

New ANSI/AGMA Accuracy Standards for Gears

Edward Lawson

Management Summary

AGMA has started to replace its 2000-A88 standard for gear accuracy with a new series of documents based largely on ISO standards. The first of the replacement AGMA standards have been published with the remainder coming in about a year. After serving as a default accuracy specification for U.S. commerce in gear products for several decades, the material in AGMA 2000-A88 is now considered outdated and in need of comprehensive revision.

Important changes include reversal of the accuracy grade system (larger grade numbers now mean larger tolerances), introduction of tolerances based on ISO 1328, new line-fit methods of analyzing helix (lead) and profile test traces, and the inclusion of single-flank composite testing as an optional alternative method of qualifying gears. Enhanced descriptions of required measurement methods are provided to reduce ambiguity and the associated potential for controversy.

Underlying these changes is the important transition from reliance upon local standards, such as AGMA, DIN, JIS, BGA, etc., to international adoption of ISO standards, which are now positioned to become the default specifications for global commerce in gear products.

Time for a Change

For many years, the U.S. system of gear accuracy tolerances has been provided by AGMA 2000-A88, *Gear Classification and Inspection Handbook*. This document has been commonly used for gear accuracy specifications in contractual agreements for vendor-supplied gears. Also, it has often been used as the basis of internal company gear tolerance systems.

The material within AGMA 2000-A88 has been carried forward without substantial change for nearly 40 years. It is widely considered to be outdated and in need of comprehensive revision, particularly with respect to the following issues:

- 1.) Lead tolerances in 2000-A88 are substantially larger than those found in other national gear accuracy standards.
- 2.) The standard lacks tolerances for cumulative pitch (a.k.a. index) deviations.
- 3.) The K-shaped tolerance band method provided in 2000-A88 for control of involute profile and helix (a.k.a. lead or tooth alignment) deviations is less desirable than line-fit tolerance methods found in other national gear accuracy standards.

Recognizing that the standard was overdue for

revision, the AGMA Inspection Handbook Committee developed a new suite of replacement documents. The first three of these new standards was published about a year ago. After the remaining documents are published in about a year, AGMA 2000-A88 will be withdrawn. Consequently, it is very important to understand the coming changes.

The ISO Connection

In recent years, AGMA technical standards development has increasingly focused upon achieving harmony with ISO gear standards. The AGMA Technical Division Executive Committee (TDEC) now requires technical committees to consider adoption of relevant ISO standards, wherever possible, instead of writing new AGMA documents. Also, it is required that all new standards produced by AGMA committees be in SI (metric) units of measure.

These changes are seen by the AGMA as an important element in its increasing emphasis on assuring the competitiveness of the U.S. gear industry in the rapidly evolving world marketplace. With make/buy decisions becoming an increasingly prevalent issue for gear product users, selection of a genuinely international gear accuracy standard is increasingly attractive.

Given the international makeup of ISO standards writing committees, their documents are viewed as inherently global in nature. The importance of ISO gear standards is expected to increase substantially in coming years. An example of the potential power of ISO standards can be seen in the widespread adoption of ISO 9000 standards.

Accordingly, existing ISO gear accuracy standards and technical reports were used as starting templates, along with selected material from current AGMA standards, in the development of the new ANSI/AGMA standards. Also, AGMA hopes that much of the new material in its new accuracy standards will gain acceptance for inclusion in the next-generation ISO standards.

Organization of Material

AGMA 2000-A88 combined all of the materi-

al for measuring and tolerancing gears in a single document. The new AGMA accuracy standards segregate the material into four main documents, following the organization of the analogous ISO documents.

Topics are divided according to tangential (single-flank) vs. radial (double-flank) considerations. Additionally, material is presented in either: 1.) a standard limited to definitions, the tolerance system, and required related information; or 2.) an information sheet containing measuring methods and other helpful information (referred to as a technical report in ISO).

The existing ISO and new AGMA gear accuracy documents correlate as shown in Figure 1.

Current Status of New Standards

In late 2002, the new tangential accuracy standard ANSI/AGMA 2015-1-A01, *Accuracy Classification System—Tangential Measurements for Cylindrical Gears*, was published. It provides the tolerance system for profile, helix, pitch (single and cumulative), and single-flank composite deviations.

