American Gear Manufacturers Association

Technical Resources

ANSI/AGMA 2111-A98

Metric Edition of ANSI/AGMA 2011-A98

Reaffirmed December 2004

American National Standard

Cylindrical Wormgearing Tolerance and Inspection Methods (Metric)

ANSI/AGMA 2111-A98

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American National Standard

Cylindrical Wormgearing Tolerance and Inspection Methods (Metric)
ANSI/AGMA 2111–A98
(Metric Edition of ANSI/AGMA 2011–A98)

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Approved October 1, 1998

ABSTRACT

This standard describes and defines variations that may occur in unassembled wormgearing. It displays measuring methods and practices, giving suitable warnings if a preferred probe cannot be used. The applicability of single or double flank composite testing is discussed, using a reference gear. Tooth thickness measurement is shown using direct measurement as well as the use of measurements over wires or pins. Equations for the maximum variations are given for the stated ranges, as a function of size, pitch and tolerance grade.

Published by

American Gear Manufacturers Association
1500 King Street, Suite 201, Alexandria, Virginia 22314

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Printed in the United States of America

ISBN: 1–55589–717–7

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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 2111–A98, *Cylindrical Wormgearing Tolerance and Inspection Methods (Metric)*.]

The purpose of this standard is to establish geometrical accuracy communication between a manufacturer and purchaser of unassembled cylindrical wormgearing with axes at right angles.

AGMA 390.02 September 1964 was a replacement for AGMA 234.01 for fine pitch wormgearing. ANSI/AGMA 2000–A88 is a partial revision of AGMA 390.03, but does not cover wormgearing. AGMA 390.03a of 1988 still only covered fine pitch wormgearing. ANSI/AGMA 2111–A98 then is a replacement for AGMA 390.03a for fine pitch wormgearing. In addition, it also covers coarse pitch wormgearing.

The Cylindrical Wormgearing Committee began working on this standard in August, 1993. At that time, it was determined the International Standards Organization's (ISO) method for tolerance grades would be used in this standard.

ANSI/AGMA 2111–A98 was approved by the AGMA membership in June, 1998 and approved as an American National standard on October 1, 1998.

Suggestions for improvement of this standard 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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American National Standard –

Cylindrical Wormgearing Tolerance and Inspection Methods (Metric)

1 Scope

This standard establishes a classification system which may be used to communicate geometrical accuracy specifications of unassembled cylindrical wormgearing with axes at right angles. It also provides information on measuring methods and practices. This standard provides the gear manufacturer and the gear purchaser with a mutually advantageous reference for uniform tolerances and inspection procedures. Tolerance grades 3 through 12 are defined in this standard and are based on the relative effect of geometrical errors on conjugate action for wormgear sets acting as speed reducers.

1.1 Tolerance equations and tables

Tolerance equations are provided in clause 5 for calculating the maximum values allowed by the specific tolerance grade. Tables are provided in annex A for reference.

1.2 Measuring methods and practices

Measuring methods and practices are included in order to promote uniform inspection procedures (see clause 4). These methods permit the manufacturer and purchaser to conduct measuring procedures which are accurate and repeatable to a degree compatible with the specified tolerance grade.

1.3 Exceptions

This standard applies to individual worm and gear components. It does not establish a tolerance grade for enclosed drive assemblies. Establishing ratings based on tolerance grade is beyond the scope of this standard. Gear design and backlash are also beyond the scope of this standard. Refer to the latest AGMA Publications Catalog for applicable standards. This standard does not apply to worms with mean diameters larger than 400 mm, nor does it apply to wormgears with mean diameters larger than 2540 mm. This standard does not apply to geometry finer than 0.5 module. This standard does not apply to spiral gears or any type other than cylindrical single enveloping wormgearing.

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2 Symbols, terms and definitions

The symbols, terms and definitions used in this standard are, wherever possible, consistent with ANSI/AGMA 1012–F90 and other approved AGMA documents.

2.1 Symbols

Table 1 is a list of the symbols used in this standard, along with the associated terms. The “Where first used” column gives the clause or equation number where the particular symbol is first used.

2.2 Definition of terms

axial plane: The axial plane is the plane containing the line of axis of the worm. Diameters may be measured in this plane but thread surfaces would require a theoretical knife edge measurement. These measurements may be obtained by indirect means using normal plane measurements. The probe measurement in Method “A” will give a direct axial measurement, however, since the normal to probe center is repeated at each point.

datum thread: The designated thread used as the starting point for measuring other threads.

