

AMERICAN GEAR MANUFACTURERS ASSOCIATION

*Inspection Practices - Part 1:
Cylindrical Gears -
Tangential Measurements*



AGMA INFORMATION SHEET

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American
Gear
Manufacturers
Association

Inspection Practices - Part 1: Cylindrical Gears - Tangential Measurements

AGMA 915-1-A02

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ABSTRACT

This information sheet provides a code of practice dealing with inspection relevant to tangential element and composite deviations of cylindrical involute gears (measurements referred to single flank contact) and serves as a supplement to ANSI/AGMA 2015-1-A01, *Accuracy Classification System - Tangential Measurements for Cylindrical Gears*.

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Foreword

This Information Sheet, AGMA 915-1-A02, *Inspection Practices – Part 1: Cylindrical Gears – Tangential Measurements* is provided for informational purposes and is intended for use with the Standard ANSI/AGMA 2015-1-A01, *Accuracy Classification System – Tangential Measurements for Cylindrical Gears*.

AGMA 915-1-A02 replaces AGMA ISO 10064-1, *Cylindrical Gears – Code of Inspection Practice – Part 1: Inspection of Corresponding Flanks of Gear Teeth*, and the information on similar subjects as covered in ANSI/AGMA 2000-A88, *Gear Classification and Inspection Handbook – Tolerances and Measuring Methods for Unassembled Spur and Helical Gears*.

The user of this Information Sheet is alerted that differences exist between it and ANSI/AGMA 2000-A88 and AGMA ISO 10064-1. These include, but are not limited to:

- Measuring methods refer to an accuracy grade numbering system that is reversed, such that the smallest number represents the smallest tolerance;
- Probe direction and measurement requirements for elemental and composite tolerances may differ from ANSI/AGMA 2000-A88 or AGMA ISO 10064-1;
- The measurement “profile evaluation range” and “helix evaluation range”, where the tolerances are applied, are defined for different area than in ANSI/AGMA 2000-A88 or AGMA ISO 10064-1;
- The measurement of undulations is included;
- Concepts of “mean measurement trace”, “design trace”, “slope deviation”, “form deviation”, “gear form filter cutoff”, “tolerance diameter” and “data density” are defined.

Therefore, the user of this information sheet must be very careful when comparing measurement methods formerly specified using ANSI/AGMA 2000-A88 or AGMA ISO 10064-1.

The first draft of AGMA 915-1-A02 was made in May, 1998. This document was approved by the Inspection Handbook Committee on January 31, 2002. It was approved by the Technical Division Executive Committee as an AGMA Information Sheet on April 16, 2002.

Suggestions for improvement of this document will be welcome. They should be sent to the American Gear Manufacturers Association, 1500 King Street, Suite 201, Alexandria, Virginia 22314.

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Inspection Practices – Part 1: Cylindrical Gears – Tangential Measurements

1 Scope

This information sheet constitutes a code of practice dealing with tangential measurements on flanks of individual cylindrical involute gears, i.e., with the measurement of pitch, profile, helix and tangential composite characteristics.

In providing advice on gear measuring methods and the analysis of measurement results, it supplements the standard ANSI/AGMA 2015-1-A01, *Accuracy Classification System – Tangential Measurements for Cylindrical Gears*.

2 References

The following standards contain provisions which are referenced in the text of this information sheet.

At the time of publication, the editions indicated 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 standards indicated.

AGMA 915-3-A99, *Inspection Practices – Gear Blanks, Shaft Center Distance and Parallelism*

ANSI/AGMA 2015-1-A01, *Accuracy Classification System – Tangential Measurements for Cylindrical Gears*

ISO 53:1998, *Cylindrical gears for general and heavy engineering – Standard basic rack tooth profile*

ISO 54:1996, *Cylindrical gears for general engineering and for heavy engineering – Modules*

ISO 701:1998, *International gear notation – Symbols for geometrical data*

ISO 1122-1:1998, *Vocabulary of gear terms – Part 1: Definitions related to geometry*

3 Symbols and corresponding terms

The symbols and terms used throughout this manual are in basic agreement with the symbols and terms given in ISO 701:1998, *International gear notation – Symbols for geometrical data*. In all cases, the first time that each symbol is introduced, it is defined and discussed in detail. See table 1.