In early 2003, the associated tangential accuracy information sheet AGMA 915-1-A02, *Inspection Practices—Part 1: Cylindrical Gears—Tangential Measurements*, was published. It provides the required measurement methods and supplementary guidance.

In mid-2003, an additional document, Supplemental Tables for AGMA 2015/915-1-A02, *Accuracy Classification System—Tangential Measurement Tolerance Tables for Cylindrical Gears*, was published. Since 2015-1 tolerances are provided in the form of equations, many users were asking for a set of tables, which are more convenient for quick reference. However, it must be noted that most tolerance equations are non-linear, so interpolation between table values will not produce accurate tolerance values.

A tolerance calculation program for ANSI/AGMA 2015-1-A01 has also been produced that provides a quick, easy way to accurately determine tolerances for a given gear. It is available free in the members-only section of the AGMA website.

The Inspection and Handbook Committee is currently developing a new standard, ANSI/AGMA 2015-2-AXX, and associated information sheet, AGMA 915-2-AXX, pertaining to radial (primarily double-flank composite) accuracy specifications.

Once the radial accuracy documents are published, the AGMA intends to withdraw AGMA

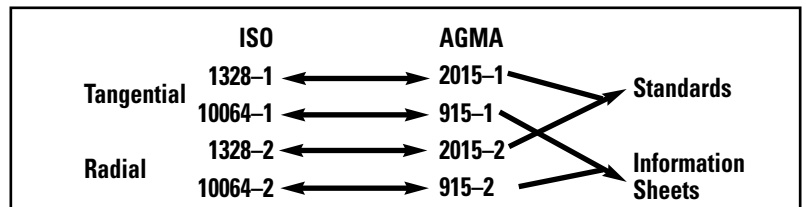


Figure 1—Correlation of existing ISO and new AGMA gear accuracy documents.

2000-A88 as an active standard. It will, however, continue to be available for sale for the foreseeable future.

The New Accuracy Grade System

AGMA 2000-A88 includes 13 quality classes numbered Q3 through Q15, in order of increasing precision. ANSI/AGMA 2015-1-A01 provides 10 accuracy grades numbered A2 through A11, in order of *decreasing* precision. In other words, the smaller the accuracy grade number in the new standard, the smaller the tolerances. While this is the opposite of the structure of 2000-A88, it follows the convention of all other major gear accuracy standards.

This difference inevitably raises questions as to how one can compare tolerance grades between old and new AGMA standards. It is never really valid to compare accuracy grades from one standard to another. The old “apples & oranges” analogy inevitably applies, owing primarily to the differences in test analysis methods and tolerance curves. This having been said, it can be recognized that a rough approximation can often be made of the relationship between accuracy grades provided by different standards.

For comparison of the old AGMA (2000-A88) to the new ANSI/AGMA (2015-1-A01, etc.) standards, use of the “magic number” 17 is suggested. By this method, the tolerance grade of a given standard can be subtracted from 17 to produce a roughly corresponding accuracy grade for the other standard. For example, an AGMA 2000-A88 class Q10 could be considered roughly equivalent to a grade A7 in ANSI/AGMA 2015-1-A01.

Continuing a concept developed for the ANSI/AGMA 2009-A99 bevel gear accuracy standard, required measuring methods in ANSI/AGMA 2015-1-A01 are determined by the specified accuracy grade. This involves first segregating accuracy grades into three groups, generally termed low (A10–A11), medium (A6–A9), and high (A2–A5) accuracy. Each group then has a list of required accuracy parameters to be met for qualification of the gear.

As accuracy increases, the list of required parameters grows. This is not unlike AGMA 2000-A88, which for lower classes required only

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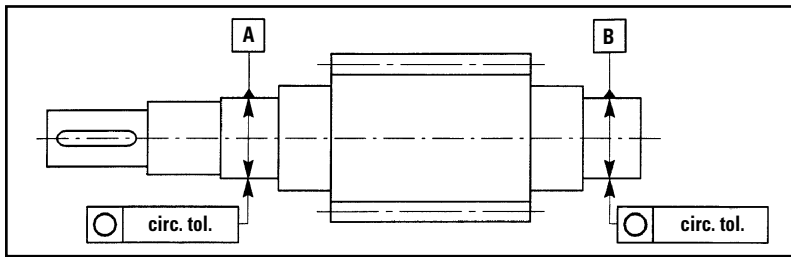


Figure 2—Guidance for proper specification of gear datum axis is provided in AGMA 915-3-A99.

