American Gear Manufacturers Association

**ANSI/AGMA 2002-D19**
(Revision of ANSI/AGMA 2002-C16)

**American National Standard**

# Tooth Thickness and Backlash Measurement of Cylindrical Involute Gearing

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Approved December 9, 2019

## ABSTRACT

This standard establishes the procedures for determining the specification limits for tooth thickness of external and internal cylindrical involute gearing. It includes equations and calculation procedures for the commonly used measuring methods. A specific tooth thickness specification limit can be established from the design thickness or from another tooth thickness measurement. The procedures can be used with an established design tooth thickness, or with actual tooth thickness dimensions. The effect of tooth geometric quality variations on tooth thickness dimensions is discussed. Calculations for backlash are included, and are based on the specified tooth thickness, center distance, and tolerances.

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## Foreword

[The foreword, footnotes and annexes, if any, in this standard are provided for informational purposes only and are not to be construed as a part of AGMA Standard 2002-D20, *Tooth Thickness and Backlash Measurement of Cylindrical Involute Gearing.*]

This Standard presents calculation procedures for determining tooth thickness dimensions of external and internal cylindrical involute gearing. It supersedes AGMA 231.52, *Inspection – Pin Measurement Tables for Involute Spur Gears*.

This Standard has been prepared to consolidate previously published AGMA tooth thickness information, to add more information on internal and helical gears and to add details on more measurement methods.

Previous AGMA publications have presented this information in tabular form, calculated for 1 DP and standard tooth proportions, with adjustment factors for nonstandard conditions. This Standard is arranged for direct calculation of the desired results, to eliminate the intermediate calculation steps and interpolation previously required.

The study of tooth thickness and backlash has been a major interest of gear technicians throughout the history of the industry. In the last fifty years, many clarifications and contributions have been made by Buckingham, Candee, Leming, Vogel, Wildhaber and others. Their work is consolidated here, without further attribution, and the work of more recent contributors is added where it improves the presentation.

In this edition of ANSI/AGMA 2002-C16, the concept of functional tooth thickness has been broadened, and the treatment of the effects of tooth profile, pitch, lead, and runout deviations on tooth thickness dimensions has changed. This edition uses a direct calculation of measured tooth thickness from a nominal circular tooth thickness, and a clear distinction is made between measurement methods for nominal and functional tooth thickness. A section on the calculation of backlash was added, and the effects of tolerances are included in the calculation of backlash. As a result of these changes, the title of this standard has been revised to reflect the new content.

An annex was added to provide sample calculations.

ANSI/AGMA 2002-D19 is a revision of ANSI/AGMA 2002-C16. It was created to update:

– equation 87 – in the enominator minus was changed to plus;
– equation 104 - removed absolute value signs around the first and third z, and;
– corrected the calculated value of equation 113 in E.3.7.

The first draft of ANSI/AGMA 2002-D19 was created in September 2018. It was approved by the membership on May 17, 2019 and as an American National Standard on December 9, 2019.

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

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American National Standard–

# Tooth Thickness and Backlash Measurement of Cylindrical Involute Gearing

## 1 Scope

This standard establishes the calculation procedures for determining specification limits for external and internal cylindrical involute gearing when the desired tooth thickness is known. This standard also shows the relationships between backlash and the tooth thickness, center distance, and tooth deviations in a pinion and gear mesh.

### 1.1 Measurement methods included in standard

Equations and procedures are included for the following tooth thickness measuring methods:

- measurement by pitch or index;
- measurement with a master gear on a double flank tester;
- measurement with a master gear on a single flank tester;
- span measurement;
- measurement over or between balls or pins;
- measurement with measuring blocks;
- chordal measurement.

### 1.2 Types of gears

This standard applies to the following types of gears:

- external and internal involute spur gears;
- external and internal parallel axis involute helical gears;
- involute worms and other crossed-axis helical gears;
- spur and helical racks;
- involute sector gears, spur, and helical.

### 1.3 Dimensional and material limitations

The equations in this standard apply to gears of all sizes and materials, and to all manufacturing methods. However, practical considerations and availability of test equipment can preclude the use of some methods on some sizes of gears.

Some methods may not be appropriate for compliant materials if the use of the tooth thickness measuring tools and techniques result in deformation of the gear teeth.

### 1.4 Exclusions

The determination of design tooth thickness for a given application is beyond the scope of this standard.

## 2 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 standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below.

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

## 3 Symbols and terminology

### 3.1 Symbols

The symbols used in this standard are as shown in Table 1. The symbols and terms referenced in footnote 1 as "Input variable" should be measured, known, or determined by the designer. Methods to calculate these input variables are beyond the scope of this standard.

**NOTE 1:** The symbols and terms contained in this standard may vary from those used in other AGMA and ISO standards. Users of this standard should assure themselves that they are using these symbols and terms in the manner indicated herein.