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Table 1 – Symbols used

Symbol	Description	Units	Where first used
B	Axial backlash in the worm	mm	Eq 3
D_m	Mean diameter of gear	mm	Fig. 10
d	Worm pitch diameter	mm	Eq 2
d_m	Mean diameter of worm	mm	Eq 13
d_{pin}	Best pin diameter	mm	4.12.2
d_3	$d - \Delta d$, undersize pitch diameter of worm with backlash	mm	Eq 1
F	Distance from worm center to pin center	mm	Eq 6
G	Available pin diameter	mm	4.12.2
L	Thread lead	mm	Eq 5
M	Diameter over best pins	mm	Eq 6
M_A	Actual over pin measurement	mm	4.12.2
M_3	Dimension over pins unequal to theoretical pins	mm	4.12.2
m_t	Transverse module of wormgear	mm	Eq 19
m_x	Axial module of worm	mm	Eq 13
p_m	True position pitch	µm	4.7.8.1
V_{ap}	Total accumulated pitch variation	µm	2.2
V_{ap2}	Wormgear accumulated pitch variation (total index variation)	µm	4.7
V_{apk2}	Wormgear total accumulated pitch variation within a sector of k pitches	µm	4.7.10
V_{apT}	Total accumulated pitch variation tolerance	µm	2.2
V_{apT2}	Wormgear total accumulated pitch variation tolerance	µm	Eq 21
V_{apT1}	Worm total accumulated pitch variation tolerance	µm	Eq 16
V_{ap1}	Accumulated worm pitch variation	µm	4.2.4
V_l	Lead variation	µm	2.2
V_{lf}	Lead form variation	µm	2.2
V_{lfT}	Lead form tolerance	µm	2.2
V_{lfT1}	Worm lead form tolerance	µm	4.5
V_{lf1}	Worm lead form variation	µm	4.5
V_{lT}	Lead tolerance	µm	2.2
V_{lT1}	Worm lead variation tolerance	µm	4.4
V_{l1}	Worm lead variation	µm	4.4
V_p	Pitch variation	µm	2.2
V_{p2}	Wormgear pitch variation	µm	4.7
V_{pT}	Pitch variation tolerance	µm	2.2
V_{pT2}	Wormgear pitch variation tolerance	µm	Eq 20
V_{pT1}	Worm pitch variation tolerance	µm	4.2.2
V_{p1}	Worm pitch variation	µm	4.2
V_r	Runout	µm	2.2
V_{r2}	Wormgear tooth runout	µm	4.6

(continued)

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Table 1 (*concluded*)

Symbol	Description	Units	Where first used
V_{rT}	Runout tolerance	μm	2.2
V_{rT2}	Wormgear runout tolerance	μm	Eq 19
V_{rT1}	Worm runout tolerance	μm	Eq 13
V_{r1}	Worm thread radial runout	μm	4.1
V_{s2}	Wormgear spacing variation	μm	Fig 13
V_t	Thread thickness variation	μm	2.2
V_{tT}	Thread thickness tolerance	μm	2.2
V_x	Index variation	μm	2.2
V_{x2}	Wormgear index variation reading	μm	Fig 12
V_ϕ	Profile variation	μm	2.2
$V_{\phi 2}$	Wormgear profile variation	μm	4.8
$V_{\phi T}$	Profile tolerance	μm	2.2
$V_{\phi T1}$	Worm profile variation tolerance	μm	4.3
$V_{\phi 1}$	Worm profile variation	μm	4.3
w	Tolerance grade	– –	Eq 13
z_1	Number of worm threads	– –	4.2.2
z_2	Number of gear teeth	– –	Eq 19
Δd	$B \cot \phi_x$, the amount by which the pitch diameter of a worm with backlash may be considered undersize	mm	Eq 2
ΔM	Change in calculated over pin measurement	mm	Eq 9
ΔM_A	Change in actual over pin measurement	mm	Eq 11
Δt	Thread thickness difference between calculated and measured	mm	4.12.2
ϕ_n	Normal pressure angle	degrees	Eq 1
ϕ_t	Transverse pressure angle	degrees	Eq 7
ϕ_x	Axial pressure angle	degrees	Eq 3
λ	Lead angle	degrees	Eq 4
λ_m	Mean lead angle	degrees	4.7.5
λ_3	Lead angle at undersize pitch diameter	degrees	Eq 1

