



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

ANSI/AGMA 2002-D19

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**American
National
Standard*****Tooth Thickness and Backlash Measurement of Cylindrical Involute Gearing***

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[Revision of ANSI/AGMA 2002-C16]

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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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Contents

Foreword	iv
1 Scope	1
1.1 Measurement methods included in standard	1
1.2 Types of gears.....	1
1.3 Dimensional and material limitations	1
1.4 Exclusions	1
2 Normative references.....	2
3 Symbols and terminology.....	2
3.1 Symbols.....	2
3.2 Definitions.....	8
4 Application.....	11
4.1 General.....	11
4.2 Datum surfaces and the datum axis	11
4.3 Gear tooth thickness specification systems	12
4.4 Gear tooth thickness measurement methods	13
4.5 Reporting of gear tooth thickness	14
4.6 Measurement diameter versus contact diameter.....	14
4.7 Gear geometry calculations	15
5 Measurement by pitch or index.....	19
5.1 Principle of measurement	19
5.2 Underlying assumptions and limitations.....	19
5.3 Advantages and disadvantages	19
5.4 Selection of measurement diameter	20
5.5 Tooth thickness from index measurement.....	20
6 Measurement with a master gear on a double flank tester.....	20
6.1 Principle of measurement	20
6.2 Underlying assumptions and limitations.....	22
6.3 Advantages and disadvantages.....	23
6.4 Master gear design considerations	23
6.5 Tight mesh center distance limits.....	25
6.6 Test radius limits from tight mesh center distance limits	28
6.7 Functional normal circular tooth thickness from double flank test results.....	28
7 Measurement with a master gear on a single flank tester	29
7.1 Principle of measurement	29
7.2 Underlying assumptions and limitations.....	29
7.3 Advantages and disadvantages.....	30
7.4 Master gear design considerations	30
7.5 Functional circular tooth thickness from single flank test results	30
8 Span measurement.....	30
8.1 Principle of measurement	30
8.2 Underlying assumptions and limitations.....	32
8.3 Advantages and disadvantages.....	32
8.4 Number of teeth or tooth spaces spanned	33
8.5 Span measurement limits.....	35
8.6 Angle of rock	36
8.7 Tooth thickness from span measurement.....	37
9 Measurement over or between balls or pins	37
9.1 Principle of measurement	37
9.2 Underlying assumptions and limitations.....	38
9.3 Advantages and disadvantages.....	39
9.4 Selection of the ball or pin diameter.....	40
9.5 Calculations with specified ball or pin diameter	46
9.6 Measurement over one ball or pin	47
9.7 Measurement over two balls or pins	49
9.8 Free pin measurement over two pins on a helical gear with an odd number of teeth	51
9.9 Transverse measurement over two pins on a helical gear with an odd number of teeth	53
9.10 Transverse plane measurement method over three balls or pins.....	54
9.11 Axial plane measurement over three pins on a helical gear or cylindrical worm	56

10	Measurement with measuring blocks	57
10.1	Principle of measurement	57
10.2	Underlying assumptions and limitations	58
10.3	Advantages and disadvantages	58
10.4	Measuring block sets	59
10.5	Block measurement limits	59
10.6	Tooth thickness from block measurements	60
11	Chordal measurement	60
11.1	General	60
11.2	Measurements with a gear tooth caliper (in the normal plane)	60
11.3	Chordal measurement with an optical device (in the transverse plane)	65
11.4	Chordal measurement with a coordinate measurement machine (CMM)	69
12	Backlash in gear meshes	69
12.1	General	69
12.2	Factors that influence backlash	70
12.3	Backlash in the functional system	70
12.4	Backlash in the nominal system	72
12.5	Other potential influences on backlash	75
12.6	Ways to express backlash	75
12.7	Variations in backlash	77

Annexes

Annex A	Tooth thickness measurement using analytical machines	78
Annex B	Establishing tooth thickness specifications in the nominal system	80
Annex C	Establishing tooth thickness specifications in the functional system	82
Annex D	Calculation method for the inverse involute function	84
Annex E	Example calculations	85
Annex F	Acknowledgements	144
Annex G	Bibliography	146