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

Table 1 – Symbols and definitions

Symbols	Definition ¹⁾	Units	Where first used
b	Facewidth	mm	Figure 24
D	Design pitch diameter	mm	Eq 4
D_b	Design base diameter	mm	Eq 3
d	Reference diameter	mm	Eq 24
$d_{b\text{ eff}}$	Effective base diameter	mm	6.5.3
d_T	Tolerance diameter	mm	6.2
F_β	Total helix deviation	μm	Figure 22

(continued)

Table 1 (continued)

Symbols	Definition ¹⁾	Units	Where first used
F_{is}	Total single flank composite deviation	μm	9.1
F_p	Total cumulative pitch deviation	μm	6.1
$F_{ps/8}$	Sector pitch deviation ²⁾	μm	6.2
F_r	Radial runout	μm	9.3.6
F_α	Total profile deviation	μm	Figure 17
f_{dbm}	Mean base diameter difference ²⁾	μm	6.5.3
f_e	Eccentricity between gear axis and axis of gear teeth	μm	Figure 18
$f_{f\alpha}$	Profile form deviation	μm	Figure 17
$f_{f\beta}$	Helix form deviation	μm	Figure 24
$f_{H\alpha}$	Profile slope deviation ²⁾	μm	Figure 17
$f_{H\alpha m}$	Mean profile slope deviation ²⁾	μm	7.6
$f_{H\beta}$	Helix slope deviation ²⁾	μm	Figure 24
$f_{H\beta m}$	Mean helix slope deviation ²⁾	μm	8.6
$f_{H\beta mt}$	Mean helix slope deviation, in the transverse plane and tangent to the tolerance diameter ²⁾	μm	Eq 18
f_{id}	Tooth-to-tooth double flank composite deviation	μm	9.3.6
f_{is}	Tooth-to-tooth single flank composite deviation	μm	9.1
f_{Lm}	Mean lead difference ²⁾	mm	8.7
f_{pbm}	Mean normal base pitch deviation ²⁾	μm	6.5.3
f_{pbn}	Normal base pitch deviation ²⁾	μm	6.5
f_{pt}	Single pitch deviation ²⁾	μm	6.1
$f_{w\beta}$	Undulation height (along helix)	μm	Figure 24
f_1, f_2	Reading head frequency	pulses/sec	Figure 32
f_α	Pressure angle deviation ²⁾	degrees	7.5
$f_{\alpha mn}$	Mean normal pressure angle deviation ²⁾	degrees	6.5.3
$f_{\alpha mt}$	Mean transverse pressure angle deviation ²⁾	degrees	6.5.3
f_β	Helix angle deviation ²⁾	degrees	8.5
$f_{\beta m}$	Mean helix angle deviation ²⁾	degrees	8.7
g_α	Length of path of contact	mm	Figure 36
k	Number of pitches in a sector	- -	5.6
L	Left flank	- -	5.2
L	Lead of the design helix	mm	Eq 17
L_{eff}	Effective lead	mm	8.7
L_α	Profile evaluation range	mm	Figure 17
$L_{\alpha c}$	Functional profile length	mm	Eq 9
L_β	Helix evaluation range	mm	Figure 24
L_ϵ	Base tangent length to start of active profile	mm	Figure 17
l	Left hand helix	- -	5.3
m_n	Normal module	mm	Eq 1
N	Pitch number	- -	5.5
n	Number of deviation values included in the mean	- -	Eq 8
p_b	Base pitch	mm	Figure 36
p_{bn}	Theoretical normal base pitch	mm	6.5
p_m	True position pitch ²⁾	μm	6.3.2