**NOTE 2:** An “i” at the end of a variable subscript should be replaced with a “1” when the variable is used for a pinion and should be replaced with a “2” when the variable is used for a gear.

**Table 1 – Symbols and terms**

| Symbol | Term | Units | Equation[2)] |
|---|---|---|---|
| $a$ | Standard center distance | mm | 24 |
| $a_{\text{d max}}$ | Tight mesh center distance limit, maximum | mm | 25 |
| $a_{\text{d min}}$ | Tight mesh center distance limit, minimum | mm | 26 |
| $a_{\text{dm max}}$ | Measured tight mesh center distance, maximum[1)] | mm | 40 |
| $a_{\text{dm min}}$ | Measured tight mesh center distance, minimum[1)] | mm | 41 |
| $a_{\text{w max}}$ | Operating center distance, maximum[1)] | mm | 169 |
| $a_{\text{w min}}$ | Operating center distance, minimum[1)] | mm | 170 |
| $b_{\text{min}}$ | Minimum width of the unmodified portion of face[1)] | mm | 50 |
| $D_{\text{Bm}}$ | Measured dimension over blocks[1)] | mm | 146 |
| $D_{\text{B max}}$ | Over blocks measurement limit, maximum | mm | 142 |
| $D_{\text{B min}}$ | Over blocks measurement limit, minimum | mm | 143 |
| $D_{\text{d}}$ | Diameter of the ball or pin[1)] | mm | 99 |
| $D_{\text{d a}}$ | Ball or pin diameter for the ball or pin to be tangent to the tip diameter | mm | 79 |
| $D_{\text{d dy}}$ | Ball or pin diameter for contact at the desired contact diameter, $d_{\text{y}}$ | mm | 89 |
| $D_{\text{d f}}$ | Ball or pin diameter for the ball or pin to be tangent to the root diameter | mm | 82 |
| $D_{\text{d Lf}}$ | Ball or pin diameter for contact at the root involute limit diameter | mm | 78 |
| $D_{\text{d ll}}$ | Limit for a valid numerical solution, mm | mm | 81 |
| $D_{\text{d max}}$ | Ball or pin diameter, maximum | mm | 74 |
| $D_{\text{d min}}$ | Ball or pin diameter, minimum | mm | 84 |
| $D_{\text{dm}}$ | Diameter of the ball or pin used for measurement[1)] | mm | 104 |
| $d$ | Reference diameter | mm | 1 |
| $d_{\text{a avg}}$ | Tip diameter, average | mm | 149 |
| $d_{\text{a max}}$ | Tip diameter, maximum[1)] | mm | 79 |

| Symbol | Term | Units | Equation[2] |
|---|---|---|---|
| $d_{\mathrm{a\ min}}$ | Tip diameter, minimum[1] | mm | 80 |
| $d_{\mathrm{am}}$ | Measured tip diameter of the gear being checked[1] | mm | 158 |
| $d_{\mathrm{b}}$ | Base diameter | mm | 7 |
| $d_{\mathrm{b1}}$ | Base diameter of the pinion | mm | 171 |
| $d_{\mathrm{bi}}$ | Base diameter of the pinion or gear | mm | 201 |
| $d_{\mathrm{c\ max}}$ | Contact diameter with maximum tooth thickness | mm | 98 |
| $d_{\mathrm{c\ min}}$ | Contact diameter with minimum tooth thickness | mm | 99 |
| $d_{\mathrm{f\ max}}$ | Root diameter, maximum[1] | mm | 82 |
| $d_{\mathrm{f\ min}}$ | Root diameter, minimum[1] | mm | 83 |
| $d_{\mathrm{k\ max}}$ | Diameter through the center of the ball or pin for maximum tooth thickness | mm | 96 |
| $d_{\mathrm{k\ min}}$ | Diameter through the center of the ball or pin for minimum tooth thickness | mm | 97 |
| $d_{\mathrm{k2\ max}}$ | Measurement limit over two balls or pins for maximum tooth thickness | mm | 108 |
| $d_{\mathrm{k2\ min}}$ | Measurement limit over two balls or pins for minimum tooth thickness | mm | 109 |
| $d_{\mathrm{k2F\ max}}$ | Measurement limit over two pins, free pin method, maximum | mm | 124 |
| $d_{\mathrm{k2F\ min}}$ | Measurement limit over two pins, free pin method, minimum | mm | 125 |
| $d_{\mathrm{k2m}}$ | Measured dimension over two balls or pins[1] | mm | 112 |
| $d_{\mathrm{k2t\ max}}$ | Measurement limit over two pins, transverse method, maximum | mm | 131 |
| $d_{\mathrm{k2t\ min}}$ | Measurement limit over two pins, transverse method, minimum | mm | 132 |
| $d_{\mathrm{k3A\ max}}$ | Measurement limit over three pins, axial plane method, maximum | mm | 138 |
| $d_{\mathrm{k3A\ min}}$ | Measurement limit over three pins, axial plane method, minimum | mm | 139 |
| $d_{\mathrm{k3Am}}$ | Measured dimension over three pins, axial plane method[1] | mm | 140 |
| $d_{\mathrm{k3t\ max}}$ | Measurement limit over three balls or pins, transverse plane method, for maximum tooth thickness | mm | 133 |
| $d_{\mathrm{k3t\ min}}$ | Measurement limit over three balls or pins, transverse plane method, for minimum tooth thickness | mm | 134 |
| $d_{\mathrm{k3tm}}$ | Measured dimension over three balls or pins, transverse plane method[1] | mm | 135 |
| $d_{\mathrm{La}}$ | Tip involute limit diameter[1] | mm | 48 |
| $d_{\mathrm{Lf}}$ | Root involute limit diameter[1] | mm | 49 |
| $d_{\mathrm{M}}$ | Measurement diameter | mm | 68 |
| $d_{\mathrm{m}}$ | Diameter where the ball or pin contacts the involute | mm | 106 |
| $d_{\mathrm{wfi\ max}}$ | Functional operating pitch diameter, pinion or gear, maximum | mm | 183 |
| $d_{\mathrm{wfi\ min}}$ | Functional operating pitch diameter, pinion or gear, minimum | mm | 184 |
| $d_{\mathrm{wi\ max}}$ | Operating pitch diameter, pinion or gear, maximum | mm | 169 |
| $d_{\mathrm{wi\ min}}$ | Operating pitch diameter, pinion or gear, minimum | mm | 170 |
| $d_{\mathrm{y}}$ | Calculation diameter[1] | mm | 13 |
| $d_{\mathrm{y\ min}}$ | Chordal contact diameter with minimum tooth thickness | mm | 151 |
| $d_{\mathrm{yt\ min}}$ | Contact diameter for the minimum tooth thickness at the specified chordal radius | mm | 161 |
| $E$ | Error term | - - | 71 |
| $F_{\mathrm{idT}}$ | Total composite tolerance of the product gear[1] | μm | 25 |

