

AMERICAN GEAR MANUFACTURERS ASSOCIATION

***Code of Inspection Practice - Part 5:
Recommendations Relative to Evaluation
of Gear Measuring Instruments***

AGMA ISO 10064-5-A06



AGMA INFORMATION SHEET

(This Information Sheet is NOT an AGMA Standard)

American
Gear
Manufacturers
Association

Code of Inspection Practice - Part 5: Recommendations Relative to Evaluation of Gear Measuring Instruments

AGMA ISO 10064-5-A06

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ABSTRACT

This information sheet provides methods and examples to support the implementation of ANSI/AGMA ISO 18653-A06. It proposes evaluation and calibration procedures for involute, helix, runout, and tooth thickness measurement processes. Methods are given for the evaluation of condition and alignment of instrument elements such as centers, guideways, probe systems, etc. Guidance is given on the application of measurement processes to the inspection of product gears, including fitness for use and the recommended limits for U_{95} uncertainty based upon the accuracy tolerances of product gears to be inspected.

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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 AGMA ISO 10064-5-A06, *Code of Inspection Practice – Part 5: Recommendations Relative to Evaluation of Gear Measuring Instruments*.]

In 1988, The American Gear Manufacturers Association recognized the need for establishment of standards for the calibration of gear measuring instruments. The AGMA Calibration Committee was formed between April 1989 and their first meeting in February 1990. Between 1995 and 1999, this committee, as members of the Committee on Gear Metrology (COGM), was instrumental in the establishment of the Oak Ridge Gear Metrology Laboratory for the purpose of calibrating gear artifacts traceable to the National Institute for Standards and Technology.

The AGMA Calibration Committee, between 1990 and 1998, developed and published three national standards on calibration of gear measuring instruments: ANSI/AGMA 2110-A94, *Measuring Instrument Calibration – Part I, Involute Measurement*, ANSI/AGMA 2113-A97, *Measuring Instrument Calibration, Gear Tooth Alignment Measurement*, and ANSI/AGMA 2114-A98, *Measuring Instrument Calibration, Gear Pitch and Runout Measurements*.

These standards covered elemental measurements specified in the accuracy requirements of ANSI/AGMA 2015-1-A01, *Accuracy Classification System – Tangential Measurements for Cylindrical Gears*.

In 1999, the content of these standards was combined and submitted to ISO as a proposed work item. As a result, ISO TC60/WG2 used this as the basis for development of ISO 18653:2003, *Gears – Evaluation of instruments for the measurement of gears*, and ISO/TR 10064-5:2005, *Code of inspection practice – Part 5: Recommendations relative to evaluation of gear measuring instruments*.

During the ISO development period the Calibration Committee decided that supplemental information, on measurement system conditions for calibration, accuracy requirements and uncertainty determination, was desirable to have in an AGMA Information Sheet. This resulted in the publication of AGMA 931-A02, *Calibration of Gear Measuring Instruments and Their Application to the Inspection of Product Gears*, in 2002.

The ISO documents expanded the AGMA work and included material on the determination of uncertainty of measurement and the introduction of spherical calibration artifacts. The natural evolution, therefore, was the adoption of the two comprehensive ISO documents as national documents in place of the four AGMA documents.

AGMA ISO 10064-5-A06 replaces AGMA 931-A02, also the instrument set-up and measurement recommendations contained within ANSI/AGMA 2010-A94, ANSI/AGMA 2110-A94, ANSI/AGMA 2113-A97, and ANSI/AGMA 2114-A98. The requirements for instrument calibration can be found in ANSI/AGMA ISO 18653-A06.

This information sheet is an identical adoption of ISO/TR 10064-5:2005.

The first draft of AGMA ISO 10064-5-A06 was made in October 2005. It was approved by the AGMA membership in July 2006.

Suggestions for improvement of this standard will be welcome. They should be sent to the American Gear Manufacturers Association, 500 Montgomery Street, Suite 350, Alexandria, Virginia 22314.

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American National Standard –

Code of Inspection Practice – Part 5:

Recommendations

Relative to Evaluation of

Gear Measuring Instruments

1 Scope

This information sheet provides additional information and examples to support the implementation of ANSI/AGMA ISO18653. It provides evaluation and calibration procedures for involute, helix, pitch, runout, and tooth thickness measurement processes.

Methods are provided for evaluation of the condition and alignment of instrument elements such as centers, guide ways, probe systems, etc. Recommendations are included for establishment of a proper environment and for statistical data evaluation procedures.

It also covers the application of gear artifacts to the estimation of U_{95} measurement process uncertainty. Guidance on the application of measurement processes to the inspection of product gears is provided, including fitness for use and the recommended limits for U_{95} uncertainty based upon the accuracy tolerances of product gears to be inspected.

Many of its recommendations may also be applicable to the measurement of worms, worm wheels, bevel gears and gear cutting tools.

2 References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ANSI/AGMA ISO 18653-A06, *Gears – Evaluation of instruments for the measurement of gears*

ISO 1122-1:1998, *Glossary of gears – Geometrical definitions*

ISO1328-1:1995, *Cylindrical gears – ISO system of accuracy – Part 1: Definitions and allowable values of deviations relevant to corresponding flanks of gear teeth*

ISO1328-2:1997, *Cylindrical gears – ISO system of accuracy – Part 2: Definitions and allowable values of deviations relevant to radial composite deviation and runout information*

ISO/TR 10064-1:1995, *Code of inspection practice – Part 1: Inspection of corresponding flanks of gear teeth;*

ISO/TR 10064-2:1996, *Code of inspection practice – Part 2: Inspection related to radial composite deviations, runout, tooth thickness and backlash*

ISO/TR 10064-3:1996, *Code of inspection practice – Part 2: Recommendations relative to gear blanks, shaft center distance and parallelism of axes*

ISO 10360-1:2000, *Geometrical Product Specifications (GPS) – Acceptance and reverification tests for coordinate measuring machines (CMM) – Part 1: Vocabulary*

ISO 14253-1:1998, *Geometrical Product Specifications (GPS) – Inspection by measurement of workpieces and measuring equipment – Part 1: Decision rules for proving conformance or non-conformance with specifications*

ISO/TS 14253-2:1999, *Geometrical product specifications (GPS) – Inspection by measurement of workpieces and measuring equipment – Part 2 Guide to the estimation of uncertainty in GPS measurement, in calibration of measuring equipment and in product verification*

Guide to the expression of uncertainty in measurement (GUM), BIPM, IEC, IFCC, ISO, IUPAC, IUPAP, OIML 1st edition 1993, corrected and reprinted in 1995

3 Definitions of terms

For the purpose of this document, the terms and definitions given in ISO 1122-1, ISO1328-1, ISO1328-2 and ANSI/AGMA ISO 18653-A06 apply.

4 Instrument environment

4.1 Environment

The stability of the environment will affect accuracy of the calibration process and measurement of production parts. The measurement temperature should be maintained as a constant. It is recommended that the temperature be 20 °C. Standards or instrument manufacturer's recommendations often require an environment controlled to the extent necessary to assure continued measurements of required accuracy considering temperature, humidity, vibration, cleanliness and other controllable factors affecting precision measurement.

4.1.1 Important parameters

The following parameters are of primary importance¹⁾:

- the cooling (heating) medium, usually air;
- flow rate, distribution and velocity of the cooling (heating) medium;
- frequency and amplitude of temperature variations of the cooling (heating) medium;
- temperature gradients within the cooling (heating) medium;
- vibrations;
- electrical power supply quality.

4.1.2 Practical guidelines

The following are practical guidelines for gear measurements. However, compliance with these guidelines does not guarantee measurements to a specific accuracy.

- **Artifact temperature.** Tooling, artifacts and other test pieces should be left for an adequate period to stabilize to ambient temperature. Artifact temperature ideally should be the temperature at which it was calibrated.