(continued)

Table 1 (concluded)

Symbols	Definition ¹⁾	Units	Where first used
R	Right flank	- -	5.2
r	Right hand helix	- -	5.3
s	Undulation measurement bar length	mm	Figure 30
z	Number of teeth	- -	Eq 2
z_M	Number of teeth in master indexing worm wheel	- -	Eq 24
z_1	Driving gear	- -	Figure 32
z_2	Driven gear	- -	Figure 32
α_{Tt}	Transverse pressure angle at the tolerance diameter	degrees	6.5.2
α_n	Normal pressure angle	degrees	Eq 1
$\alpha_{n \text{ eff}}$	Effective normal pressure angle	degrees	6.5.3
α_t	Design transverse pressure angle	degrees	Eq 6
$\alpha_{t \text{ eff}}$	Effective transverse pressure angle	degrees	6.5.3
β	Helix angle	degrees	Eq 5
β_b	Design base helix angle	degrees	Eq 2
β_{eff}	Effective helix angle at the standard pitch diameter	degrees	8.7
$\beta_{T \text{ eff}}$	Effective helix angle at the tolerance diameter	degrees	8.7
ε_γ	Total contact ratio	- -	9.3.5
λ_β	Undulation wave length	mm	Eq 24
$\lambda_{\beta x}$	Axial wavelength of undulation	mm	Figure 24
ξ	Involute roll angle	degrees	Figure 17
I	Reference face	- -	5.2
II	Non-reference face	- -	5.2

NOTE:

1) Symbols used for deviations of individual element measurements from specified values are composed of lower case letters “f” with subscripts (exceptions include f_e , f_1 and f_2) whereas symbols used for “cumulative” or “total” deviations, which represent combinations of several individual element deviations, are composed of capital letters “F” also with subscripts. It is necessary to qualify some deviations with an algebraic sign. A deviation is positive when e.g., a dimension is larger than optimum and negative when smaller than optimum.

2) These deviations can be + (plus) or - (minus).

4 Extent of gear inspection

It is rarely necessary or economical to measure all possible deviations on all gears manufactured. Certain elements may not significantly influence the function of the gear under consideration. Some measurements can be substituted for others. Stable manufacturing processes allow a relatively small number of samples to be measured and still ensure that the required quality level is maintained. It is recommended that specific measuring plans be negotiated between purchaser and supplier.

4.1 Required inspection information

Certain necessary information should be provided to the operator(s) of the measuring equipment. The information required will vary depending on the type of measurement(s) required. Most measurement

processes require basic gear and blank data, number of teeth, pitch, pressure angle, helix angle, tooth size, outside diameter, root diameter, face width, design profile, design helix, etc. Certain measuring tasks require additional information. For example, to measure profile, the profile control diameter and start of tip break must be provided.

With mechanical measuring equipment, additional information may be required: base circle diameter (radius), base helix angle, sine bar setting, etc.

The design engineer or engineering department should be responsible for supplying this minimum required inspection information to those performing the measurements.

4.2 Measurement selection

Inspection may be carried out using a number of alternate methods. Some measurements may be

substituted for others. For example single flank composite measurement may be substituted for pitch measurement, or radial composite measurement may replace runout measurement.

A number of factors should be considered when selecting the measurements, including the quality level required, size of the gear, manufacturing cost and most important the application of the product gear.

4.2.1 Sampling

Gears, like other parts, are manufactured to a certain level of accuracy dependant on the production process used. When the process used is proven capable of producing the required accuracy level using statistical methods, sampling inspection may be utilized. Many factors may influence the sample size and frequency, foremost among these should be the assurance that the required accuracy level of the parts is met.

4.2.2 First piece inspection

It may be possible to inspect only the first piece of a batch to verify that the setup is correct, allowing the inherent accuracy of the process to assure the quality of subsequent parts.