Subscripts

a	Accumulated	t	Thickness, transverse
f	Form	x	Axial plane
k	Number of pitches within a sector	ϕ	Profile
l	Lead	A	Actual
m	Mean	T	Tolerance
n	Normal plane	1	Worm
p	Pitch	2	Gear
r	Runout		

direction of measurement: The direction of measurement is considered as the direction of probe deflection during the measurement process. The most common options are *axial* – in the direction of the axis of the worm, and *normal* – along the mathematical normal to the surface being measured.

functional part of the profile: In figure 1, the part starting with the point closest to the root of the worm that engages in meshing with a wormgear tooth (*cutoff point A*), and ending with the point just before the *drop–off region* (*cutoff point B*) is the functional part of the profile. The region beyond cutoff point B is characterized by strictly minus profile errors and does not participate in meshing.

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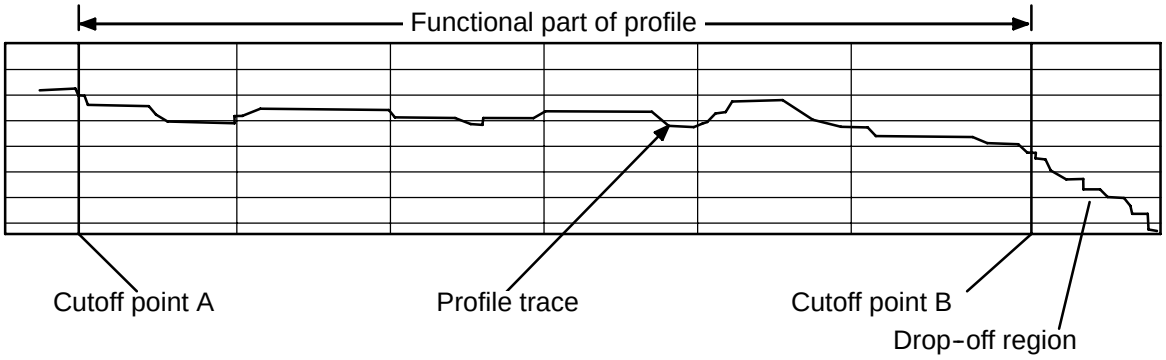

Figure 1 - Functional part of the profile - cutoff points, drop-off region

index variation, V_x: Index variation is the displacement of a thread from its theoretical position with respect to another thread established as the datum thread. The values are given in the worm axial/gear transverse plane and should be corrected if measured in the normal or any other plane. Tolerances are only given for *Total Index Variation*, which is the difference between the largest positive and largest negative *Index Variation* on a given worm.

lead form tolerance, V_{lfT}: The lead form tolerance is the allowable amount of lead form variation over the evaluation range.

lead form variation, V_{lf}: The lead form variation is the total variation distance between the actual lead trace from the mean lead trace. The total variation is the sum of the maximum upper deviation and the maximum lower deviation between the two traces (see figure 2). The mean lead trace is established using the least squares method. This is to be done, so that within the evaluation range, the sum of the squares of the deviations of the actual lead trace from the mean lead trace is minimal. The evaluation range is equal to four axial pitches of the worm. The distance referred to in this clause is to be measured in the direction parallel to the lead variation measurement as shown in figure 2.

lead tolerance, V_{lT}: The lead tolerance is the allowable amount of lead variation over four axial pitches, as determined from the equations and shown in the tables.

lead variation, V_l: Lead variation is the difference between the theoretical and the observed axial advance of the thread for the amount of rotation necessary to advance through four axial pitches of the worm (lead variation for functional thread length). See figure 2.

normal plane: The normal plane is a plane normal to the thread surface at a specified point. At such a point, the normal plane contains the line normal to the thread surface.

pitch variation, V_p: The pitch variation is the displacement of the thread or tooth from its theoretical position with respect to its adjacent thread or tooth.