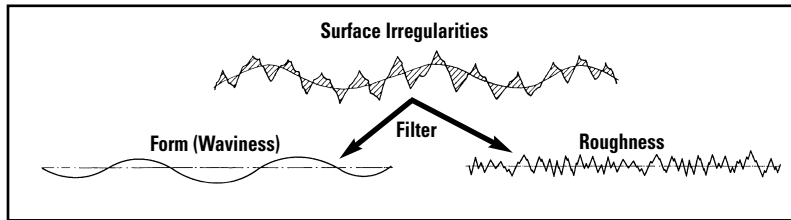


Figure 3—Low-pass filtering is required to segregate and remove high-frequency surface finish effects.

pitch and runout.

Included in the low accuracy group are only single pitch, total cumulative pitch, and tooth thickness parameters. The medium accuracy group adds total helix and total profile parameters. The high accuracy group additionally requires slope and form parameters for helix and profile. Functional/composite methods are offered as optional alternatives.

The Tolerance Structure

The tolerance structure of the new ANSI/AGMA standards is very similar to those provided in the ISO standards.

One point of significant deviation occurs in the case of single pitch and total cumulative pitch tolerances applied to gears at or below 400 mm in diameter. In these cases, the tolerance curves have been straightened to avoid the excessive slope of the ISO tolerance curve at smaller diameters.

While the tolerances in ANSI/AGMA 2015-1-A01 are based on ISO 1328 formulas, they are implemented in a significantly different manner. ISO tolerance formulas require entry of gear parameters (including module, diameter, and face width) as the geometric mean of the associated table range limits rather than as the actual values. The result is a tolerance identical to that listed in the tolerance table. A proper plot of ISO tolerance curves therefore looks like a series of stair steps rather than a continuous curve.

ANSI/AGMA 2015-1-A01 specifies entry of *actual* gear parameter values, thereby producing a smooth tolerance curve. This is the same method specified in AGMA 2000-A88.

Another way to look at this is to say that, according to ISO the standard tolerances are pro-

vided in tables with formulas offered to permit their calculation (by tortured means), while according to ANSI/AGMA the standard tolerances are provided by formulas with tables offered for convenient approximations.

The stepping factor is the factor by which tolerances increase with each increase in accuracy grade number. The stepping factor for both AGMA 2000-A88 and ANSI/AGMA 2015-1-A01 (and also ISO 1328) is the square root of 2 or approximately 1.4, thereby providing a 40% change in tolerance from grade to grade. So, for example, if a grade A5 tolerance for a given gear was 10 μm , the same gear with a grade A6 specification would have a tolerance 1.4 times larger, or 14 μm .

It is generally agreed that the new ISO-based ANSI/AGMA 2015-1-A01 tolerance system achieves significantly better internal coherence than its predecessor, AGMA 2000-A88. The relatively tighter lead tolerances included in the new system are an important contributor to this improvement. ANSI/AGMA 2015-1-A01 tolerances correlate very well with those found in other major national standards.

As is the case with all major gear accuracy standards except AGMA 2000-A88, ANSI/AGMA 2015-1-A01 includes tolerances on total cumulative pitch.

The new ANSI/AGMA 2015-1-A01 standard is limited as to scope of application. The overall limitations apply as follows:

number of teeth	$5 \leq z \leq 1,000$ or $10,000/m_n$ (whichever is less)
pitch diameter	$5 \text{ mm} \leq D \leq 10,000 \text{ mm}$
normal module	$0.5 \leq m_n \leq 50$
face width	$4 \text{ mm} \leq b \leq 1,000 \text{ mm}$
helix angle	$\beta \leq 45^\circ$

Additionally, scope-of-application limitations are specified for the individual tolerance parameters.