5 Identification of deviation position

It is convenient to identify deviations associated with measurements of gear teeth by specific reference to individual right flanks, left flanks, pitches or groups of these.

In the following, conventions are described which enable positive determination of the location of deviations.

5.1 Datum axis

Specification of the design profile, design helix, and design pitch requires definition of an appropriate reference axis of rotation, called the datum axis. It is defined by specification of datum surfaces. See AGMA 915-3-A99.

The datum axis determines tooth geometry, thereby being the reference for measurements and associated tolerances. The location and orientation of the tolerance diameter circle are determined by the datum axis.

Ideally the surfaces used to construct the datum axis, the surfaces used to locate the gear for manufacturing, and the functional surfaces that define the gear axis of rotation in its final assembly would all be the same. In practice this is often not the case. For example, shaft type parts are often manufactured and inspected using female centers to define the datum axis. In cases where the inspection, manufacturing, and/or functional datum surfaces are different, these surfaces must be coincident with each other to a level of accuracy sufficient to assure the final quality of the gear is adequately represented during measurement.

The gear being measured should be oriented so that its datum axis is coincident with the axis of rotation of the measuring instrument. In the case of mounting the gear between centers, care must be taken to assure that the mounting arbor, if used, is in good condition, and the female centers are clean and concentric with the datum surfaces of the gear. In the case of computer controlled measuring instruments, it may be possible to mount the gear with significant deviation to the instrument's axis of rotation. In that case, the measuring program must be capable of mathematically correcting the errors resulting from this off axis mounting condition.

5.2 Right or left flank

It is convenient to choose one face of the gear as the reference face and to mark it with the letter "I". The other non-reference face might be termed face "II".

For an observer looking at the reference face, so that the tooth is seen with its tip uppermost, the right flank is on the right and the left flank is on the left.

Right and left flanks are denoted by the letters "R" and "L" respectively.

5.3 Right hand or left hand helical gears

The helix of an external or internal helical gear is referred to as being right hand or left hand. The hand of helix is denoted by the letters "r" and "l" respectively.

The helix is right hand (left hand) if, when looking from one face, the transverse profiles show successive clockwise (counter-clockwise) displacement with increasing distance from an observer.

5.4 Numbering of teeth and flanks

Looking at the reference face of a gear, the teeth are numbered sequentially in the clockwise direction. The tooth number is followed by the letter R or L,

indicating whether it is a right or a left flank. Example: "Flank 29 L".

5.5 Numbering of pitches

The numbering of individual pitches is related to tooth numbering as follows: pitch number " N " lies between the corresponding flanks of teeth numbers " $N-1$ " and " N "; with a letter R or L it is indicated whether the pitch lies between right or left flanks. For example "Pitch 2 L", (see figures 1 and 2).

5.6 Number of pitches " k "

The subscript " k " of a deviation symbol denotes the number of consecutive pitches to which the deviation applies.

In practice, a number is substituted for " k ", for example F_{p3} indicates that a given cumulative pitch deviation refers to three pitches.

6 Measurement of pitch deviations

6.1 Pitch deviation

Index, single pitch (f_{pt}), and total cumulative pitch (F_p) are elemental parameters relating to the accuracy of tooth locations around a gear. The following is a description of the measuring methods and a guide to the interpretation of data generated by the measuring devices.

6.2 Pitch deviation measurement

Measurements for determining index, single pitch (f_{pt}), and total cumulative pitch (F_p) are made:

- relative to the datum axis of the gear;
- at the tolerance diameter, d_T ;
- In the specified tolerancing direction (within the transverse plane along the arc of the tolerance diameter).

