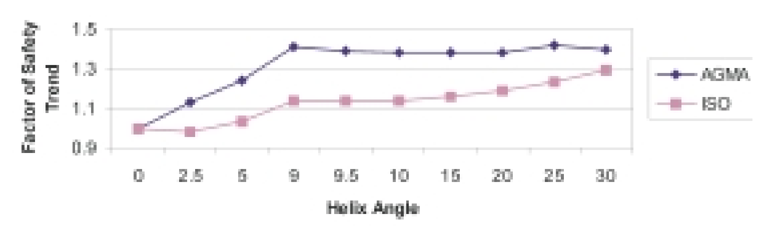


Figure 6-3 Example #6 Pinion Durability

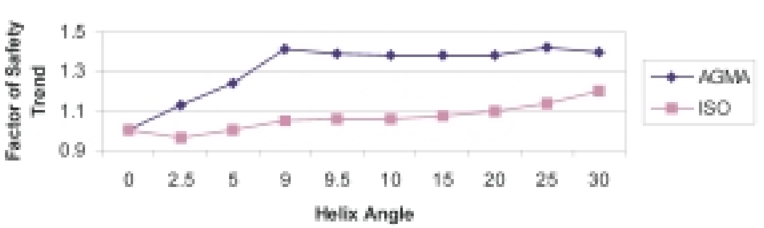


Figure 6-4 Example #6 Gear Durability

Example #6—Helical Gearing With Varying Helix Angles

This example is also a helical gear set. The numbers of teeth, transverse module/pitch, pressure angle, center distance, and face width are the same as in Example #2. The only difference is that the helix angle will be varied from a spur gear (0° helix angle) to a helix angle of 30°. To maintain the same transverse pitch/module and center distance, the normal pitch/module will be changed as required.

We will rate the gearing for each of the different helix angles and the corresponding normal pitch/module. All other gear geometry is being kept constant.

Again, below 9°, the helical gear sets have a helical overlap or face contact ratio less than 1.0. At 9.5° or higher, the face contact ratio is greater than 1.05.

The factors of safety have been normalized around the rating for a spur gear and have been plotted in Figures 6-1, 6-2, 6-3 and 6-4.

In AGMA, for bending on this helical pinion, as the helix angle varies from 0° to the helix angle that has a helical overlap greater than 1.0, the factor of safety increased significantly. From the helix angle where the helical overlap is greater than 1.0 to a helix angle of 25°, the AGMA factor of safety is almost independent of the helix angle. Above 25°, the factor of safety goes down with an increase in the helix angle. In ISO, the factor of safety for a helical gear is less than that of a spur gear until the helix angle is greater than 15°. In ISO, the factor of safety increases with an increasing helix angle if you do not consider the spur gear case.

For bending on this helical gear, as the helix angle varies from 0° to the helix angle that has a helical overlap greater than 1.0, the factor of safety increased significantly. From the helix angle where the helical overlap is greater than 1.0 to a helix angle of 25°, the AGMA factor of safety tends to be reduced with an increase in the helix angle. Above 25°, the factor of safety goes down at a steeper slope with an increase in the helix angle. In ISO, the factor of safety for a helical gear is less than that of a spur gear until the helix angle is greater than 20°. In ISO, the factor of safety increases with an increasing helix angle if you do not consider the spur gear case. Above a 15° helix angle, the ISO factor of safety increases as the helix angle is increased and at a steeper slope.

In AGMA, for durability on this helical pinion, as the helix angle increases from 0° to the helix angle that has a helical overlap greater than 1.0, the factor of safety increased significantly. Above the helix angle where the helical overlap is greater than 1.0 to a helix angle of 25°, the AGMA factor of safety is almost independent of the helix angle. Above 25°, the factor of safety goes down with an increase in the helix angle. In ISO, the factor of safety for a helical gear is less than that of a spur gear at a low helix angle. The ISO factor of safety increases with an increase in the helix angle. The increase is greater until the helix angle reaches the value where the helical overlap ratio is greater than 1.0. The ISO factor of safety continues to increase but at a lower slope above the point where the helical overlap is greater than 1.0. Both AGMA and ISO have two distinct curves, one below where the value of the helix angle is such that the helical overlap is greater than 1.0 and another curve above that helix angle value.

For durability on this helical gear, as the helix angle increases from 0° to the helix angle that has a helical overlap greater than 1.0, the AGMA factor of safety increased significantly. Above the helix angle where the helical overlap is greater than 1.0 to a helix angle of 25°, the AGMA factor of safety is almost independent of the helix angle. Above 25°, the AGMA factor of safety goes down with an increase in the helix angle. In ISO, the factor of safety for a helical gear is less than that of a spur gear at a low helix angle. The ISO factor of safety increases with an increase in the helix angle with a greater increase until the helix angle reaches the value where the helical overlap ratio is greater than 1.0. From the point where the helical overlap ratio is greater then 1.0 until 15°, the ISO factor of safety for durability on the gear is almost independent of the helix angle. Above 20°, the increase in factor of safety is at a steeper slope.

Both AGMA and ISO have two distinct curves, one below where the value of the helix angle is such that the helical overlap is greater than 1.0 and another curve above that helix angle value.

Conclusions

The purpose of this paper is to show the differences in the rating trends between the ISO and AGMA rating standards by independently varying specific gear parameters. The parameters chosen are those that have the most significant effects on ratings that consequently are quite often adjusted by gear designers to achieve optimized designs. It is beyond the scope and was not the intent of this article to point out the specific reasons for the differences between each of these trends. However, it is quite evident that the two standards differ for many of the examples shown. These trends show that there is a discrepancy between how the two rating systems handle changes in profile shift (tooth thickness), pressure angle, and helix angle.

Although this information should be of little surprise to many who have worked often with these two rating systems, hopefully this paper reveals these differences to those who may only be familiar with one of the two standards. It highlights the need for further investigation into why these differences exist and to eventually resolve them.

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