- **Mean temperature variation.** The instrument manufacturer's temperature variation guidelines for the desired accuracy should be consulted. If this information is not available, it is recommended that the mean temperature should not change more than 1 °C per hour, with a maximum change of 3.5 degrees per day.
- **Temperature cycles.** The temperature may cycle ± 2 °C, centered on the mean temperature, every 5 minutes or faster. The thermal inertia of most mechanical systems will allow for rapid cyclic temperature undulations within these guidelines for the stated accuracy. If a temperature cycle of the instrument approaches 1 °C in 15 minutes, serious effects on the measuring system accuracy may occur. Many people use an air conditioner in an attempt to achieve thermal control. The temperature sensors in these units may be very slow to respond to temperature changes. If the response is slower than 5 minutes, serious effects on measurement accuracy may be noted.
- **Temperature gradient.** The temperature should be within 0.5 °C over the entire area of the instrument surface. The best way to do this is with a high air flow. Air flow must be uniform throughout the room to prevent dead spots and prevent gradients. To accomplish this, diffuse the air coming in to the room and if possible design multiple air returns to further diffuse the air uniformly in the room. The goal is to have all air moving uniformly in the room and at the same temperature. Moving air must remove heat from electronic controls, computers, motors, hydraulics, people, lights, etc., to prevent gradients.
- **Vibrations.** Vibrations caused by instrument movements should not be allowed to interfere with measurements. Also, vibrations from the surrounding environment should be observed or measured. If they are affecting instrument accuracy, vibration isolation of the instrument or a suitable foundation may be necessary.
- **Electrical power supply.** Power fluctuation may cause some electronic instruments and computer numerical control positioning systems to malfunction.

¹⁾ A more thorough discussion of the effects may be found in such standards as ASME B89.6.2, *Temperature and Humidity Environment for Dimensional Measurement* (R2002)

4.1.3 Workshop environment

It is recommended that measuring instruments are situated in a temperature controlled room. However many measuring instruments are placed in a shop environment where it is difficult to maintain a process measurement uncertainty of 5 microns. Accumulation of dirt or other contaminants on the ways of the instrument can cause inaccuracies as well as premature wear.

If an instrument must be used in this kind of environment, care must be taken to avoid certain conditions, such as:

- local radiant heat sources such as space heaters or sunlight through nearby windows that may distort the instrument;
- roof vents that allow cold air to drop on the instrument;
- cooling systems or open windows that cause a draft to hit one side of the instrument.

The formulae in 4.2.1 and 4.2.2 may also be used for estimating the effect of a stable, but consistent difference in instrument temperature from the standard temperature (20 °C). If the formulae are used, the coefficient of thermal expansion (CTE) should be the instrument material or encoder scale value and the sign of the resulting compensation should be changed. The user should be aware that the results might vary depending upon the location of temperature measurement.

4.2 Effect of temperature on gears and artifacts

Temperature can have a significant effect on the geometry of gears and artifacts. Temperature effects upon involute profile slope, $f_{H\alpha}$, helix slope, $f_{H\beta}$, and tooth thickness measurements of external gears and artifacts can be predicted using the following formulas. Such calculations assume uniform temperature of the given test piece; localized temperature variations cannot be conveniently modeled. Temperature of the measuring instrument is not considered in these calculations.

The temperature of the measuring instrument is not considered in these calculations, but a difference between standard temperature (20 °C) and the instrument temperature will also cause errors in measurement result.

It may be desirable to correct profile and helix slope measurement values for temperature effect. Such

corrections are required by U_{95} estimation methods described in clause 7 of this document.

Uniform temperature variations of a gear or artifact are not considered to have an effect upon pitch or runout (tooth position) parameters.

4.2.1 Profile temperature effect calculation

For involute profile measurement, the effect of temperature can be modeled by considering the associated change in the base circle diameter. The effect upon profile slope, $f_{H\alpha}$, can be calculated as follows:

- a) Given (typical) data

z is number of teeth;
 m_n is normal module;
 β is helix angle;
 α_n is normal pressure angle;
 $L_{\alpha s}$ is roll length to the start of profile analysis;
 $L_{\alpha e}$ is roll length to the end of profile analysis;
 CTE is coefficient of thermal expansion (approximately $11.5 \times 10^{-6} \text{ C}^{-1}$ for steel).

NOTE: When profile analysis start and end points are specified in roll angle degrees (ξ_y), conversion to roll length can be done with the following formula.

$$L_y = \left(\frac{\xi_y}{360} \right) (d_b \pi) \quad (1)$$

- b) Calculate the slope change due to the temperature difference.

$$\Delta f_{H\alpha} = (L_{\alpha e} - L_{\alpha s})(t_a - t_s) \text{ CTE} \quad (2)$$

where

t_a is the actual (measured) temperature;
 t_s is the standard temperature (20 °C).

See annex A for an example and further information.

4.2.2 Helix temperature effect calculation

For helix measurement, the effect of temperature can be modeled by considering the associated change in the lead. The effect upon helix slope, $f_{H\beta}$, can be estimated as follows:

- a) Given (typical) data in 4.2.1 a), plus:

L_β is helix evaluation range;

- b) Calculate the base helix angle, β_b :

$$\beta_b = \arcsin(\sin \beta \cos \alpha_n) \quad (3)$$

- c) Calculate the slope change due to the temperature difference:

$$\Delta f_{H\beta} = -L_\beta \tan \beta_b (t_a - t_s) \text{ CTE} \quad (4)$$

See annex A for an example and further information.

4.2.3 Tooth thickness temperature effect calculation

In addition to involute profile and helix, tooth thickness may be significantly affected by temperature. These effects can be modeled by considering the associated change in the tooth section intersecting the pitch diameter, where tooth thickness is usually measured. The effect of temperature upon normal tooth thickness of an external gear can be estimated as follows:

- a) Given (typical) data in 4.2.1 a), plus:

s_n is normal tooth thickness at the reference pitch diameter, d :

- c) Calculate the reference pitch diameter, d :

$$d = z \frac{m_n}{\cos \beta} \quad (5)$$

- b) Calculate the change in normal circular tooth thickness at the reference pitch diameter of an external gear due to the temperature difference.

$$\Delta s_n = d \tan \alpha_n (t_a - t_s) \text{ CTE} \quad (6)$$

See annex A for an example and further information.

5 Measurement system condition

Many factors affect the accuracy of gear measuring instruments. These include squareness and parallelism of the instrument guideways to each other and to the rotary table, straightness of the guideways, linear positioning errors, and angular motion errors (pitch, roll and yaw) of the moving components of the instrument. Errors caused by electronic components, scales, controls, and software may also adversely effect the accuracy of a measuring instrument. There are various methods of measuring these errors. While a complete discussion of machine kinematics and electronic controls is beyond the scope of this document, it is recommended that users of these instruments be aware of the many possible sources of inaccuracy.

Some manufacturers of measuring instruments provide detailed procedures for periodically verifying their product's conformance to original factory

specifications. The generalized tests and recommended tolerances found in this section are for use in the absence of, or in addition to, the instrument manufacturer's recommended procedures. These tests are not to be considered a replacement for the manufacturer's procedures.

Gear accuracy grade and parameters to be tested should be identified prior to starting verification procedures. The actual work envelope should also be known. Results of all procedures should be recorded to document this verification work and to provide data for statistical analysis.

5.1 Evaluation procedure for generative instruments

Proper operation of important components of gear measuring instruments can be verified by the procedures outlined in the following. This verification procedure should begin with a visual inspection of the instrument to assure that no obvious detrimental conditions exist that would impair proper operation. Centers, drivers and measuring probe styli that are subject to wear and damage should be checked. Confirm also that environmental conditions meet the requirements of 4.1.

The probe systems and indicators that measure instrument errors should be calibrated and have an appropriate discrimination (1 μm or less is recommended). The user should note that data capture rates and filters will affect the measurement results. See 5.4 for further information.

5.1.1 Verification of mounting centers

Inspection of gear geometry by generative methods requires mounting the gear such that its datum axis of rotation is coincident with the instrument's main spindle axis. See ISO/TR 10064-3. Any eccentricity or non-parallelism of this mounting will cause an error of measurements. See figure 1.