| Symbol | Term | Units | Equation[2)] |
|---|---|---|---|
| $F_{idTi}$ | Total composite tolerance for the pinion or gear[1)] | μm | 181 |
| $F_{pTi}$ | Total cumulative pitch (index) tolerance for the pinion or gear[1)] | μm | 182 |
| $F_{pc}$ | Multiplier to adjust conversion from total cumulative pitch to total composite tolerance | - - | 182 |
| $F_{rc}$ | Multiplier to adjust conversion from runout to total composite tolerance | - - | 181 |
| $F_{rTi}$ | Runout tolerance for the pinion or gear[1)] | μm | 181 |
| $F_{\alpha Ti}$ | Total profile tolerance for the pinion or gear[1)] | μm | 181 |
| $F_{\beta Ti}$ | Total helix tolerance for the pinion or gear[1)] | μm | 181 |
| $F_2$ | Calibrated value of the tooth profile coefficient for the female block[1)] | - - | 144 |
| $f_{pTi}$ | Single pitch tolerance for the pinion or gear[1)] | μm | 181 |
| $f_{\alpha s}$ | Modification coefficient for span profile limits | - - | 48 |
| $f_{\beta s}$ | Modification coefficient for span helix limit | - - | 50 |
| $H_{k1\ max}$ | Measurement limit over one ball or pin to the rack datum, maximum | mm | 102 |
| $H_{k1\ min}$ | Measurement limit over one ball or pin to the rack datum, minimum | mm | 103 |
| $H_{k1m}$ | Measured dimension over one ball or pin to the rack datum[1)] | mm | 105 |
| $h_{cy}$ | Chordal addendum | mm | 150 |
| $h_{cytw}$ | Chordal addendum for measurement of transverse chordal tooth thickness | mm | 166 |
| $h_{cyw}$ | Chordal addendum to be used for the tooth thickness measurement | mm | 157 |
| $i$ | Subscript which denotes either the pinion (subscript 1) or gear (subscript 2) | - - | 169 |
| $j_{bn\ max}$ | Base normal (feeler gage) backlash, maximum | mm | 199 |
| $j_{bn\ min}$ | Base normal (feeler gage) backlash, minimum | mm | 200 |
| $j_{bt\ max}$ | Base transverse backlash, maximum | mm | 195 |
| $j_{bt\ min}$ | Base transverse backlash, minimum | mm | 196 |
| $j_{wt\ max}$ | Transverse circular backlash at the operating pitch diameter, maximum | mm | 177 |
| $j_{wt\ min}$ | Transverse circular backlash at the operating pitch diameter, minimum | mm | 178 |
| $j_{\theta i\ max}$ | Angular backlash of the pinion or gear, maximum | degree | 201 |
| $j_{\theta i\ min}$ | Angular backlash of the pinion or gear, minimum | degree | 202 |
| $k$ | Number of teeth spanned on an external gear; or the number of tooth spaces spanned on an internal gear[1)] | - - | 51 |
| $k_{max\ a}$ | Maximum number of teeth spanned on an external gear based on the tip involute limit diameter | - - | 48 |
| $k_{max\ b}$ | Maximum number of teeth spanned based on face width of an external helical gear; or the maximum number of tooth spaces spanned based on the face width of an internal helical gear | - - | 50 |
| $k_{max\ f}$ | Maximum number of tooth spaces spanned on an internal gear based on the root involute limit diameter | - - | 53 |
| $k_{min\ a}$ | Minimum number of tooth spaces spanned on an internal gear based on the tip involute limit diameter | - - | 54 |