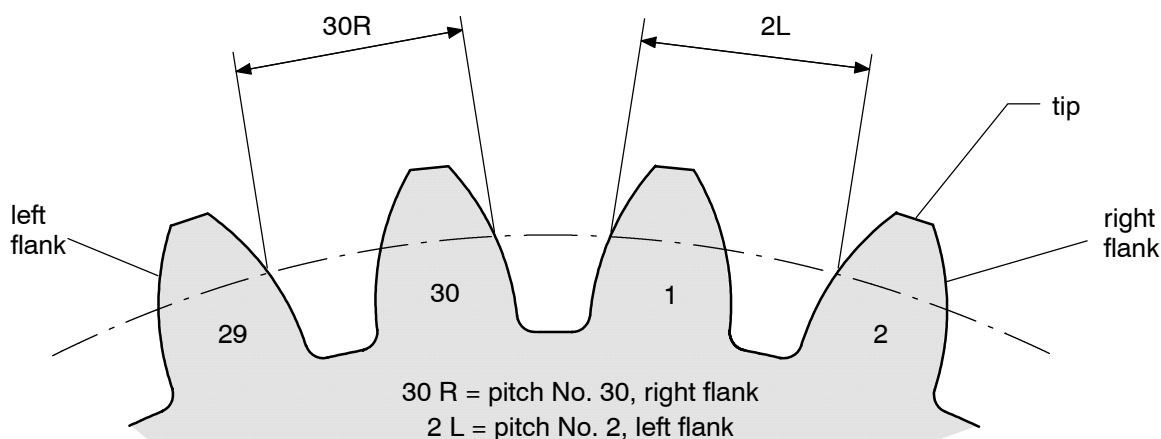


Figure 1 - Notation and numbering for external gear

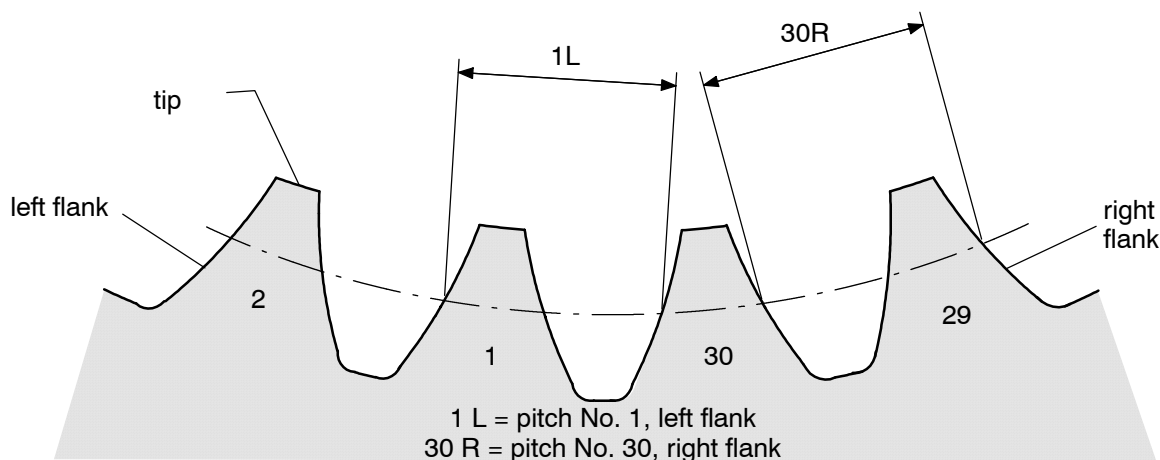


Figure 2 - Notation and numbering for internal gear

Measurements made at different diameters or in other directions must be adjusted so that they are equivalent to measurements at the tolerance diameter and in the tolerance direction. This adjustment must be made before comparison of test results to tolerances.

Sector pitch deviation ($F_{ps/8}$) is an optional parameter described in Annex E of ANSI/AGMA 2015-1-A01. Measurements of sector pitch deviation are also expected to conform to the above specified requirements.

Pitch should be measured on both left and right flanks. However, if the specific operating direction of the gear is known, only the loaded flanks need to be measured.