Between-centers mounting of test gears is a common practice. Most gear testing instruments are fitted with centers, one on the main spindle and one on a tailstock assembly. Misalignment and runout of these centers are common. Verification of instruments used for testing should therefore begin with the observation of these mounting centers.

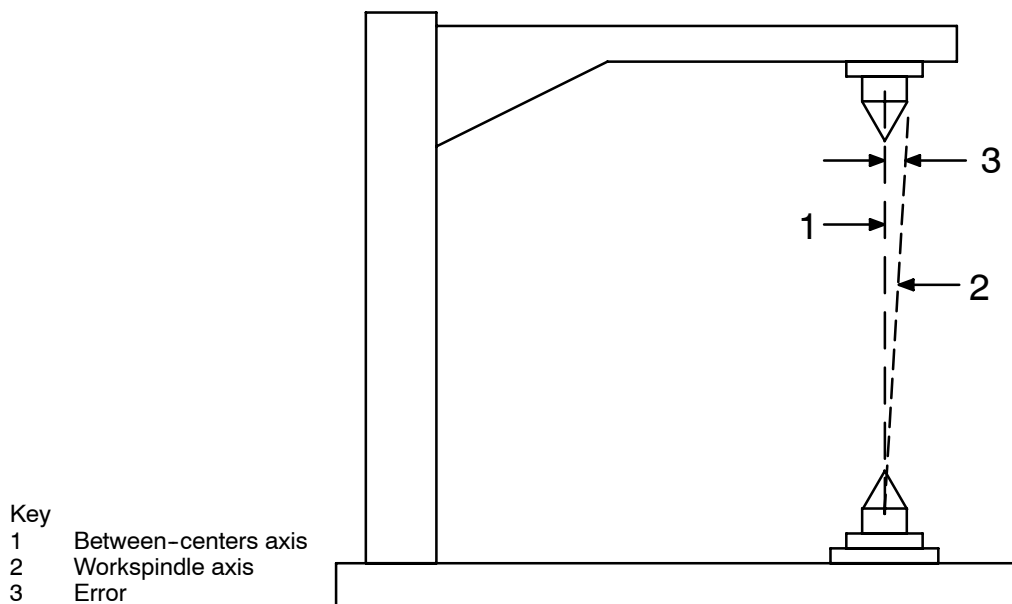


Figure 1 - Alignment error of the spindle axis and the between-centers axis

5.1.1.1 Center runout

Using an indicator with an appropriate discrimination, measure the runout (TIR) of the main spindle center in a direction normal to the surface. This measurement of runout should be within the manufacturer's specifications or the guidelines listed in table 1. It is advisable to measure runout of each

center at the small and large end to detect bent or skewed centers.

Load the spindle assemblies by mounting an arbor between centers. The length, accuracy, or configuration of this arbor is not significant. See figure 2.

Table 1 - Recommended guidelines for deviations when checking instrument alignment¹⁾

Accuracy grade to be tested ISO 1328-1 ISO 1328-2	Runout of centers (TIR) μm	Z-axis parallelism with spindle axis in any observed 200 mm region		Alignment of top center with spindle axis (TIR) per 200 mm ⁴⁾
		A ²⁾ , μm	B ³⁾ , μm	
2	1	1	2	2
3	1	2	2	2
4	1	2	3	3
5	2	3	4	4
6	2	4	6	6
7	3	5	6	6
8	4	5	6	6
9	5	7	6	6
10	7	10	8	8
11	10	10	12	12
12	10	10	12	12

NOTES:

- 1) The guidelines are for multi-purpose instruments. Single purpose instruments may only require one or more of the parameters.
- 2) In the measuring (base tangent) plane. See figure 5.
- 3) Perpendicular to the measuring plane. See figure 6.
- 4) Alignment tolerance is the greater of 2 μm or the table tolerance per 200 mm of the length, R , in figures 3 and 4.

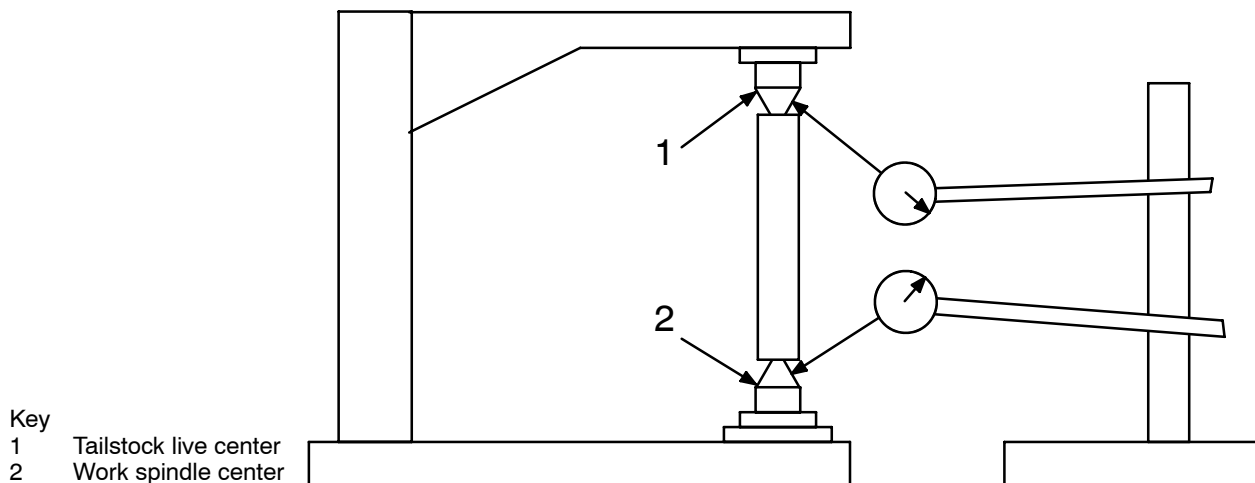


Figure 2 - Center runout test

5.1.1.2 Tailstock center positioning

A testing practice often called sweeping can be used to effectively evaluate the position of the tailstock center relative to the main spindle axis. Sweeping the tailstock center at only one location on the tailstock slide verifies its positioning for testing gears at that location only. Sweeping the tailstock center at two significantly separated tailstock slide locations verifies both lateral positioning and angular alignment of the tailstock slide with the main spindle axis. If straightness of travel of the tailstock slide has been confirmed to be within manufacturer's specifications by other methods, a two-location test will verify tailstock center positioning at all locations. Otherwise, sweeping of the tailstock center at a minimum of three significantly separated locations within its range of operation is required. For high quality gears, it is recommended to sweep the tailstock for each unique configuration before inspection.

Two sweeping test setups will be described.

- a) The first is recommended only for instruments with a vertical main spindle axis. Figure 3 provides an example of this setup. The spindle assemblies are loaded by mounting an arbor between centers. The accuracy and configuration of this arbor is not significant as the indicator and arbor rotate together. A minimum of two such sweeping tests, each using different length arbors, is normally required. The lengths of the two arbors should be selected to be toward opposite ends of the range of tailstock operation.

An indicator with an appropriate discrimination is mounted so as to be carried by the rotating main spindle and simultaneously to measure in a radial

direction the alignment (TIR) of the arbor near the tailstock center. These measurements of the tailstock center alignment with the spindle axis should be within the value listed in table 1.

The value is stated as a ratio of permissible center alignment (TIR) to the axial distance of that measurement from the main spindle center. The recommended value therefore changes with measurement location and should be adjusted accordingly. The tolerance value is the greater of 2 μm or the table tolerance per 200 mm of the length, R , in figure 3.

- b) The second sweeping test setup is recommended for instruments with a horizontal main spindle axis but may also be used for vertical instruments. Figure 4 provides an example of this setup. This figure shows the sweeping setup made at two locations, L_1 and L_2 . As before, the spindle assemblies are loaded by mounting different length arbors between centers at the two locations.

