

Code of inspection practice —

Part 5: Recommendations relative to evaluation of gear measuring instruments

ICS 21.200

National foreword

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TECHNICAL REPORT

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10064-5**

First edition
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Code of inspection practice —

Part 5: Recommendations relative to evaluation of gear measuring instruments

Engrenages cylindriques — Code pratique de réception —

*Partie 5: Recommandations relatives à l'évaluation des instruments de
mesure des engrenages*



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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TR 10064-5 was prepared by Technical Committee ISO/TC 60, *Gears*.

ISO/TR 10064 consists of the following parts, under the general title *Code of inspection practice*:

- *Part 1: Inspection of corresponding flanks of gear teeth*
- *Part 2: Inspection related to radial composite deviations, runout, tooth thickness and backlash*
- *Part 3: Recommendations relative to gear blanks, shaft centre distance and parallelism of axes*
- *Part 4: Recommendations relative to surface texture and tooth contact pattern checking*
- *Part 5: Recommendations relative to evaluation of gear measuring instruments*

Cylindrical gears — Code of inspection practice —

Part 5:

Recommendations relative to evaluation of gear measuring instruments

1 Scope

This part of ISO/TR 10064 provides additional information and examples to support the implementation of ISO 18653. It proposes evaluation and calibration procedures for involute, helix, pitch, runout, and tooth thickness measurement processes.

Methods are given for evaluation of the condition and alignments of instrument elements such as centres, guideways, 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 Normative 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.

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

ISO 1328-1:1995, *Cylindrical gears — ISO system of accuracy — Part 1: Definitions and allowable values of deviations relevant to corresponding flanks of gear teeth*

ISO 1328-2:1997, *Cylindrical gears — ISO system of accuracy — Part 2: Definitions and allowable values of deviations relevant to radial composite deviation and runout information*

ISO/TR 10064-1:1992, *Cylindrical gears — Code of inspection practice — Part 1: Inspection of corresponding flanks of gear teeth*

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

ISO/TR 10064-3:1996, *Cylindrical gears — Code of inspection practice — Part 3: Recommendations relative to gear blanks, shaft centre 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/TS 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*

ISO 18653:2003, *Gears — Evaluation of instruments for the measurement of individual gears*

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 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 1122-1, ISO 1328-1, ISO 1328-2 and ISO 18653 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 importance ¹⁾:

- 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.

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* R(2002).

4.1.2 Practical guidelines

The following are practical guidelines for gear measurement. 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, centred on the mean temperature, every 5 min 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 min, 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 min, 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 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** 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 computers of numerical control positioning systems to malfunction.

4.1.3 Workshop environment

It is recommended that measuring instruments be situated in a temperature controlled room. However, many measuring instruments are placed in a workshop 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, and
- 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, 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 formulae. Such calculations assume uniform temperature of the given test piece; localized temperature variations cannot be conveniently modelled. 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 modelled 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 modelled 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 modelled 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 :

- b) Calculate the reference pitch diameter, d :

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

- c) 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

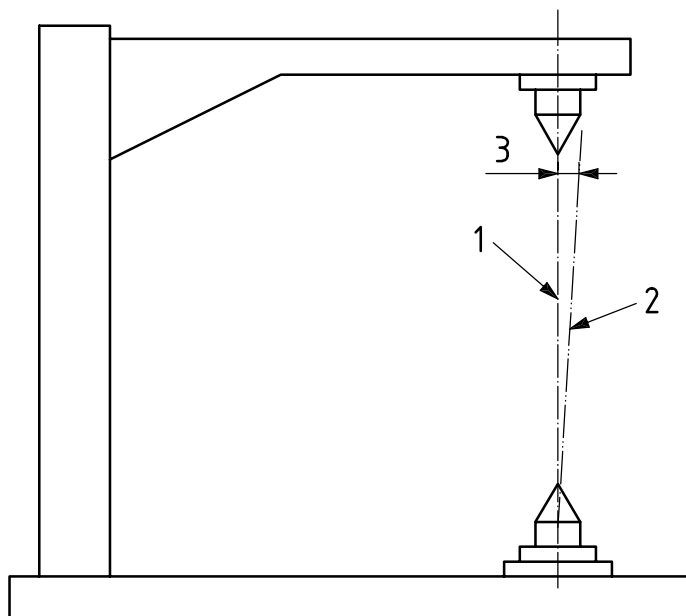
Proper operation of important components of gear measuring instruments can be verified by the procedures outlined in the following. This verification procedure should begin with a visual inspection of the instrument to assure that no obvious detrimental conditions exist that would impair proper operation. Centres, 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 ($1\text{ }\mu\text{m}$ 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 centres

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 in measurement results. See Figure 1.