6.3 Pitch deviation measurement methods

Pitch parameters can be measured by either of two types of device. The indexing (single probe) device determines the location of each tooth around a gear, relative to a datum tooth (the index). The pitch comparator (two probe) device compares the distances between adjacent tooth flanks to the distance

between an initial reference pair of adjacent tooth flanks.

The various pitch parameters can all be determined by either measuring device with the application of suitable calculations. The indexing method is usually preferred because of its accuracy and simplicity. However, for large diameter gears, use of the pitch comparator method may be preferable.

Coordinate measuring machines without a rotating table can also be used for measurements of pitch parameters by probe movements that correspond to the principle of the indexing method.

6.3.1 Indexing pitch measurement method

The indexing (single probe) device uses an angular indexing apparatus such as an index plate, circle divider, optical or electronic encoder, or polygon and auto collimator to precisely rotate the gear by an angular increment equal to its pitch, or $360^\circ/z$ (see figure 3). The degree of its precision must be consistent with the quality grade and diameter of the gear.

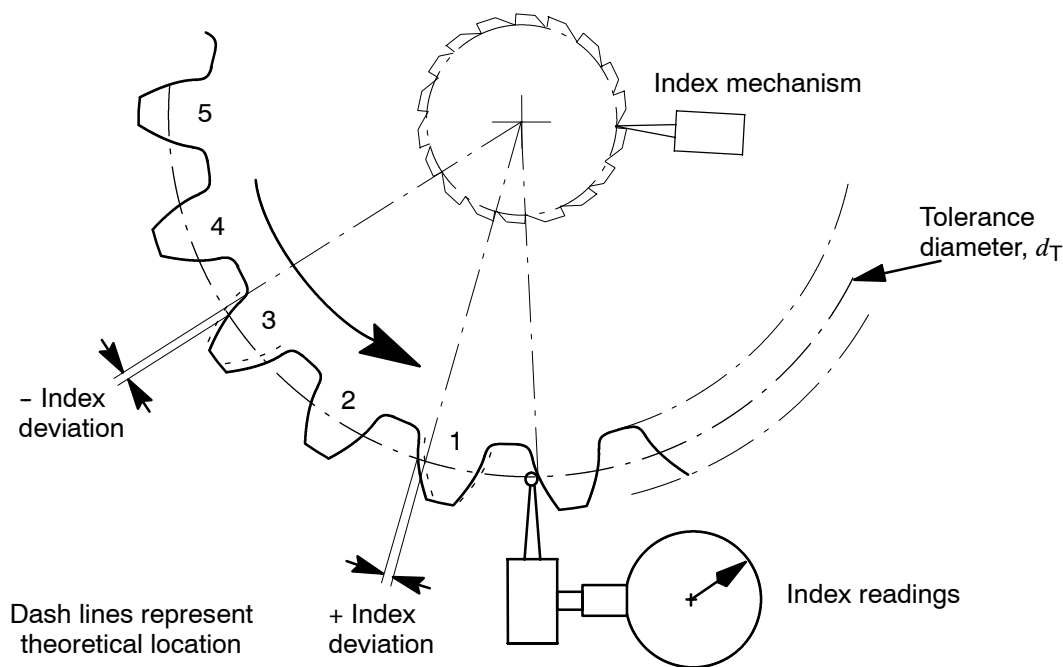


Figure 3 - Schematic of single probe measuring device

The single probe should be oriented to contact the tooth flanks at the tolerance diameter, d_T , and to gather measurements in the specified measurement direction. The single probe is adjusted to indicate zero while the device is contacting the randomly selected initial test tooth flank. As the gear is incrementally rotated around its datum axis, the single probe moves in and out on a precision slide and stop, measuring each successive tooth flank position, relative to the indexing mechanism. This process is repeated until every tooth has been measured.

It is common practice to complete this series of measurements by taking a final measurement on the initial reference tooth, thereby closing the circle. Ideally, this would produce a second measurement value of zero for the first tooth, as was set at the beginning of the process. Excessive deviation of this second measurement value from zero indicates a problem with the measurement.