In this case, an indicator with appropriate discrimination is mounted so as to be carried by the rotating test arbor and to measure in an axial direction the alignment (TIR) of a fixture carried by the rotating main spindle. These alignment measurements of the tailstock center with the spindle axis should be within the value listed in table 1.

The value is stated as a ratio of permissible center alignment (TIR) to the axial distance of that measurement from the main spindle center. The recommended value therefore changes with measurement location and should be adjusted accordingly. The tolerance value is the greater of 2 μm or the table tolerance per 200 mm of the length, R , in figure 4.

5.1.2 Axial measuring slide verification

Parallelism of the path of the axial measuring slide with the main spindle axis should be confirmed. A parallel mandrel is required for this evaluation.

Alternatively, an accurately manufactured mandrel can be used in conjunction with a self-proving, reversal-method. This verification should apply to the length of the work envelope, or a minimum 80% of the full travel, see figures 5 and 6.

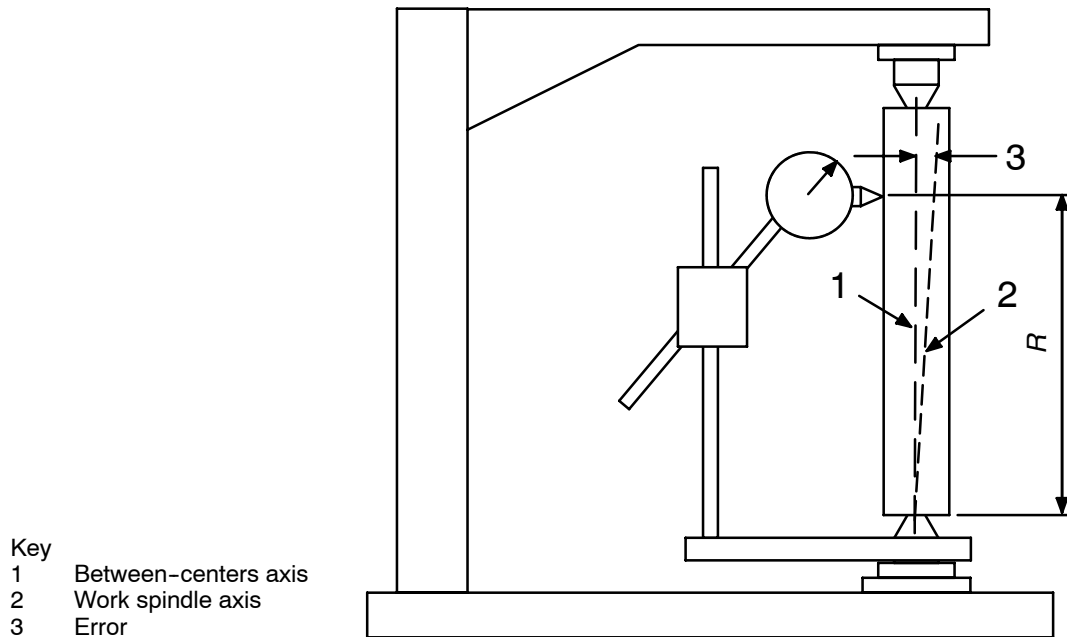


Figure 3 - Tailstock alignment measurement method (vertical axis instruments only)

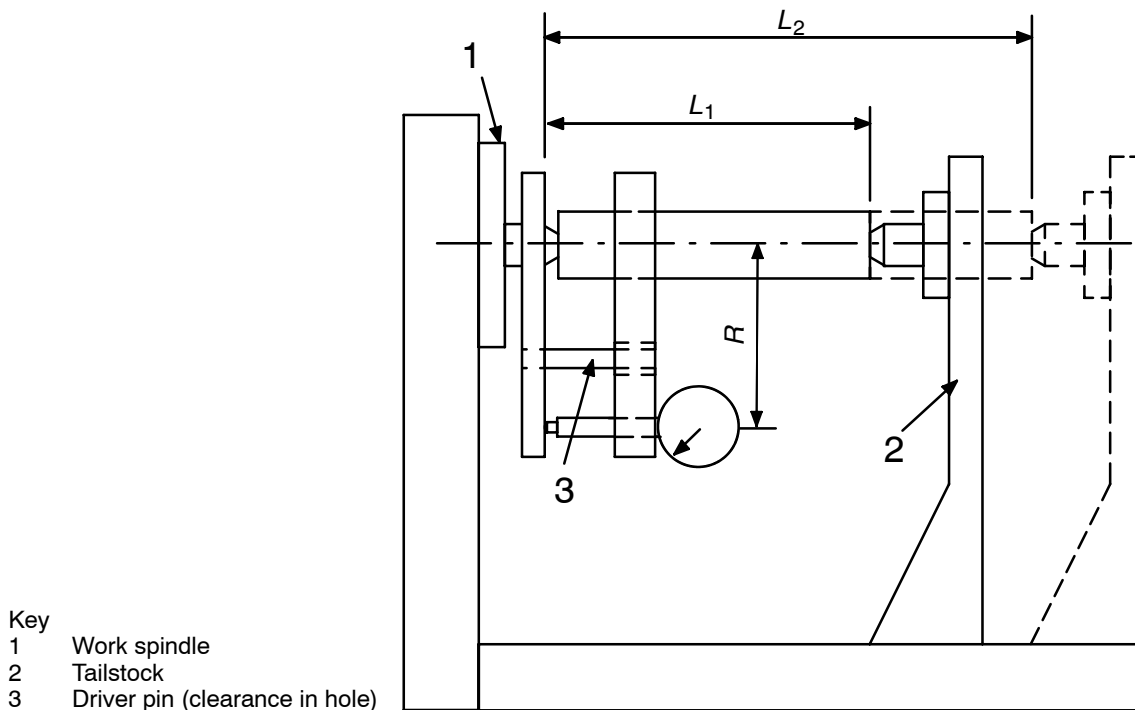


Figure 4 - Tailstock center alignment fixture for horizontal or vertical work spindles

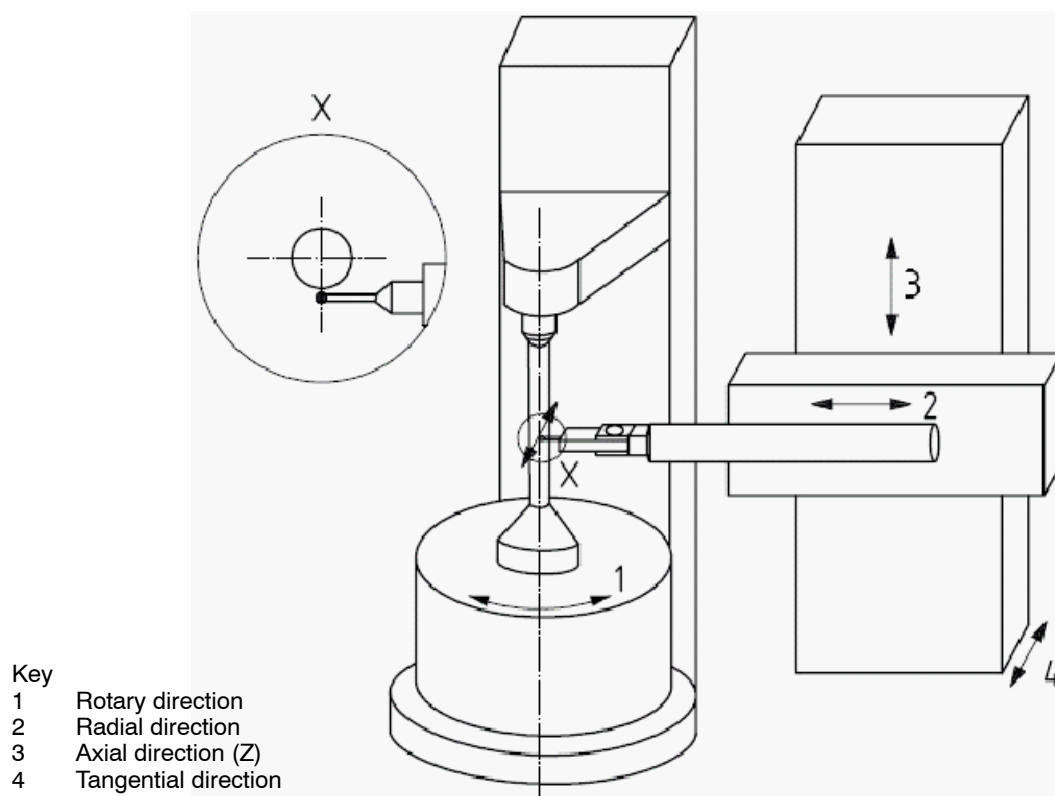


Figure 5 - Z-axis to “between centers” axis alignment verification - axial plane parallel to the measuring (base tangent) plane