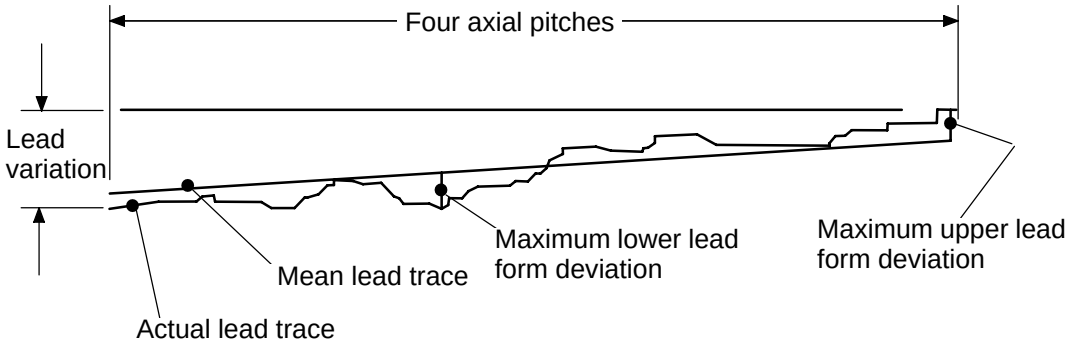

Figure 2 - Lead and lead form variation

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pitch variation tolerance , V_{pT}: The pitch variation tolerance is the permissible plus or minus pitch variation from the true position, as determined from the equations and shown in the tables. This is the maximum value for the worst two adjacent teeth.

pitch variation tolerance, total, accumulated, V_{apT}: The total accumulated pitch variation tolerance is the permissible amount of total accumulated pitch variation.

pitch variation, total, accumulated, V_{ap}: The total accumulated pitch variation is the algebraic difference between the maximum and the minimum values obtained from the summation of successive values of pitch variation, V_p. Total accumulated pitch variation is the same as total index variation. Total accumulated pitch variation is only applicable to multi–thread worms.

profile tolerance, $V_{\phi T}$: The profile tolerance is the permissible amount of profile variation in the functional profile (see figures 1 and 7).

profile variation, V_{ϕ}: The profile variation is the deviation of the measured worm thread axial section curve from the defined curve. This definition applies only to the functional part of the profile (see 4.3).

reference thread: See **datum thread**.

runout, V_r: Runout is the total variation of the radial distance between the axis and the measured surface. In addition to eccentricity, the runout measurement may also include the effects of profile, lead, index and thread or tooth thickness variations.

runout tolerance, V_{rT}: The runout tolerance is the permissible amount of runout.

thread thickness tolerance, V_{tT}: The thread thickness tolerance is the permissible amount of thread thickness variation.

thread thickness variation, V_t: The thread thickness variation is the deviation from the specified value of the thickness of the thread measured in the direction parallel to the axis of the worm, and at the specified diameter.

tolerance, $_T$ (subscript): A tolerance is the amount by which a specific dimension is permitted to vary. The tolerance is the difference between the maximum and the minimum limits, and is an absolute value without a sign.

transverse plane: The transverse plane is the plane perpendicular to the axial plane. This plane may be used as a secondary reference to the pitch variation measurement.

worm reference axis: The worm reference axis is the functional line passing through the centers of the circles of the two bearing journals of the worm or the line coinciding with the axis of the worm bore.

3 Manufacturing and purchasing considerations

This clause presents considerations for control of the various phases of manufacturing, including the recommended methods of inspection control.

These methods provide the manufacturer and purchaser with recommendations for verifying the accuracy of a manufactured product, as well as information relative to the interpretation of inspection data.

Some design and application considerations may warrant inspection or documentation not normally available in standard manufacturing processes. Specific requirements are to be stated in the contractual documents.

Throughout this clause, the term gear is meant to include both the worm and wormgear.

NOTE: This standard provides tolerances for unassembled gears. The inspection of gearing mated in an assembly for a specific application is beyond the scope of this document.

3.1 Manufacturing certification

Dimensional certification of elemental measurements in accordance with the gear's specific AGMA tolerance grade and inspection charts or data can be requested as part of the purchase contract.

The manufacturing of gearing to a specified accuracy may or may not include specific inspections. When applications warrant, detailed specific inspections, data analysis and additional considerations may be necessary to establish acceptance criteria for a gear. The specific methods of inspection, documentation of tolerance grade and other geometric tolerances of a gear are normally considered items which are to be mutually agreed upon between manufacturer and purchaser.

