American
Gear Manufacturers
Association

ANSI/AGMA 2003-D19
(Revision of ANSI/AGMA 2003-C10)

**American National Standard**

# Rating the Pitting Resistance and Bending Strength of Generated Straight Bevel, Zerol Bevel and Spiral Bevel Gear Teeth

ANSI/AGMA 2003-D19

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***Rating the Pitting Resistance and Bending Strength of Generated Straight Bevel, Zerol Bevel and Spiral Bevel Gear Teeth***

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[Revision of ANSI/AGMA 2003-C10]



Approved May 14, 2019

**ABSTRACT**

This standard specifies a method for rating the pitting resistance and bending strength of generated straight bevel, zerol bevel and spiral bevel gear teeth. A detailed discussion of factors influencing gear survival and a calculation method are provided.

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## Foreword

[The foreword, footnotes and annexes, if any, in this document are provided for informational purposes only and are not to be construed as a part of ANSI/AGMA Standard 2003-D19, *Rating the Pitting Resistance and Bending Strength of Generated Straight Bevel, Zerol Bevel and Spiral Bevel Gear Teeth*.]

This standard presents general formulas for rating pitting resistance and bending strength of generated straight bevel, zerol bevel and spiral bevel gear teeth, and supersedes the following previous standards:

AGMA 212.02, *Standard for Surface Durability (Pitting) Formulas for Straight Bevel and Zerol Bevel Gear Teeth*

AGMA 216.01, *Standard for Surface Durability (Pitting) Formulas for Spiral Bevel Gear Teeth*

AGMA 222.02, *Standard for Rating the Strength of Straight Bevel and Zerol Bevel Gear Teeth*

AGMA 223.01, *Standard for Rating the Strength of Spiral Bevel Gear Teeth*

The purpose of standard 2003-A86 was to establish a common base for rating various types of bevel gears for differing applications and to encourage the maximum practical degree of uniformity and consistency between rating practices within the gear industry.

The formulas presented in this standard contain numerous terms whose individual values can vary significantly depending on application, system effects, accuracy and manufacturing method. Proper evaluation of these terms is essential for realistic rating. The knowledge and judgment required to properly evaluate the various rating factors come primarily from years of accumulated experience in designing, testing, manufacturing and operating similar gear units. The detailed treatment of the general rating formulas for specific product applications is best accomplished by those experienced in the field.

ANSI/AGMA 2003-A86 consolidated and updated previous standards to facilitate application by elimination of redundant material, and also to stress the importance of checking both pitting resistance and bending strength aspects to insure a reliable and well balanced design.

The first draft of ANSI/AGMA 2003-A86 was made in May 1980. It was approved by the AGMA membership in June 1985. It was approved as an American National Standard on May 2, 1986, but was not published until early 1987. The edition contained editorial items which were discovered after publication and corrected by the members of the AGMA Gear Rating Committee in the spring of 1988.

AGMA 2003-B97 began as a proposal by the US Delegation to the International Standards Organization (ISO) in 1988 as an effort to reach a consensus. It contained revisions and updates which made it closer to ISO as follows:

– The calculations for dynamic factor and geometry factors appeared in a draft of ISO 10300;
– The table for load distribution factor was the same as appears in a draft of ISO 10300;
– The material grade requirements were similar to those of ISO 6336-5;
– Each symbol used in AGMA 2003-B97 had the ISO equivalent symbol adjacent to it in parentheses.

Several significant changes were introduced in AGMA 2003-B97:

– The introduction of material grade requirements to provide guidance in the selection of stress numbers;
– The replacement of the external dynamic factor;
– Replacing the internal dynamic factor with a new dynamic factor;
– Equations for size factor for bending and pitting resistance were introduced;
– An adjustment of the load distribution factor;
– Revision of the allowable stress numbers;
– Elimination of the stress correction factor;
– The life factor curve for pitting resistance was adjusted to compensate for revisions to previously mentioned factors;
– The fundamental contact stress formula was adjusted to remove the term accommodating light load conditions.

The term zerol or Zerol is used to define a spiral bevel gear with a zero spiral angle. Zerol is a registered trademark of the Gleason Works [4].

The earlier version of this standard, ANSI/AGMA 2003-C10, was a revision of its superseded version. The size factor for pitting resistance addressed in Clause 11 was updated to incorporate experience which was gained with use of the standard. Editorial changes were made to Equations 10M, C103M and Figure 3. All other material in the standard remained unchanged.

In addition to a general update to match current industry practices, ANSI/AGMA 2003-D19, which replaces ANSI/AGMA 2003-C10, also includes the following updates:

a. extensively rewrote Clause 4 criteria for gear tooth capacity;
b. adjusted constants in equations for more accurate imperial-to-metric results;
c. added to section 21 explanation why bending stress numbers of bevel gears are lower compared to spur and helical gears;
d. recalculated the sample problem with additional information.