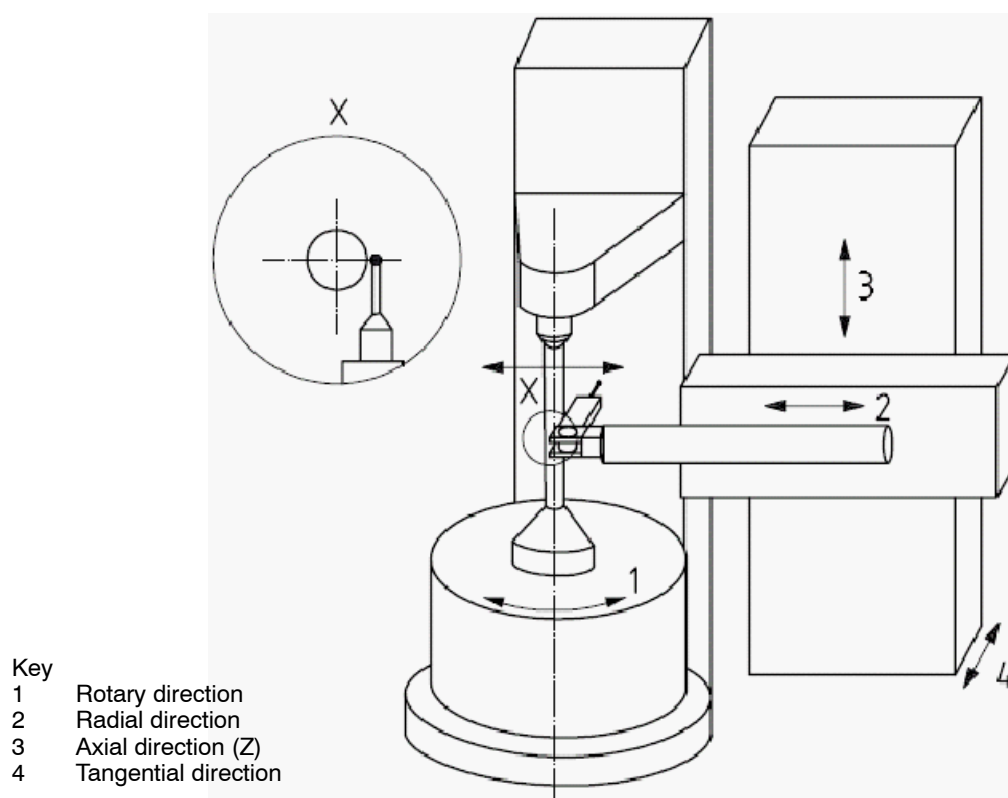


Figure 6 - Z-axis to “between centers” axis alignment verification - perpendicular to measuring plane

5.1.2.1 Center mounted mandrel

The mandrel may be mounted between centers. In this case, its orientation concentric with the main spindle axis should be confirmed by two observations. First, its concentricity near the main spindle center and near the tailstock center can be confirmed by measuring its radial runout near those centers. Second, its concentricity near the tailstock center can be confirmed by sweeping the mandrel. If the sweeping setup recommended for vertical axis instruments is used, the test indicator should be positioned near the tailstock center. It is recommended that this mounting of the test mandrel be optimized before observation of axial measuring slide parallelism. This may include minimizing runout of the main spindle center, runout of the tailstock spindle center, and alignment error of the tailstock slide assembly at this test location.

5.1.2.2 Direct mounted mandrel

Alternatively, the test mandrel can be attached directly to the main spindle, thereby eliminating adverse influences of mounting centers. In this case, its orientation concentric with the main spindle axis must be confirmed by observation of radial runout near each end of the mandrel. Centering and tilting adjustments will be required to optimize this mounting before observation of axial measuring slide parallelism.

5.1.2.3 Axial slide parallelism testing

Once a calibrated mandrel has been properly oriented on the instrument, it should be tested by traversing its length with the measuring probe carried by the axial measuring slide. This will reveal errors of straightness and alignment of the axial slide. The observation should be made in a radial direction within two different axial planes:

- the plane parallel with the measuring plane (the base tangent plane);
- the plane perpendicular to the measuring plane.

See figures 5 and 6.

These measurements of axial measuring slide parallelism with the main spindle axis should be within the guidelines listed in table 1. Two such guideline values are provided: one for observations parallel with the measuring plane, and one for those perpendicular to the measuring plane. These value(s) apply to any observed 200 mm region of the axial measuring slide.

5.1.3 Change in alignment with heavy load

Ideally, tests should be carried out with the instrument head placed at the limits of the measuring capacity [i.e., with the tangential slide length at $\pm$ the maximum length of roll (4 axis instruments only) and radial slide at the limiting base radius], see figure 7.

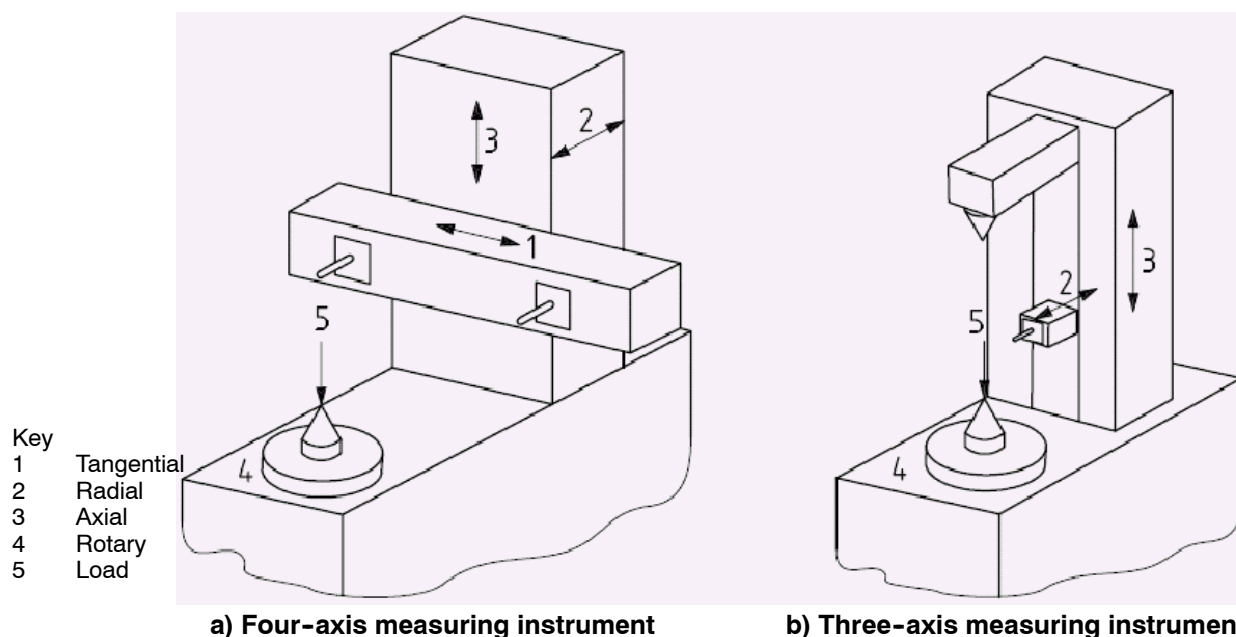


Figure 7 - Position of the base tangent slide during the deflection tests ($\pm$ maximum length of roll for the verified measuring volume)

The measuring instrument table or table center should be loaded with a test gear or artifact that provides a tooth geometry that satisfies the measuring volume as mentioned above. Weights are then to be added in increments to represent the maximum weight capacity expected in service or the instrument's work spindle weight capacity as stated by the original equipment manufacturer. The smaller of the two values should be used.