NOTE: Specifying an AGMA tolerance grade or inspection criteria which are in excess of those required by the application may increase the cost unnecessarily.

3.2 Process control

Process control is defined as the method by which gear accuracy is maintained through control of each

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individual step of the manufacturing process. Upon completion of all manufacturing operations, a specific gear has an inherent level of accuracy; this level of accuracy was established during the manufacturing process and is totally independent of any final inspection.

Process control includes elements such as manufacturing planning, maintenance of machine tools, cutting tool selection and maintenance, heat treatment control and quality assurance programs, as needed, to achieve and maintain the necessary gear accuracy. When properly applied, gears manufactured by specific control techniques will be found to have consistent accuracy. Therefore, careful manufacturing control at each step of the process should eliminate the need for final inspection.

However, based on appropriate confidence in the applied process control, the manufacturer of that gear must be able to certify that its tolerance grade is at least equal to that of the gears that were inspected.

NOTE: Documentation may be deemed unnecessary for products manufactured under process control when inspection records are not specified in the purchase contract.

3.3 Inspection methods

Gear geometry may be inspected by a number of methods as described in clause 4. The selection of the particular method depends on the magnitude of the tolerance, the size of the gear, the production quantities, equipment available, accuracy of gear blanks and inspection costs.

When prior agreement between the manufacturer and purchaser specifies inspection of gears, the manufacturer may select:

- the inspection method to be used from among the applicable methods described in this standard;
- the piece of inspection equipment to be used by the selected inspection method, provided it is properly calibrated;
- the number of teeth or threads to be measured to assure conformance to the specified tolerance grade.

3.4 Additional considerations

In addition to tolerance grade for certain applications, other or special considerations may be required. These may include items such as:

- backlash allowances in tooth thickness;
- materials furnished by the purchaser;
- matching gears as sets;
- reference gears for composite measurement;
- replacement gearing;
- contact pattern.

The listed items and other special considerations are to be reviewed and agreed upon by the manufacturer and purchaser.

3.4.1 Backlash allowance

An individual gear does not have backlash. Backlash is only present when one gear mates with another. The theoretical backlash of a gear set is based on the tooth thickness of each member in mesh, as well as the mounting distance at which the gears are assembled. The actual backlash will also be a function of the tolerances on tooth thickness, runout, lead, profile and mounting distance.

The methods of determining the backlash required for individual applications are beyond the scope of this standard (for additional information see ANSI/AGMA 6022-C93, *Design Manual for Cylindrical Wormgearing*).

3.4.2 Material furnished by the purchaser

Gear blanks supplied by the purchaser shall meet the specifications mutually agreed upon between manufacturer and purchaser to permit the gear manufacturer to hold the tolerances for the specified tolerance grade.

3.4.3 Matching gears as sets

Matched sets are required in some applications and can be provided, but usually at extra cost. In such cases, the purchaser must agree on the details of the additional specifications concerning how the matching is to be performed and verified. Applications requiring high accuracy gearing may necessitate the matching or modifying of worm and gear profiles such that the matched set is satisfactory for the application.

NOTE: This standard provides tolerances for unassembled gears only. The inspection of gearing mated in an assembly for a specific application is beyond the scope of this standard. However, for high accuracy gearing, the matching process can be fully satisfactory even when individual element tolerances are exceeded. The matching process for such gears sold as pairs assumes greater importance than the individual absolute measurements.

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3.4.4 Reference gears for composite measurement

When a composite check is specified, a reference gear becomes necessary. The design, accuracy, AGMA tolerance grade validation procedure and cost of a reference gear shall be negotiated between the manufacturer and purchaser. A specific reference gear is required for each different production gear design. The reference gear shall be available when the manufactured gear is to be inspected by composite measurements.

3.4.5 Contact pattern

Contact pattern is beyond the scope of this standard. For information on contact pattern, see ANSI/AGMA 6022–C93.

3.4.6 Replacement gearing

For replacement gearing, the performance obtained from the previous gearing must be evaluated. If satisfactory, replace with similar material and accuracy. If improved performance is required, modifications of material, heat treatment and tolerance grade may be considered. Consult with the manufacturer for recommendations.

3.5 Acceptance criteria

The tolerances and definitions contained in this standard prevail unless contractual agreements between the manufacturer and purchaser contain specific exceptions.