The first draft of ANSI/AGMA 2003-D19 was made in June 2016. It was approved by the AGMA membership in March 2019. It was approved as an American National Standard on May 14, 2019.

Suggestions for improvement of this standard will be welcome. They should be sent to tech@agma.org.

## PERSONNEL of the AGMA Bevel Gearing Committee

Chairman: Robert F. Wasilewski ............................................ Arrow Gear Company
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American National Standard –

# Rating the Pitting Resistance and Bending Strength of Generated Straight Bevel, Zerol Bevel and Spiral Bevel Gear Teeth

## 1 Scope

### 1.1 Rating formulas

This standard provides a method by which different gear designs can be compared.

The formulas in this standard are intended to establish a uniformly acceptable method for calculating the pitting resistance and bending strength capacity of generated straight bevel, zerol bevel and spiral bevel gear teeth; curved and skewed tooth. They apply equally to tapered depth and uniform depth teeth.

The knowledge and judgment required to evaluate the various rating factors come from years of accumulated experience in designing, manufacturing and operating gear units. Empirical factors given in this standard are general in nature. AGMA application standards may use other empirical factors that are more closely suited to the particular field of application. This standard is intended for use by the experienced gear designer, capable of selecting reasonable values for the factors. It is not intended for use by the engineering public at large.

### 1.2 Exceptions

The rating formulas in this standard are not applicable to other types of gear tooth deterioration such as scuffing, wear, plastic yielding, scoring, case crushing and welding and are not applicable when vibratory conditions exceed the limits specified for the normal operation of the gears (see ANSI/AGMA 6000-B96, *Specification for Measurement of Lateral Vibration on Gear Units*).

The formulas of this standard are not applicable when any of the following conditions exist:

- bevel gears with offset, such as hypoids;
- straight and zerol bevel gears with transverse contact ratios, $m_p$ ($\varepsilon_\alpha$) less than 1.0;
- bevel gears with modified contact ratios, $m_o$ ($\varepsilon_o$) less than 1.0;
- bevel gears which have a poor contact pattern;
- interference exists between tips of teeth and root fillets;
- teeth are pointed;
- backlash is zero;
- bevel teeth finished by forging, casting or sintering.

Design considerations to prevent fractures emanating from stress risers on the tooth profile, tip chipping and failures of the gear blank through the web or hub should be analyzed by general machine design methods.

**NOTE:** For the purposes of this document, pitting is meant as macropitting unless otherwise stated.

#### 1.2.1 Scuffing

Formulas for scuffing resistance on bevel gear teeth are not included in this standard. At the present time, there is insufficient agreement concerning the method for designing bevel gears to resist scuffing failure.

#### 1.2.2 Wear

Very little attention and concern have been devoted to the study of gear tooth wear. This subject primarily concerns gear teeth with low surface hardness or gears with improper lubrication. No attempt has been made to cover gear tooth wear in this standard.

#### 1.2.3 Plastic yielding

This standard does not extend to stress levels above those permissible for $10^3$ cycles, since stresses in this range may exceed the elastic limit of the gear tooth in bending or in surface compressive stress. Depending on the material and the load imposed, a single load cycle exceeding the stress level for $10^3$ life cycles (see Clause 16) can result in plastic yielding of the gear tooth.

## 2 Nomenclature

### 2.1 Normative references

The following documents contain provisions which, through reference in this text, constitute provisions of this American National Standard. At the time of publication, the editions were valid. All standards are subject to revision and parties to agreements based on this document are encouraged to investigate the possibility of applying the most recent editions of the documents indicated below.

The terms used in this standard, wherever applicable, conform to the definitions given in the following standards:

AGMA 390.03a, *Handbook Gear Classification, Materials and Measuring Methods for Bevel, Hypoid, Fine Pitch Wormgearing and Racks Only as Unassembled Gears*

AGMA/ISO 22849-A12, *Design Recommendations for Bevel Gears*

AMS 2300G, *Cleanliness, Premium Aircraft-Quality, Magnetic Particle Inspection Procedure*

AMS 2301G, *Cleanliness, Aircraft-Quality Steel Magnetic Particle Inspection Procedure*

AMS 2304, *Special Aircraft-Quality Steel Cleanliness, Magnetic Particle Inspection Procedure*

ANSI/AGMA 1010-F14, *Appearance of Gear Teeth – Terminology of Wear and Failure*

ANSI/AGMA 1012-G05, *Gear Nomenclature, Definitions of Terms with Symbols*

ANSI/AGMA 2005-D03, *Design Manual for Bevel Gears*

ANSI/AGMA 2007-C00, *Surface Temper Etch Inspection After Grinding*

ANSI/AGMA 2008-D11, *Standard for Assembling Bevel Gears*

ANSI/AGMA 6000-B96, *Specification for Measurement of Lateral Vibration on Gear Units*