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



Key

- 1 between-centres axis
- 2 workspindle axis
- 3 error

Figure 1 — Alignment error of the spindle axis and the between-centres axis

5.1.1.1 Centre runout

Using an indicator with an appropriate discrimination, measure the runout (TIR) of the main spindle centre 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 centre at the small and large end to detect bent or skewed centres.

Table 1 — Recommended guidelines for deviations when checking instrument alignment ^a

Accuracy grade to be tested ISO 1328-1 ISO 1328-2	Runout of centres (TIR) μm	Z-axis parallelism with spindle axis in any measured 200 mm region		Alignment of top centre with spindle axis (TIR) per 200 mm ^d
		A ^b μm	B ^c 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

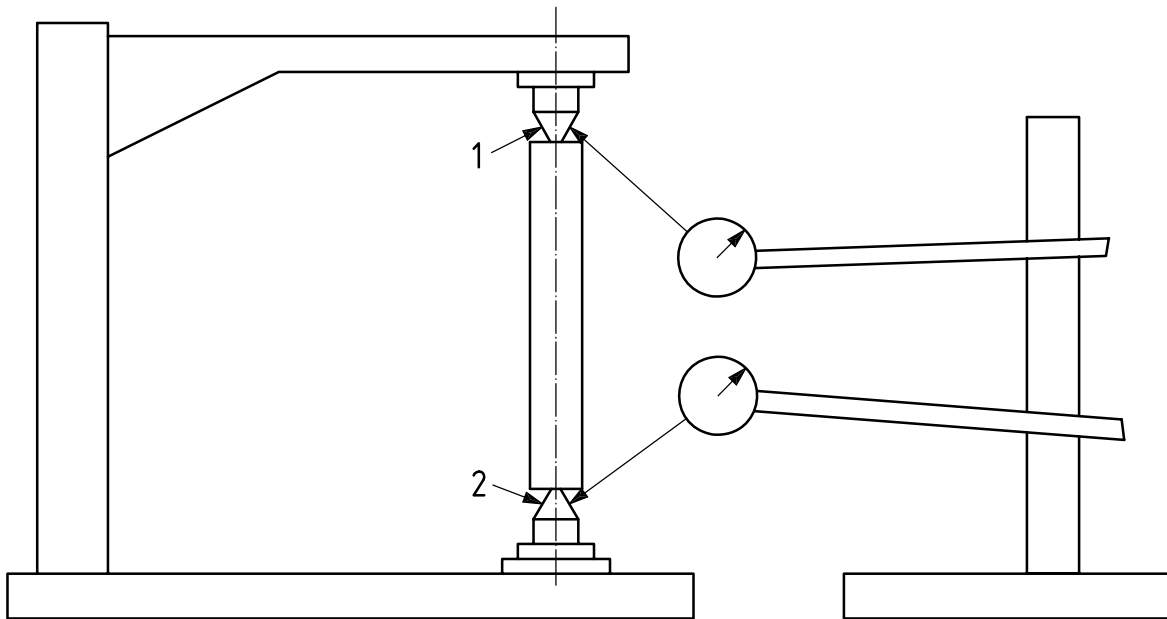
^a The guidelines are for multi-purpose instruments. Single-purpose instruments may only require one or more of the parameters.

^b In the measuring (base tangent) plane. See Figure 5.

^c Perpendicular to the measuring plane. See Figure 6.

^d Alignment tolerance is the greater of 2 μm or the table tolerance per 200 mm of the length, R , in Figures 3 and 4.

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

**Key**

- 1 tailstock live centre
- 2 work spindle centre

Figure 2 — Centre runout test**5.1.1.2 Tailstock centre positioning**

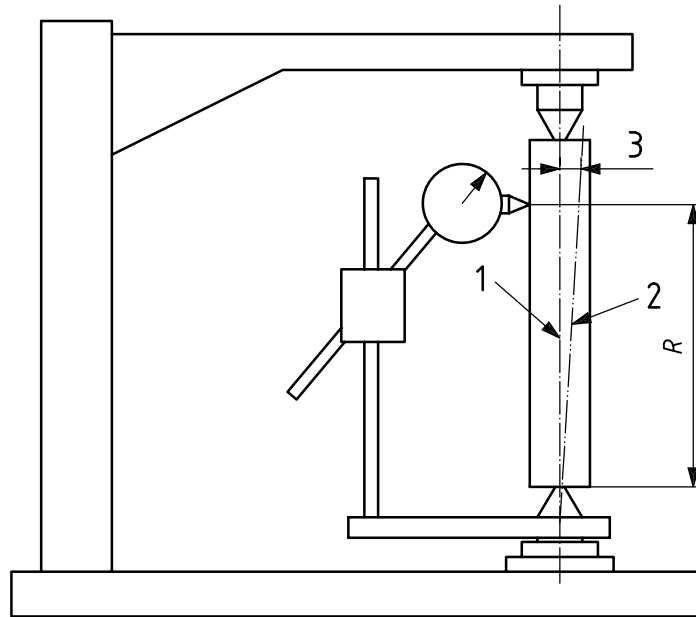
A testing practice often called sweeping can be used to effectively evaluate the position of the tailstock centre relative to the main spindle axis. Sweeping the tailstock centre at only one location on the tailstock slide verifies its positioning for testing gears at that location only. Sweeping the tailstock centre 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 centre positioning at all locations. Otherwise, sweeping of the tailstock centre at a minimum of three significantly separated locations within its range of operation is required. For high-quality gears, it is recommended sweeping of the tailstock be done for each unique configuration before inspection.