These scope limits of ANSI/AGMA 2015-1-A01 are generally equivalent to those specified in AGMA 2000-A88. Notable exceptions to this generality include the extension of elemental tolerances to finer pitches and lower accuracy grades and the inclusion of face widths up to one meter.

Profile and Helix Analysis

The AGMA 2000-A88 standard specifies tolerances for profile test results using a particular K-shaped tolerance band. For a gear to be considered acceptable, each profile test trace must fit within this specified tolerance band, which applies to the full active, unmodified portion of the gear tooth.

The K-shaped band applies the full tolerance at the extreme ends but tapers to provide only 50% tolerance at the middle. The same method is applied to tolerances for helix (tooth alignment) deviations.

There are three significant limitations to the band-fit method of tolerancing profile or helix traces.

The first is that any trace that fits in the band is acceptable and any trace that fails to fit in the band is rejected. It is easy to visualize examples of test traces fitting within a K-shaped band that would not be acceptable for use in given applications and vice versa.

The second limitation of band tolerancing is that any band infers a nominal that may not be the desired nominal. Consider the AGMA band, which infers a nominal situated midway between the maximum and minimum limits of the tolerance band (as is the case for all band tolerances of whatever shape). This inferred nominal is convex by 25% of the tolerance due to the K-shape of the band. However, this is clearly in opposition to the intent of the standard, which applies only to unmodified forms.

The third and possibly the most significant limitation of the band method of tolerancing is that it only serves as a go/no go observation of gear quality. Ideally, gear measurement operations serve to provide data for process control as well as sorting accepted from rejected workpieces. Band analysis provides no variable data to consider statistically or by other analytical means.

The new ANSI/AGMA 2015-1-A01 standard uses a fundamentally different analysis method commonly referred to as line-fit analysis. A key characteristic of this method is the specification of a design profile or helix. This permits the gear engineer to unambiguously specify the shape that he considers ideal for the application at hand. In the absence of such a specification, the standard defaults to an unmodified involute or helix.

Three tolerance parameters are specified for profile and helix analysis: total deviation, slope deviation, and form deviation. Total deviation analysis is only required for medium and high accuracy specified gears. Slope and form deviation analysis is also required for high accuracy gears.

Slope deviation represents the tilt deviation of the test trace, exclusive of its form (or shape) deviation. Form deviation represents the shape deviation, exclusive of its slope (or tilt) deviation. Total deviation represents the combined net effects of both the slope and form deviations of the test trace.

In contrast with the AGMA 2000-A88 go/no go

method of band-fit analysis, the ANSI/AGMA 2015-1-A01 line-fit methods produce variables that can be applied to observation of process performance.

Slope deviations of profile or helix are given a plus or minus polarity. In the ANSI/AGMA 2015-1-A01 standard, profile slope is considered plus when the trend corresponds with a decrease in pressure angle (increase in base diameter). Helix slope in this standard is considered plus when the helix angle is increased (decrease in lead).

Reduced Ambiguity

It is unfortunately common for gear accuracy standards to inadequately address important metrology issues that can have substantial influence upon measurement test results and associated accept/reject decisions. ANSI/AGMA 2015-1-A01 and AGMA 915-1-A02 have been written to minimize such ambiguities and associated confusion and controversy.

First on this list is the obligation to specify the datum axis of the given gear, without which the nominal geometry of the gear teeth cannot be defined. Commonly, this is based upon bearing surfaces that establish the gear's axis of rotation in assembly. Reference is made to information sheet AGMA 915-3-A99, which provides detailed guidance concerning proper specification of the datum axis (see Fig. 2).

The ANSI/AGMA 2015-1-A01 standard specifies a tolerance diameter, which is the probe contact diameter during helix and pitch testing. It is also required information for proper management of direction of measurement issues.

Profile and helix traces are usually low-pass filtered to remove the effects of surface roughness before presentation and analysis, as shown in Figure 3. It is not common for the filtering method or the filter cutoff (the dividing line between wavelengths that are kept and those that are discarded) to be specified. ANSI/AGMA 2015-1-A01 recommends use of the digital Gaussian filter. Filter cutoffs are specified for both profile and helix test traces.