6.3.1.1 Calculation of index

If the indicator always reads plus material as a plus reading and the gear is indexed counterclockwise (teeth are numbered clockwise), then the right flank measurement values provided by the indexing (single probe) pitch measurement device can be used directly as the plus and minus values of index for each tooth of the gear (see figure 3). Left flank single probe measurement values must be multiplied by -1 to produce plus and minus index values. Other pitch parameters may then be calculated from that data.

If a graphical recorder is used, data gathered by the single probe measurement device will appear in the form shown in figure 4. This figure shows the measurement value of the initial measured tooth set to zero, thereby establishing it as the reference. The measured values shown for all other teeth then represent the positional deviations of those teeth from the initial reference tooth.

6.3.1.2 Calculation of single pitch, f_{pt}

Subtraction of each successive pair of index values produces the plus and minus values of single pitch deviation for each adjacent pair of tooth flanks of the gear. See Clause 5 for specified tooth numbering, pitch numbering, and flank naming conventions.

The number 1 single pitch deviation value is equal to the index value of the last tooth subtracted from the index value of the first tooth. The number 2 single

pitch deviation value is equal to the index value of the first tooth subtracted from the index value of the second tooth. Since the index value of the first tooth is set to zero, the number 2 single pitch deviation value is equal to the index value of the second tooth. The number 3 single pitch deviation value is equal to the index value of the second tooth subtracted from the index value of the third tooth, and so on.

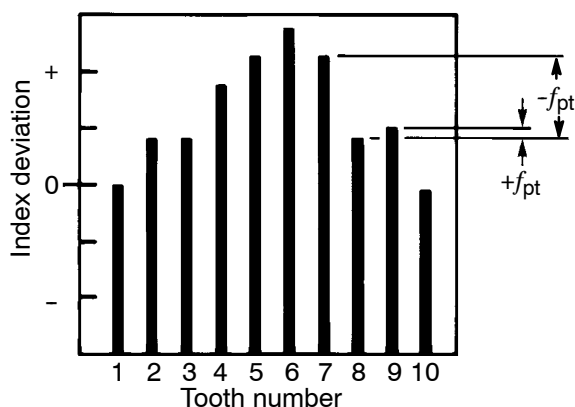


Figure 4 - Single pitch deviation, single probe device

If a graphical recorder is used, data gathered by the single probe measurement device will appear in the form shown in figure 4. Single pitch deviation values, f_{pt} , are shown as the differences between adjacent index values.

6.3.1.3 Calculation of total cumulative pitch deviation, F_p

The total cumulative pitch deviation, F_p , is equal to the difference between the most positive and the most negative index value for the complete gear.

6.3.1.4 Calculation of sector pitch deviation, $F_{ps/8}$

Calculation of the sector pitch deviation, $F_{ps/8}$, is presented in Annex E of ANSI/AGMA 2015-1-A01.

6.3.2 Comparator pitch measurement method

The pitch comparator (two probe) device may be mechanized or hand-held. Measurements made by the mechanized version are preferred. In either case, both probes should be oriented to contact adjacent tooth flanks at the tolerance diameter.

One probe serves to establish a reference position upon a tooth flank. The second probe is fitted with either a mechanical or an electronic indicator to measure variations of its position from the first probe. The device is adjusted to indicate zero while the probes are contacting the randomly selected initial pair of teeth (see figure 5).