3.6 Evaluation of tolerance grade

The manufacturer or the purchaser may wish to measure one or more of the geometric features of a gear to verify its accuracy. However, a gear which is specified to an AGMA tolerance grade must meet all the individual tolerance requirements applicable to that tolerance grade.

4 Measuring methods and practices

This section describes the recommended methods and practices used for the inspection of worms and wormgears. Practices and inspection methods which are recognized and accepted throughout the wormgear industry as being reliable are covered and should provide accurate and repeatable measurements when correctly used. Experienced personnel, using calibrated instruments in a suitable environment, are required. No particular method of inspection or document is considered mandatory unless agreed upon by the purchaser and manufacturer.

4.1 Worm thread radial runout, V_{r1}

The worm thread radial runout may be measured by positioning the worm reference bearing diameters on precision V–Blocks on a flat inspection table as shown in figure 3. A shell worm is mounted on a precision arbor. Using the reference bearing diameter or the arbor diameter at each end to establish the reference axis of the worm, the height of a pin that contacts only the thread flanks is measured. The worm is rotated as many times as necessary until the maximum reading over the pin is obtained. A minimum of four (4) readings at approximately 90° of rotation of the worm starting from the maximum reading is then recorded. The radial runout, V_{r1}, is the difference between the high and low readings. These measurements should be done first near one end of the thread and repeated near the other end of the thread to assure that the axis of the thread is parallel to the axis of the shaft bearings or arbor.

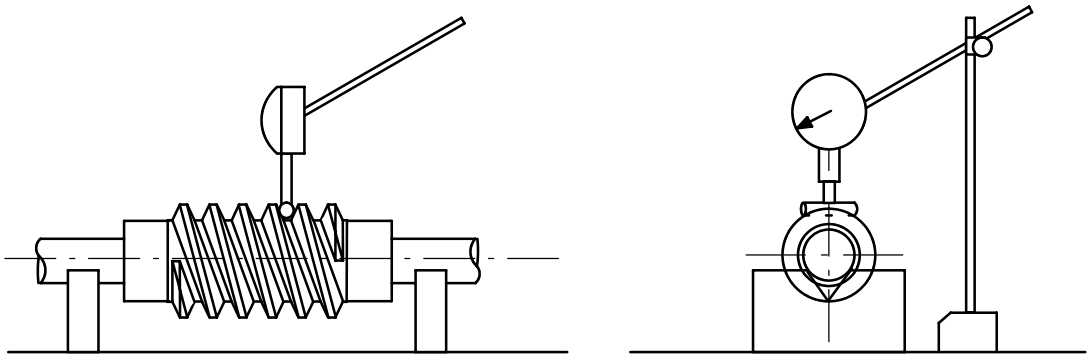

Figure 3 – Worm thread runout inspection, V_{r1}

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4.1.1 Causes of worm thread radial runout, V_{r1}

The principle cause of radial runout is eccentricity which, in turn, is caused by forming the threads from shaft centers in one machine and turning, grinding, or boring the locating reference diameters from shaft centers in another machine. However, this measurement method may include the effects of the following:

- thread thickness variations;
- out-of-roundness of either the locating reference diameters or the threads themselves;
- thread profile variations;
- variations of thread pitch in multiple thread worms;
- lead form variations in the threads.

4.1.2 Alternative method of determining worm thread runout, V_{r1}

Runout may be measured by indicating the worm root diameter in a lead checking machine, but only if the finishing tool has machined this surface simultaneously with the thread flanks. This method measures only the eccentricity component of runout and will not measure the effects of thread thickness, profile or pitch variations.

4.2 Worm pitch variation, V_{p1}

This elemental measurement applies to multiple thread worms only.

4.2.1 Worm pitch variation, V_{p1} - method A (recommended for 2 to 4 threaded worms only)

In this test, the probe of the measuring device is positioned in the plane containing the axis of the worm. The probe is then brought in contact with the first thread at the specified diameter so that it reads zero on this thread. This establishes the *reference thread*. (See figure 4.) The probe is then displaced in the axial direction by one axial pitch and the reading for the next thread is taken at the same specified diameter. Measurements are taken parallel to the worm axis. The process continues until a reading is taken for every thread. An additional reading is then taken for the reference thread to make sure it repeats. The maximum difference between adjacent thread readings is the maximum pitch variation, V_{p1}, and should be compared to the pitch variation tolerance, V_{pT1}, values given in the quality equations and tables.