Coordinate measuring machines (CMM) may be loaded uniformly over the work table area, as appropriate for typical measuring applications.

The change in relative alignment and machine bed deformation should be such that the alignment and straightness accuracy requirements specified, or in accordance with table 1, are still satisfied with the load applied.

The test procedure should be carried out as follows:

- Load and secure a flat test gear on the measuring table.
- Check the helix of the test gear on a marked and designated tooth. Note the present deviations in alignment from the recording chart.
- With the test gear remaining on the measuring table, place a weight of approximately 1/4 of the required weight capacity on top of the test gear.
- Repeat the same test as indicated in b) above. The same tooth and radial tooth position as in b) should be used. Compare the test result to that obtained in the original test b).

- Increase the incremental load, if possible, with a total of four increments, checking the test results at each incremental increase.
- Verify that the change in relative alignment and bed deformation is within the specified limits as stated, or in accordance with table 1.

5.2 Evaluation procedures for CMM type measuring instruments

On CMMs, with or without rotary table, the measurement of gears is possible when dedicated software is available. The gear axis definition is achieved by the measurement of the bearings (journals) or other reference surfaces and used for the further measurement.

5.2.1 Performance test according to ISO 10360

In ISO 10360 a special test for the performance of coordinate measuring machines is established. The verification is executed on gauge blocks and on a high precision calibration sphere with a diameter of normally 25 or 30 mm, see figure 8.

There are 3 tests specified:

- E Volumetric length measuring deviation;
- R Volumetric probing deviation;
- THP Volumetric scanning deviation.

For test E a set of 5 calibrated gauge blocks must be measured 3 times at 7 positions with 2 probing per gauge. The orientation of the gauges can be in any direction in space (volumetric). All of the 105 measurements must be in tolerance (100%).

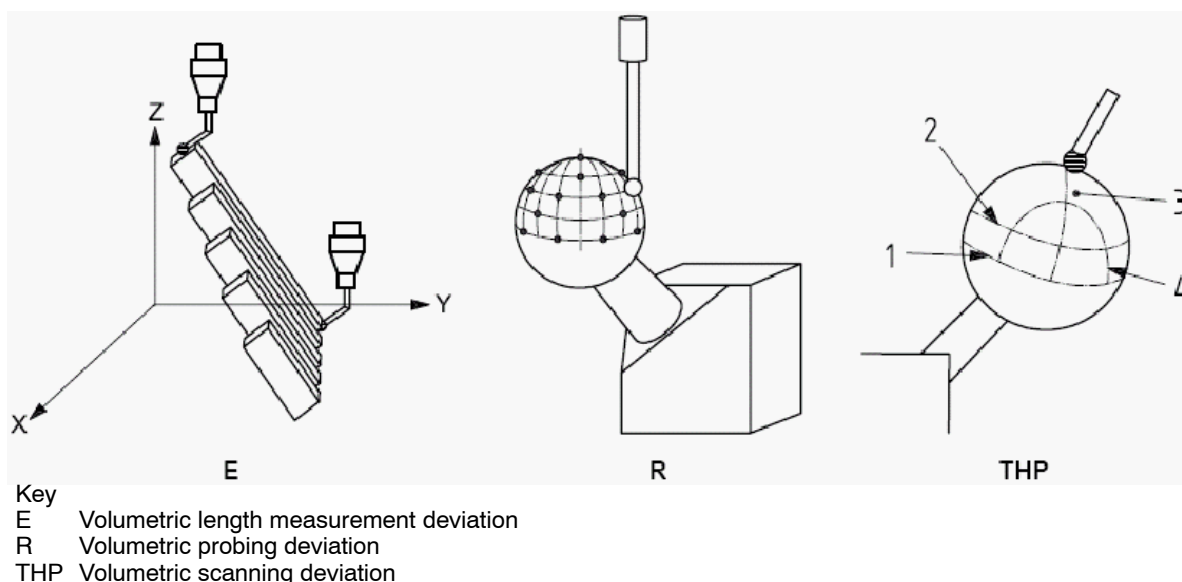


Figure 8 - CMM volumetric tests

For test R a high precision (half) sphere must be measured with 25 equally distributed single probing points. All probing (100%) must be used for the evaluations. The total measured form deviation is the volumetric probing uncertainty R.

For test THP several scanning lines on the sphere must be executed.

Tests R and THP are influenced more by the performance of the probing system, while test E covers both the probing system and the overall accuracy of the system.

5.2.2 Ball plate test

Alternatively, a ball plate is commonly used to check CMM accuracy. A ball plate consists of a steel plate or other material on which a rectangular grid pattern of high precision spheres are placed, see figure 9. With a special software program the positions of the spheres are automatically measured and compared with the calibrated positions. The ball plate is mounted in different orientations in the measuring volume, i.e., parallel to the coordinate planes and in the diagonal.

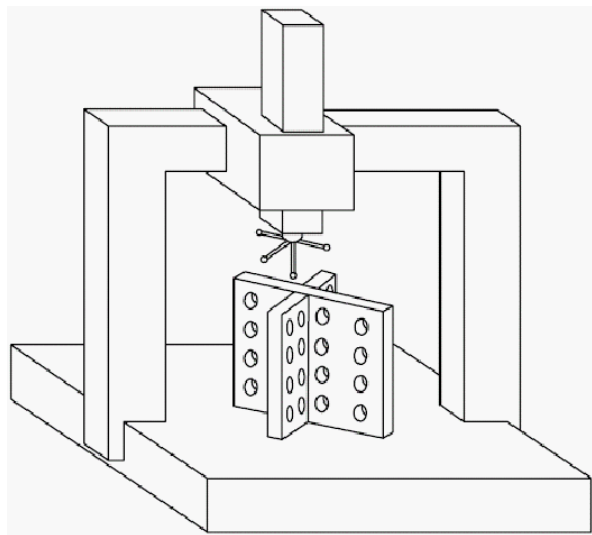


Figure 9 - Ball plate tests

5.2.3 Rotary tables

For CMM instruments with rotary tables the procedures of ISO 10360 should also be followed, see figure 10.

5.3 Probe system

The data acquisition and processing system consists of the probe stylus, probe mechanism and the data recording system.

5.3.1 Stylus

Select and check the condition of the stylus and record its size and geometry. Verify the position of the stylus on the instrument by re-qualifying, or use the manufacturer's setting fixture.

5.3.1.1 Spherical stylus tips used on generative instruments

Spherical stylus tips are often used, particularly on computer controlled generative or CMM instruments. Spherical stylus tips are less subject to wear, less likely to mark the surface of the tooth flank, and are better suited to computer controlled position qualification methods than sharp stylus tips.