Figures

Figure 1	– External gear normal circular, chordal and base tooth thickness	8
Figure 2	– Relationship of tooth thickness tolerance to total composite tolerance	11
Figure 3	– General arrangement of a double flank tester	20
Figure 4	– A double flank tester in tight mesh	21
Figure 5	– Sample double flank test report	21
Figure 6	– Tight mesh center distance limits for an external gear	27
Figure 7	– Span measurement using a disc micrometer	31
Figure 8	– Span measurement geometry for external spur gears	31
Figure 9	– Span measurement of helical gears	32
Figure 10	– Tooth thickness measurement over pins	37
Figure 11	– Rack nomenclature	45
Figure 12	– Measurement over one ball or pin for external and internal gears	48
Figure 13	– Measurement over two balls or pins for external and internal gears	50
Figure 14	– Measurement using transverse plane method for three balls or pins, external gear	55
Figure 15	– Measurement using transverse plane method for three balls or pins, internal gear	55
Figure 16	– Measurement over three pins using the axial plane three pin method on a helical gear	56
Figure 17	– Measurement over three pins using the axial plane three pin method on a cylindrical worm	56
Figure 18	– Measurement with measuring blocks for even and odd numbers of teeth	58
Figure 19	– Female block	59
Figure 20	– Male block	59
Figure 21	– Chordal tooth thickness measurement using a gear tooth caliper	61
Figure 22	– Chordal tooth thickness in plane of measurement	61
Figure 23	– Transverse chordal dimension	66
Figure 24	– Backlash in a spur gear mesh	69

Tables

Table 1	– Symbols and terms	2
Table 2	– Tooth thickness specification system and corresponding measurement methods	13
Table 3	– Gear deviations that can affect tooth thickness measurement	14
Table 4	– Ball or pin measurement usage	38