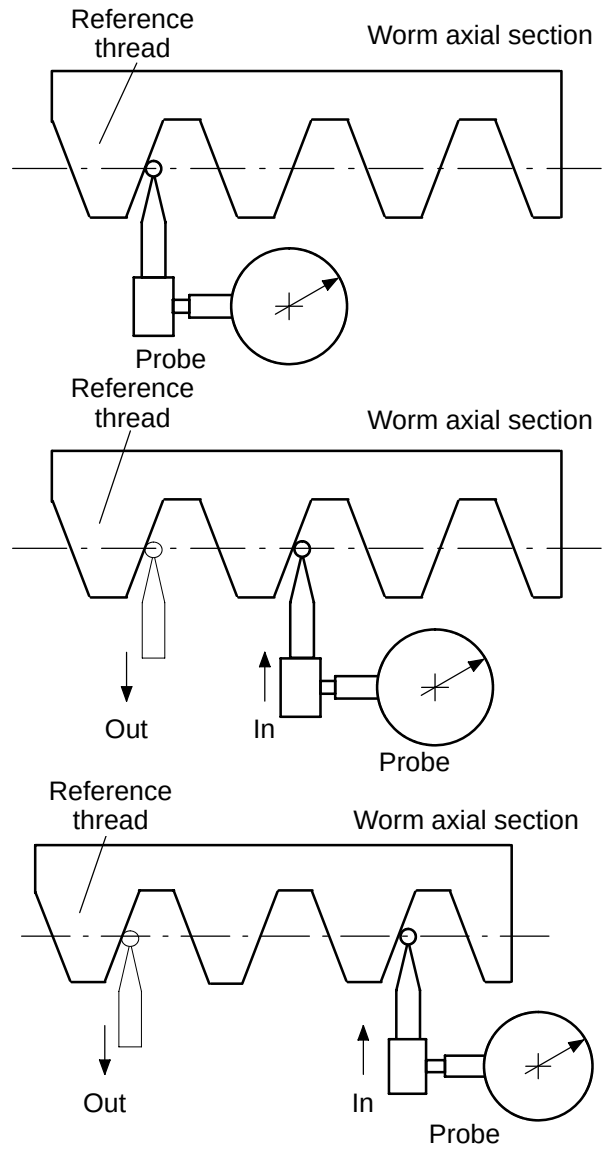

Figure 4 - Worm pitch variation inspection, V_{p1} - method A

4.2.2 Worm pitch variation, V_{p1} - method B (recommended for 2 to 20 threaded worms)

In this test, special purpose measuring machines as shown in figure 5 are required. The worm is mounted between centers with the reference bearing or arbor diameters running true and accurately driven from one end. An indicator is positioned on the first thread at approximately the worm mean diameter so as to read in the axial plane of the worm. When the worm mean lead angle is high, the indicator can be tilted to read normal to the thread but the readings, in this case, must be increased by dividing by the cosine of the worm mean lead angle. The indicator is then removed radially from the thread, the worm is accurately rotated one thread space (360 degrees/ z_1 for z_1 number of threads), and the indicator

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returned to the same radial position on the next thread. This is repeated for each thread and the starting thread to make sure it repeats. The maximum difference between adjacent thread readings is the maximum pitch variation, V_{p1}, and should be compared to the pitch variation tolerance, V_{pT1}, values given in the quality equations and tables. If the other thread flank is formed in a separate operation, the worm shaft must be turned in the checking machine and the pitch variation must be measured on the other flank. This method uses a single probe or indicator in conjunction with an indexing mechanism. A two probe device cannot normally be used to measure worm pitch variations since the two probes cannot be positioned on adjacent threads particularly when 2 through 5 thread worms are to be measured.

4.2.3 Causes of worm pitch variations, V_{p1}

The usual cause of worm pitch variation is machine inaccuracy when multiple thread worms are indexed to either chase, mill or grind each thread. The readings can reflect the eccentricity of the entire thread with respect to its reference bearing or arbor diameters. Since measurements are made at the mean diameter and at the same axial location of each thread, profile and lead variations have a lesser influence on pitch variations. A gradual increase in pitch for 180 degrees of rotation of the worm with a gradual decrease in pitch for the remaining rotation reflects eccentricity and is less detrimental to operation than having one relatively large pitch variation. Such a condition may cause a plus thread thickness condition with a minimum thread thickness condition in the adjacent thread. This suggests an alternate method of determining pitch variation values where thread thickness readings are made at the same depth of thread and at the same axial location on each thread.