| Symbol | Term | Units | Equation[2)] |
|---|---|---|---|
| $k_{\text{min f}}$ | Minimum number of teeth spanned on an external gear based on the root involute limit diameter | - - | 49 |
| $L_{\text{p}}$ | Critical pin length | mm | 129 |
| $M_2$ | Calibrated value of the tooth profile coefficient for the male block[1)] | - - | 142 |
| $m_{\text{n}}$ | Normal module[1)] | mm | 1 |
| $m_{\text{n3}}$ | Normal module of the master gear[1)] | mm | 22 |
| $P_{\text{nd}}$ | Normal diametral pitch[1)] | $\text{in}^{-1}$ | 2 |
| $p_{\text{bn}}$ | Normal base pitch | mm | 10 |
| $p_{\text{n}}$ | Normal pitch at the reference diameter | mm | 9 |
| $p_{\text{rM max}}$ | Radial offset of the contact point, maximum | mm | 120 |
| $p_{\text{rM min}}$ | Radial offset of the contact point, minimum | mm | 121 |
| $p_{\text{x}}$ | Axial pitch | mm | 11 |
| $p_{\text{z}}$ | Lead | mm | 116 |
| $R_{\text{r max}}$ | Test radius limit of product gear, maximum | mm | 38 |
| $R_{\text{r min}}$ | Test radius limit of product gear, minimum | mm | 39 |
| $R_{\text{r3}}$ | Test radius of master gear | mm | 37 |
| $r_{\text{am}}$ | Measured radius to the tip of the gear tooth being checked[1)] | mm | 157 |
| $r_{\text{cy}}$ | Chordal radius | mm | 160 |
| $r_{\text{k1 max}}$ | Measurement limit over one ball or pin, maximum | mm | 100 |
| $r_{\text{k1 min}}$ | Measurement limit over one ball or pin, minimum | mm | 101 |
| $r_{\text{k1m}}$ | Measured dimension over one ball or pin[1)] | mm | 104 |
| $s_{\text{b}}$ | Base circular tooth thickness | mm | 15 |
| $s_{\text{bn max}}$ | Nominal base normal circular tooth thickness, maximum | mm | 46 |
| $s_{\text{bn min}}$ | Nominal base normal circular tooth thickness, minimum | mm | 47 |
| $s_{\text{bt}}$ | Base transverse circular tooth thickness | mm | 15 |
| $s_{\text{cy max}}$ | Maximum normal chordal tooth thickness limit at the desired contact diameter, $d_{\text{y}}$ and chordal addendum $h_{\text{cy}}$ | mm | 155 |
| $s_{\text{cy min}}$ | Minimum normal chordal tooth thickness limit at chordal addendum $h_{\text{cy}}$ | mm | 156 |
| $s_{\text{cyt max}}$ | Maximum transverse chordal tooth thickness at the desired contact diameter | mm | 164 |
| $s_{\text{cyt min}}$ | Minimum transverse chordal tooth thickness at chordal radius $r_{\text{cy}}$ | mm | 165 |
| $s_{\text{n}}$ | Normal circular tooth thickness at the reference diameter | mm | 15 |
| $s_{\text{n max}}$ | Nominal normal circular tooth thickness at the reference diameter, maximum | mm | 5 |
| $s_{\text{n min}}$ | Nominal normal circular tooth thickness at the reference diameter, minimum | mm | 6 |
| $s_{\text{nf max}}$ | Functional normal circular tooth thickness at the reference diameter, maximum[1)] | mm | 29 |
| $s_{\text{nf min}}$ | Functional normal circular tooth thickness at the reference diameter, minimum[1)] | mm | 30 |
| $s_{\text{nfi max}}$ | Functional normal circular tooth thickness at the reference diameter for the pinion or gear, maximum[1)] | mm | 173 |
| $s_{\text{nfi min}}$ | Functional normal circular tooth thickness at the reference diameter for the pinion or gear, minimum[1)] | mm | 174 |