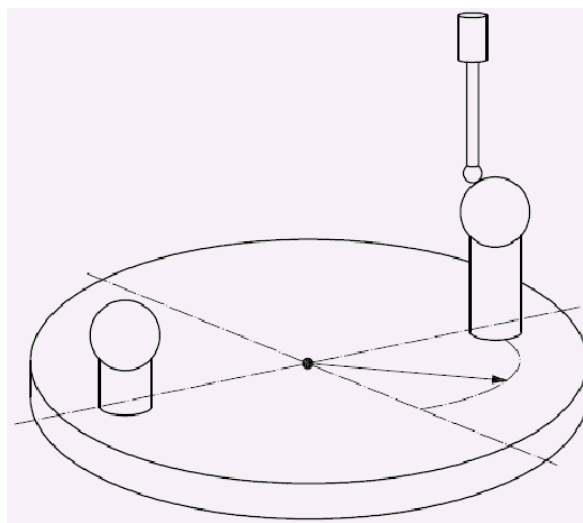


Figure 10 - Rotary table tests

Generative instruments observe tooth geometry errors as deviations from a generated nominal geometry. Involute profile testing involves generating a nominal involute according to the constant-rise-cam characteristic of that curve. During such tests, the center of the spherical probe tip and its point of contact with the tooth surface are constrained within the plane of action. Generative helix testing is carried out according to generation of the nominal helix. Generative pitch testing involves rotational positioning of the gear according to ideal equally-spaced tooth locations. On unmodified involute helicoid tooth flanks, the point of contact between the spherical stylus tip and the tooth flank will remain constant during the course of tests carried out according to these generative methods. Contact vector variation and stylus tip sphericity are not significant issues in this case.

However, tooth flanks may present substantial deviations from involute geometry. This may be due to intentional modifications such as tip relief, or unintentional production variations. Substantial deviations from involute geometry cause variation in the contact vector that may affect observations of the position and contour of these regions of deviation, even when employing generative testing methods. In such cases, it may be necessary to apply software corrections to the test data.

Use of spherical stylus tips will cause apparent rounding at the ends of tooth flank surfaces even in the presence of relatively sharp edges. This commonly occurs at the outside diameter on involute profile tests and at the face ends on helix tests. Such apparent rounding may be eliminated by application of software corrections. Alternatively, it may simply be ignored since the apparent rounding occurs only beyond the edge of the tooth flank. Evaluation of edge rounding or chamfer features is usually best carried out with instruments other than those intended for gear flank metrology.

Spherical stylus tips produce a higher level of mechanical filtering of test data than sharp stylus tips. In most cases, this is not a significant issue.

5.3.1.2 Spherical stylus tips used on CMM instruments

A CMM typically does not use generative methods. Rather, tooth flank geometry is considered as a series of points, each with a set of three dimensional coordinates. During such tests the points of contact between the spherical stylus tip and the tooth flanks will vary substantially. To achieve valid measurements, this contact vector variation must be accommodated by the associated computer program. Stylus tip sphericity should also be considered.

A polar CMM typically measures gear helix and pitch according to generative methods. This involves tracing the tooth surface along a series of radial points while gear rotational position varies as necessary to maintain contact with the measurement probe.

5.3.1.3 Sharp stylus tips

Sharp (short radius) stylus tips are often used on generative instruments, but not generally on a CMM. Sharp stylus tips are better suited to mechanical position qualification methods than spherical stylus tips. Commonly used sharp stylus tips include the chisel type and the disk (single or double conical) type.

The chisel type is relatively simple to qualify for position by contact with an accurate mandrel of known diameter. This practice is only valid if the chisel type stylus tip is kept sharp, thereby assuring that contact will occur only at the extremity of the tip. Usually, chisel type styli are only used on involute profile testers.

Disk type stylus tips are more challenging to produce and maintain with the required accuracy. They may be qualified for position with a mandrel, but often a special fixture is used instead. Disk type styli are particularly well suited to instruments that test both involute profile and helix.

Compared with spherical stylus tips, sharp stylus tips are far less affected by substantial deviations of tooth flanks from involute geometry, produce less mechanical filtering of test data, and cause very little apparent edge rounding on involute profile tests. Disk type sharp stylus tips will cause apparent edge rounding on helix tests equivalent to that caused by spherical stylus tips.

5.3.2 Data recording system

The following provides an explanation and general guidelines for critical probe measurement errors. The evaluation methods relate mainly to mechanical gear instruments using an electronic or mechanical probe system. For computer controlled measuring systems, such as CMM or CNC generative types, follow the manufacturer's recommendations for probe system evaluation and adjustment.

See table 2 for probe accuracy and measuring system guidelines.

Most probe systems are bi-directional so that they can measure left and right flanks of teeth. It is important that the probe is tested in both directions. Also note that the dynamic characteristics are not verified with this test procedure.

Table 2 - Probe system guidelines

Accuracy grade to be tested ISO 1328-1 ISO 1328-2	Probe gain error (% of measurement range)	Resolution, μm	Lost motion, μm
2	1	0.1	0.2
3	1	0.1	0.2
4	1	0.1	0.2
5	2	0.2	0.4
6	2	0.2	0.4
7	3	0.2	0.4
8	3	0.5	0.5
9	3	0.5	0.5
10	3	1.0	1.0
11	3	2.0	2.0
12	3	2.0	2.0

5.3.2.1 Gain

Evaluation of gaging system gain involves comparing the actual probe deflection to the amount of deflection indicated by the final output device, see figure 11. Gain should be measured by deflecting the probe an amount relative to the full system scale on each magnification available on the instrument. This should be done making sure all measurements are taken moving in the same direction. This can be

accomplished using gauge blocks, a micrometer, calibrated drop or flat, axis scale, or other calibrated device. Bring the probe to a known position on one end of the scale in a predetermined direction. Using one of the above methods, bring the probe to a position at the other end of the scale approaching in the same direction as before. The gain should be adjusted as necessary to obtain an acceptable comparison between actual deflection and indicated deflection.

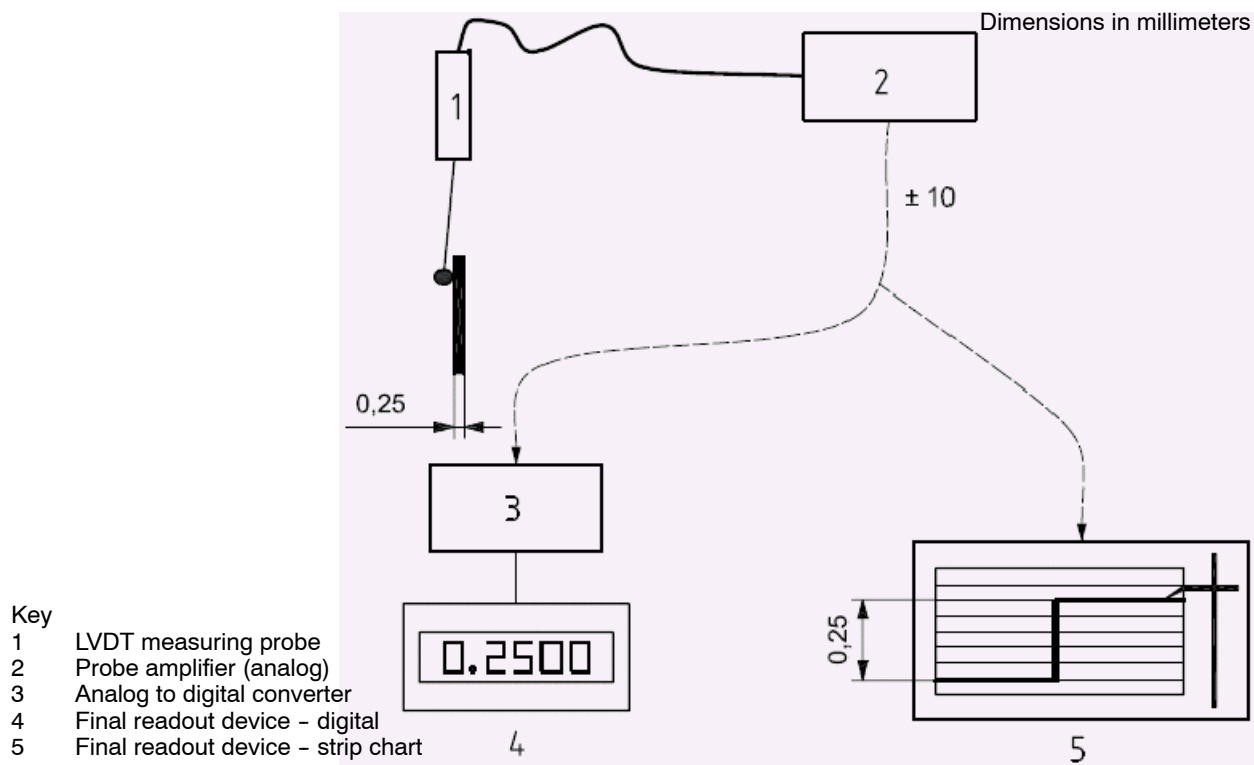


Figure 11 - Gaging system gain

In addition to this test, incremental measurements to test for linearity and bi-directional measurements to test for lost motion should be made. See figures 12 and 13.