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

Symbol	Term	Units	Equation ²⁾
$d_{a \min}$	Tip diameter, minimum ¹⁾	mm	80
d_{am}	Measured tip diameter of the gear being checked ¹⁾	mm	158
d_b	Base diameter	mm	7
d_{b1}	Base diameter of the pinion	mm	171
d_{bi}	Base diameter of the pinion or gear	mm	201
$d_{c \max}$	Contact diameter with maximum tooth thickness	mm	98
$d_{c \min}$	Contact diameter with minimum tooth thickness	mm	99
$d_{f \max}$	Root diameter, maximum ¹⁾	mm	82
$d_{f \min}$	Root diameter, minimum ¹⁾	mm	83
$d_{k \max}$	Diameter through the center of the ball or pin for maximum tooth thickness	mm	96
$d_{k \min}$	Diameter through the center of the ball or pin for minimum tooth thickness	mm	97
$d_{k2 \max}$	Measurement limit over two balls or pins for maximum tooth thickness	mm	108
$d_{k2 \min}$	Measurement limit over two balls or pins for minimum tooth thickness	mm	109
$d_{k2F \max}$	Measurement limit over two pins, free pin method, maximum	mm	124
$d_{k2F \min}$	Measurement limit over two pins, free pin method, minimum	mm	125
d_{k2m}	Measured dimension over two balls or pins ¹⁾	mm	112
$d_{k2t \max}$	Measurement limit over two pins, transverse method, maximum	mm	131
$d_{k2t \min}$	Measurement limit over two pins, transverse method, minimum	mm	132
$d_{k3A \max}$	Measurement limit over three pins, axial plane method, maximum	mm	138
$d_{k3A \min}$	Measurement limit over three pins, axial plane method, minimum	mm	139
d_{k3Am}	Measured dimension over three pins, axial plane method ¹⁾	mm	140
$d_{k3t \max}$	Measurement limit over three balls or pins, transverse plane method, for maximum tooth thickness	mm	133
$d_{k3t \min}$	Measurement limit over three balls or pins, transverse plane method, for minimum tooth thickness	mm	134
d_{k3tm}	Measured dimension over three balls or pins, transverse plane method ¹⁾	mm	135
d_{La}	Tip involute limit diameter ¹⁾	mm	48
d_{Lf}	Root involute limit diameter ¹⁾	mm	49
d_M	Measurement diameter	mm	68
d_m	Diameter where the ball or pin contacts the involute	mm	106
$d_{wfi \max}$	Functional operating pitch diameter, pinion or gear, maximum	mm	183
$d_{wfi \min}$	Functional operating pitch diameter, pinion or gear, minimum	mm	184
$d_{wi \max}$	Operating pitch diameter, pinion or gear, maximum	mm	169
$d_{wi \min}$	Operating pitch diameter, pinion or gear, minimum	mm	170
d_y	Calculation diameter ¹⁾	mm	13
$d_{y \min}$	Chordal contact diameter with minimum tooth thickness	mm	151
$d_{yt \min}$	Contact diameter for the minimum tooth thickness at the specified chordal radius	mm	161
E	Error term	- -	71
F_{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_{as}	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⁾
$k_{\min f}$	Minimum number of teeth spanned on an external gear based on the root involute limit diameter	- -	49
L_p	Critical pin length	mm	129
M_2	Calibrated value of the tooth profile coefficient for the male block ¹⁾	- -	142
m_n	Normal module ¹⁾	mm	1
m_{n3}	Normal module of the master gear ¹⁾	mm	22
P_{nd}	Normal diametral pitch ¹⁾	in ⁻¹	2
p_{bn}	Normal base pitch	mm	10
p_n	Normal pitch at the reference diameter	mm	9
$p_{rM \max}$	Radial offset of the contact point, maximum	mm	120
$p_{rM \min}$	Radial offset of the contact point, minimum	mm	121
p_x	Axial pitch	mm	11
p_z	Lead	mm	116
$R_{r \max}$	Test radius limit of product gear, maximum	mm	38
$R_{r \min}$	Test radius limit of product gear, minimum	mm	39
R_{r3}	Test radius of master gear	mm	37
r_{am}	Measured radius to the tip of the gear tooth being checked ¹⁾	mm	157
r_{cy}	Chordal radius	mm	160
$r_{k1 \max}$	Measurement limit over one ball or pin, maximum	mm	100
$r_{k1 \min}$	Measurement limit over one ball or pin, minimum	mm	101
r_{k1m}	Measured dimension over one ball or pin ¹⁾	mm	104
s_b	Base circular tooth thickness	mm	15
$s_{bn \max}$	Nominal base normal circular tooth thickness, maximum	mm	46
$s_{bn \min}$	Nominal base normal circular tooth thickness, minimum	mm	47
s_{bt}	Base transverse circular tooth thickness	mm	15
$s_{cy \max}$	Maximum normal chordal tooth thickness limit at the desired contact diameter, d_y and chordal addendum h_{cy}	mm	155
$s_{cy \min}$	Minimum normal chordal tooth thickness limit at chordal addendum h_{cy}	mm	156
$s_{cyt \max}$	Maximum transverse chordal tooth thickness at the desired contact diameter	mm	164
$s_{cyt \min}$	Minimum transverse chordal tooth thickness at chordal radius r_{cy}	mm	165
s_n	Normal circular tooth thickness at the reference diameter	mm	15
$s_{n \max}$	Nominal normal circular tooth thickness at the reference diameter, maximum	mm	5
$s_{n \min}$	Nominal normal circular tooth thickness at the reference diameter, minimum	mm	6
$s_{nf \max}$	Functional normal circular tooth thickness at the reference diameter, maximum ¹⁾	mm	29
$s_{nf \min}$	Functional normal circular tooth thickness at the reference diameter, minimum ¹⁾	mm	30
$s_{nfi \max}$	Functional normal circular tooth thickness at the reference diameter for the pinion or gear, maximum ¹⁾	mm	173
$s_{nfi \min}$	Functional normal circular tooth thickness at the reference diameter for the pinion or gear, minimum ¹⁾	mm	174