Minimum density of digital data is required for proper implementation of the specified profile and helix filter cutoffs. ANSI/AGMA 2015-1-A01 also specifies minimum measurement data densities to assure that proper digital filtering can be achieved.

ANSI/AGMA 2015-1-A01 does not specify the direction of measurement probe deflection during testing, but requires that it be known. This

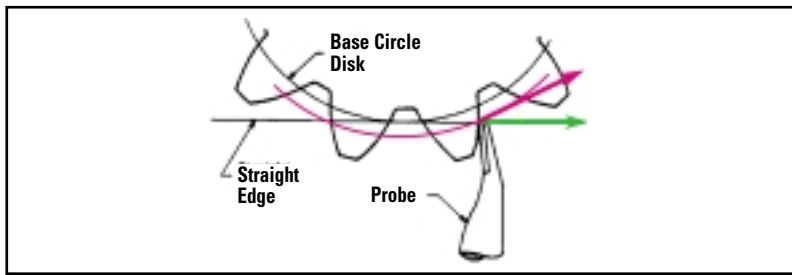


Figure 4—Direction of measurement can affect measurement results and accept/reject decisions.

Master Gear Grades	Required for	Test Gear Grades
Grade 2	→	Grades 4–5
Grade 3	→	Grades 6–7
Grade 4	→	Grades 8 and higher

Figure 5—Recommended master gear accuracy grades for given test gear accuracy grades.

measurement direction is needed for proper application of data corrections that may be required prior to reporting results and comparison to tolerances (see Fig. 4).

ANSI/AGMA 2015-1-A01 does specify a direction of tolerancing for each accuracy parameter. Measurements made or reported in other directions must be adjusted to the specified direction of tolerancing before comparison to tolerances and determination of gear conformance.

Measurement Process Calibration

Calibration is the process of evaluating the limits of validity of data coming from a given measurement process. Gear measurement processes are usually calibrated using master gear artifacts. Without current calibration reports issued by an accredited laboratory stating the measurement uncertainty of the calibration measurement process, master artifacts are of no value for measurement process calibration, measurement uncertainty estimation, or establishment of traceability.

The ANSI/AGMA 2015-1-A01 standard recommends periodic verification of elemental gear measuring instruments, according to standard calibration procedures, such as those provided in ANSI/AGMA 2110-A94 (for involute profile), ANSI/AGMA 2113-A97 (for helix), and ANSI/AGMA 2114-A98 (for pitch and runout). Further, determination of measurement process uncertainty is recommended.

Master Gears

Master gears are required for single- and double-flank composite action testing. They are subject to wear and damage and must be recalibrated

periodically. Master gear calibration reports are required by ANSI/AGMA 2015-1-A01 to include statements of measurement conditions and the measurement uncertainty for each parameter reported.

For accuracy tolerance purposes, master gears are simply defined in ANSI/AGMA 2015-1-A01 as those meeting accuracy grade 4 and better. Minimum master gear accuracy grades are recommended for test gear accuracy grades, as shown in Figure 5.

Properly calibrated master gears can provide an attractive reference for calibration of elemental gear measuring instruments, instead of special purpose reference artifact fixtures. When such master gear reference artifacts are very similar to subsequent pieces to be tested by the measurement process, resulting measurement uncertainty may be significantly reduced.

Single-Flank Composite Action Testing

New tolerances for total and tooth-to-tooth single-flank composite deviation along with associated support material are provided in ANSI/AGMA 2015-1-A01. It is listed as an acceptable alternative method for qualification of gear accuracy.

This standard requires removal of the effects of eccentricity before analysis of tooth-to-tooth single-flank composite deviations.

Conclusion

It is important to understand the fundamental changes coming with the new AGMA standards. Given the approaching withdrawal of AGMA 2000-A88, an increasing number of gears will be specified according to the replacement documents.

It is possibly more important to understand the increasing AGMA focus on ISO standards development. It appears that, in coming days, ISO documents will provide the default specifications for global commerce in gear products.

Review of the progressive revisions incorporated into the new AGMA standards should provide valuable insight into important trends in gear accuracy specifications. ⚙️

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