ANSI/AGMA 6033-A88, *Standard for Marine Propulsion Gear Units – Part 1, Materials*

ANSI/AGMA 9005-F16, *Industrial Gear Lubrication*

ASTM A48-94a, *Specification for Grey Iron Castings*

ASTM A388-M95, *Practice for Ultrasonic Examination of Heavy Steel Forging*

ASTM A534-94, *Specification for Carburizing Steels for Anti-Friction Bearings*

ASTM A535-85, *Specification for Special Quality Ball and Roller Bearing Steel*

ASTM A536-84, *Specification for Ductile Iron Castings*

ASTM A866-94, *Specification for Medium Carbon Anti-Friction Bearing Steel*

ASTM E112-95, *Test Methods for Determining the Average Grain Size*

ASTM E428-92, *Practice for Fabrication and Control of Steel Reference Blocks used in Ultrasonic Inspection*

ASTM E709-95, *Practice for Magnetic Particle Examination*

## 2.2 Symbols

The symbols used in formulas for pitting resistance and bending strength are shown in Table 1.

**NOTE:** The symbols and definitions used in this standard may differ from other AGMA standards. The user should not assume that familiar symbols can be used without a careful study of these definitions.

System International (SI) units of measure are shown in parentheses in Table 1 and in the text.

Equations are shown in two formats: first non-metric, the second is with SI units, constants and ISO symbols, designated by "M" in the equation number.

Example:

$$T_P = \frac{198\ 000 P}{\pi n_P} \tag{9}$$

The second expression uses SI units.

$$T_1 = \frac{30\ 000 P}{\pi n_1} \tag{9M}$$

**Table 1 – Symbols used in gear rating equations**

| AGMA symbol | ISO symbol | Description | Units | First used |
|---|---|---|---|---|
| $A_m$ | $R_m$ | Mean cone distance | in (mm) | Eq 21 |
| $A_o$ | $R_e$ | Outer cone distance | in (mm) | Eq 33 |
| $C_H$ | $Z_W$ | Hardness ratio factor for pitting resistance | - - | Eq 2 |
| $C_i$ | $Z_i$ | Inertia factor for pitting resistance | - - | Eq 24 |
| $C_L$ | $Z_{NT}$ | Stress cycle factor for pitting resistance | - - | Eq 2 |
| $C_p$ | $Z_E$ | Elastic coefficient | $[lb/in^2]^{0.5}$ ($[N/mm^2]^{0.5}$) | Eq 1 |
| $C_R$ | $Z_Z$ | Reliability factor for pitting | - - | Eq 2 |
| $C_{SF}$ | - | Service factor for pitting resistance | - - | Eq 10 |
| $C_s$ | $Z_x$ | Size factor for pitting resistance | - - | Eq 1 |
| $C_{xc}$ | $Z_{xc}$ | Crowning factor for pitting resistance | - - | Eq 1 |
| $D$, $d$ | $d_{e2}$, $d_{e1}$ | Outer pitch diameters of gear and pinion, respectively | in (mm) | Eq 1 |
| $E_G$, $E_P$ | $E_2$, $E_1$ | Young's modulus of elasticity for materials of gear and pinion, respectively | $lb/in^2$ ($N/mm^2$) | Eq 32 |
| $e$ | $e$ | Base of natural (Napierian) logarithms | - - | Eq 30 |
| $F$ | $b$ | Net face width | in (mm) | Eq 1 |
| $F_{eG}$, $F_{eP}$ | $b_2'$, $b_1'$ | Effective face widths of gear and pinion, respectively | in (mm) | Eq 25 |
| $f_P$ | $R_{a1}$ | Pinion surface roughness | µin (µm) | Eq 30 |
| $H_{BG}$, $H_{BP}$ | $H_{B2}$, $H_{B1}$ | Minimum Brinell hardness number for gear and pinion material | HB | Eq 28 |
| $h_c$ | $E_{ht\,min}$ | Minimum total case depth at tooth mid-depth | in (mm) | Eq 36 |
| $h_e$ | $h'_c$ | Minimum effective case depth | in (mm) | Eq 33 |
| $h_{e\,lim}$ | $h'_{c\,lim}$ | Suggested maximum effective case depth limit at tooth mid-depth | in (mm) | Eq 35 |
| $I$ | $Z_I$ | Geometry factor for pitting resistance | - - | Eq 1 |
| $J$ | $Y_J$ | Geometry factor for bending strength | - - | Eq 5 |
| $J_G$, $J_P$ | $Y_{J2}$, $Y_{J1}$ | Geometry factor for bending strength for gear and pinion, respectively | - - | Eq 26 |
| $K_F$ | $Y_F$ | Stress correction and concentration factor | - - | 21.3.3 |
| $K_i$ | $Y_i$ | Inertia factor for bending strength | - - | Eq 25 |

*(continued)*