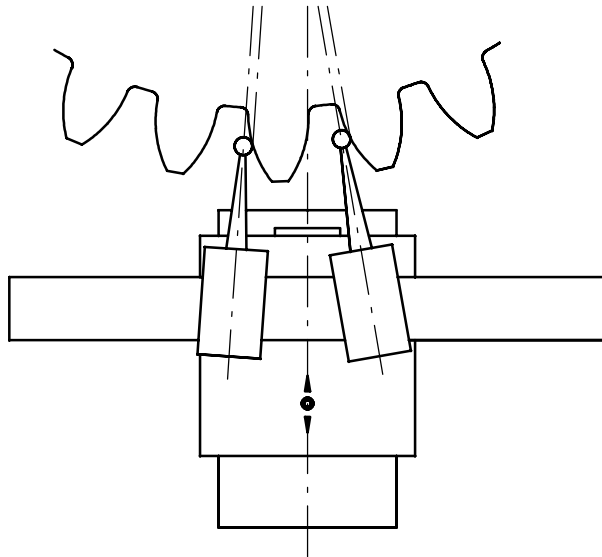


Figure 5 - Pitch measurement with a pitch comparator

The mechanized pitch comparator is a device with a rotational axis that positions the gear for measurement. The gear must be mounted with its datum axis coincident with the pitch comparator's rotational axis.

The two probes should be oriented to contact the adjacent tooth flanks within the same transverse plane, at the tolerance diameter, d_T . As the gear is rotated around its datum axis, the pitch comparator moves in and out on a precision slide and stop, measuring each successive adjacent tooth pair. This process is repeated until every adjacent pair of teeth has been measured.

The hand-held pitch comparator is a portable device that lacks a means of referencing the datum axis of the gear. It is therefore fitted with a positioning stop that contacts the outside diameter of the gear, which thereby becomes the reference for pitch measurements. This method requires that special consideration be given to the concentricity of the outside diameter of the gear with its datum axis.

The two probes must be oriented to contact the adjacent tooth flanks within a normal plane. The hand-held pitch comparator is applied successively to each pair of teeth with each indicator measurement observed and recorded. This process is repeated until every adjacent pair of teeth has been measured (see figure 6).

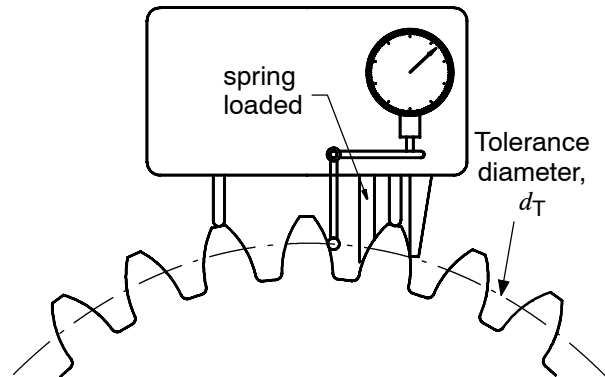


Figure 6 - Circular pitch measurement, two probe device

Since the hand-held pitch comparator measures in the normal plane, the measurements must be converted to transverse pitch deviations before being summed to determine index as described in 6.3.2.3.

It is important to understand that the readings collected from two probe pitch comparators are relative to a randomly selected tooth pair of unknown position. They must not be compared to the single pitch tolerances, until they are adjusted by true position pitch, p_m .

6.3.2.1 Calculation of true position pitch, p_m

The true position pitch, p_m , is the measurement value for any perfectly spaced tooth pair, with the given setup of the pitch comparator. It is equal to the average value found by summing all the adjacent tooth pair measurements then dividing the result by the number of tooth pairs (i.e., the number of teeth).

If a graphical recorder is used, data gathered by the pitch comparator method will appear in the form shown in figure 7. This figure shows the measurement value of the initial pair of teeth (1-2) set to zero. Also shown is the true position pitch, p_m , as the calculated mean of pitch comparator measurement values.

6.3.2.2 Calculation of single pitch deviation, f_{pt}

Subtraction of the true position pitch, p_m , from each adjacent tooth pair measurement produces the plus and minus values of single pitch deviation, f_{pt} , for each tooth pair of the gear. See Clause 5 for specified tooth numbering, pitch numbering, and flank naming conventions.

If a graphical recorder is used, data gathered by the pitch comparator method will appear in the form shown in figure 7. Single pitch deviation values, f_{pt} ,