5.3.2.2 Lost motion

Lost motion can be described as the difference displayed when the probe is at the exact same position after approaching in opposite directions. See figure 14.

This lost motion can be determined by carefully measuring a calibrated drop in an involute profile or lead surface. Since it cannot be assumed that the surface is at exactly the same position on both sides of the drop, the depth of the drop should be measured two ways. First, bring the probe to a

known position against the surface next to the drop moving in the plus direction, then measure the drop depth. Secondly, repeat the measurement after bringing the probe to the known position moving in the minus direction. The difference in the depth measured is lost motion.

On a tooth spacing instrument, the above artifacts cannot be used. One method would be to use a mandrel with a ground flat. Bring the probe to a known position on the concentric portion next to the flat moving in the plus direction, and rotate the mandrel to measure the flat depth. Next, repeat the measurement by bringing the probe to the known position moving in the minus direction. Again, the difference in the depth measured is lost motion.

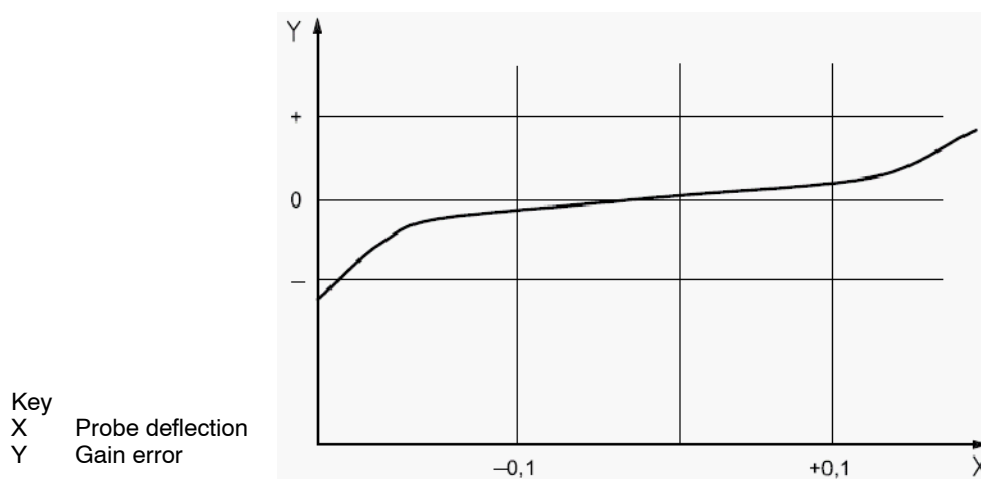


Figure 12- LVDT system linearity

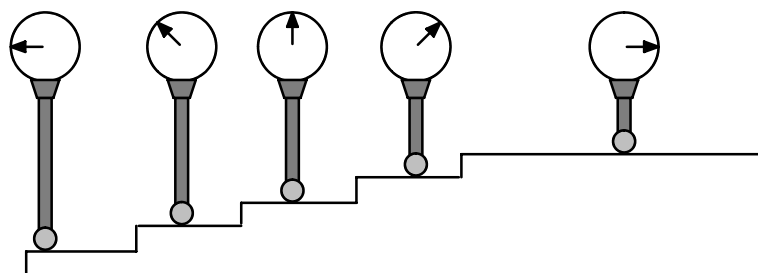


Figure 13 - Linearity with step gauge



Figure 14 - Gaging system lost motion

Another method of measuring lost motion is to approach the same position on an axis scale in opposite directions with the probe against a fixed object. The difference displayed by the probe output is the lost motion. Caution should be used to make sure there is no lost motion in the axis scale/reader head, or else this method will give false results.

5.4 Filtering

Measurements include variations of many different wavelengths or frequencies. The exclusion of certain portions of the test data frequency spectrum is called filtering. A filter that excludes short wavelength (high frequency) data is called a low-pass filter. This is the only type of filtering commonly employed by gear metrology instruments. It tends to smooth the data and eliminate the effects of surface texture.

It is important to know the type of filtering used. There are three general categories of filtering: mechanical, electrical and mathematical. See figure 15.

5.4.1 Mechanical filtering

Mechanical filtering limits the test data gathered to longer wavelength (lower frequency) values and is thus a low-pass type filter. This occurs when the surface of the probe tip bridges the high frequency (short wavelength) surface irregularities, thereby suppressing variations in that portion of the spectrum.

In most cases the wavelengths excluded from the test data by the mechanical filtering effects of the spherical stylus tip are not significant. In applications that require inclusion of this very high frequency data, smaller stylus radii designs can be specified.

When using a small-tip, long-reach probe, care must be taken that the spring-mass inertia of the instrument probe system does not dampen the trace of the actual tooth form.

5.4.2 Electrical filtering

Electrical filtering limits the test data gathered to longer wavelength (lower frequency) values and is thus a low-pass type filter. During electrical filtering, the test data signal passes from the probe head through an electrical filtering (RC) circuit and finally on to the data output devices for observation.

Electrical filtering circuits are designed to accomplish the elimination of high frequency test data at a specified wavelength called the cutoff. All data at frequencies significantly higher than the cutoff are eliminated.

An unfortunate effect of RC electrical filtering is a phase shifting of data that can influence analysis of test results.

5.4.3 Mathematical filtering

Mathematical filtering requires that test data first be converted from analog to digital to permit processing by a digital computer. Two general types of mathematical filter are commonly available. One type emulates the characteristics of electrical filters (with or without the phase shifting characteristic of RC circuits). The other type employs Gaussian mathematics. Based upon sine wave amplitude transmission characteristics and compliance with ISO standards, use of the digital Gaussian filter is recommended.

It is advantageous to be able to view the test data with different mathematical filtering applied.

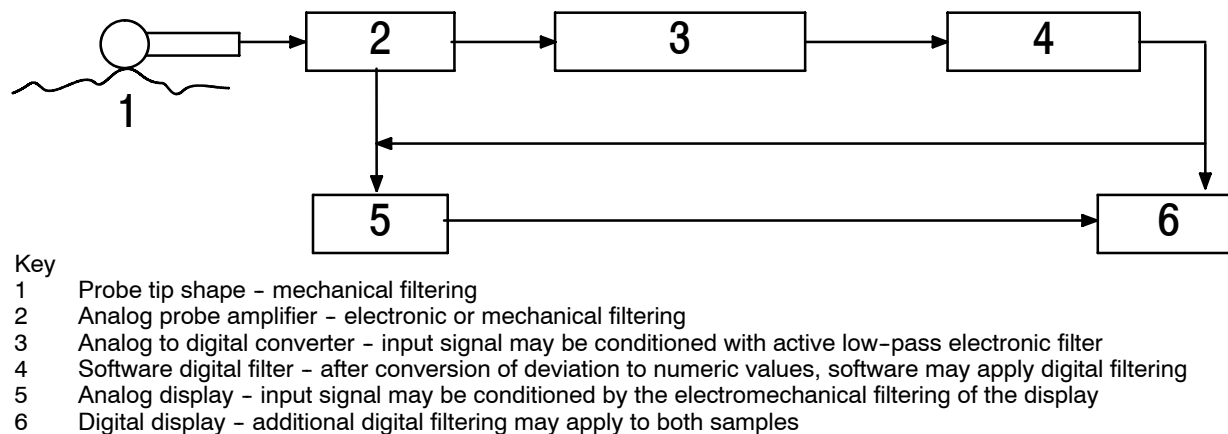


Figure 15 - Types of filtering