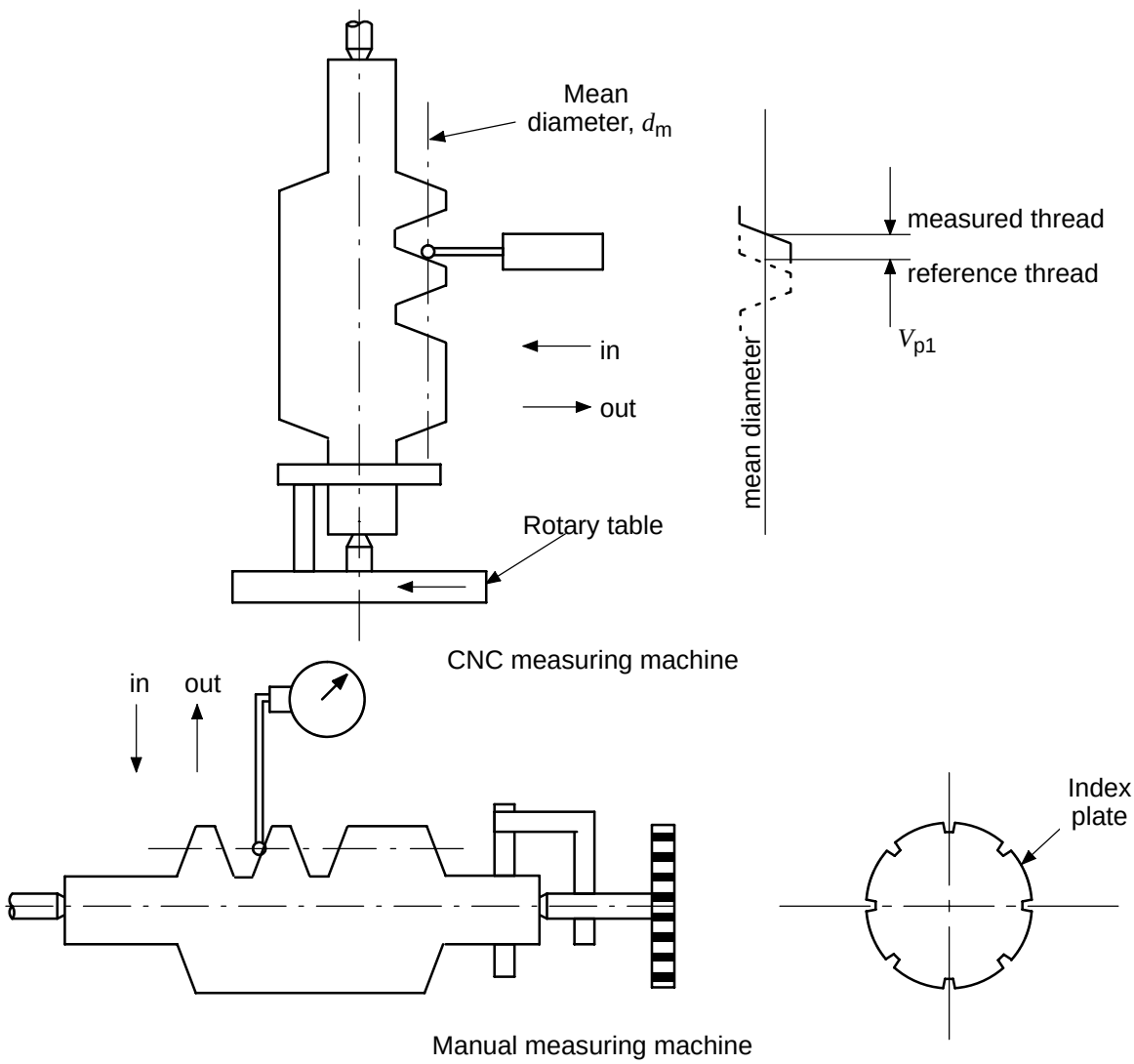

Figure 5 – Worm pitch variation inspection, V_{p1} – method B

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