Two sweeping test set-ups will be described.

- a) The first is recommended only for instruments with a vertical main spindle axis. Figure 3 provides an example of this set-up. The spindle assemblies are loaded by mounting an arbor between centres. 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. Instruments that use base discs should be tested with a base disc contacting the base tangent slide to ensure spindle clearance effects are included. 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 centre. These measurements of the tailstock centre alignment with the spindle axis should be within the value listed in Table 1.

The value is stated as a ratio of permissible centre alignment (TIR) to the axial distance of that measurement from the main spindle centre. 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.

**Key**

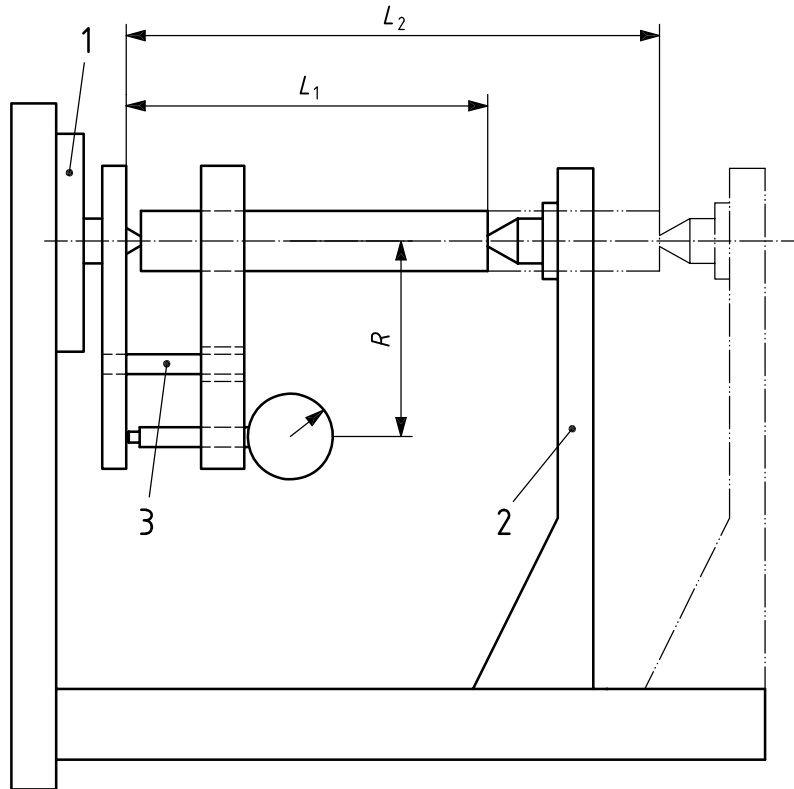
- 1 between-centres axis
- 2 work spindle axis
- 3 error

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

- b) The second sweeping test set-up 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 set-up. This figure shows the sweeping set-up made at two locations, L_1 and L_2 . As before, the spindle assemblies are loaded by mounting different length arbors between centres 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 centre with the spindle axis should be within the value listed in Table 1.

The value is stated as a ratio of permissible centre alignment (TIR) to the axial distance of that measurement from the main spindle centre. The recommended value therefore changes with measurement location and should be adjusted accordingly. The tolerance value is the greater of $2\text{ }\mu\text{m}$ or the table tolerance per 200 mm of the length, R , in Figure 4.

**Key**

- 1 work spindle
- 2 tailstock
- 3 driver pin (clearance in hole)

Figure 4 — Tailstock centre alignment fixture for horizontal or vertical work spindles

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 at minimum 80 % of the full travel, see Figures 5 and 6.

5.1.2.1 Centre-mounted mandrel

The mandrel may be mounted between centres. In this case, its orientation concentric with the main spindle axis should be confirmed by two observations. First, its concentricity near the main spindle centre and near the tailstock centre can be confirmed by measuring its radial runout near those centres. Second, its concentricity near the tailstock centre can be confirmed by sweeping the mandrel. If the sweeping set-up recommended for vertical axis instruments is used, the test indicator should be positioned near the tailstock centre. 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 centre, runout of the tailstock spindle centre, and alignment error of the tailstock slide assembly at this test location.

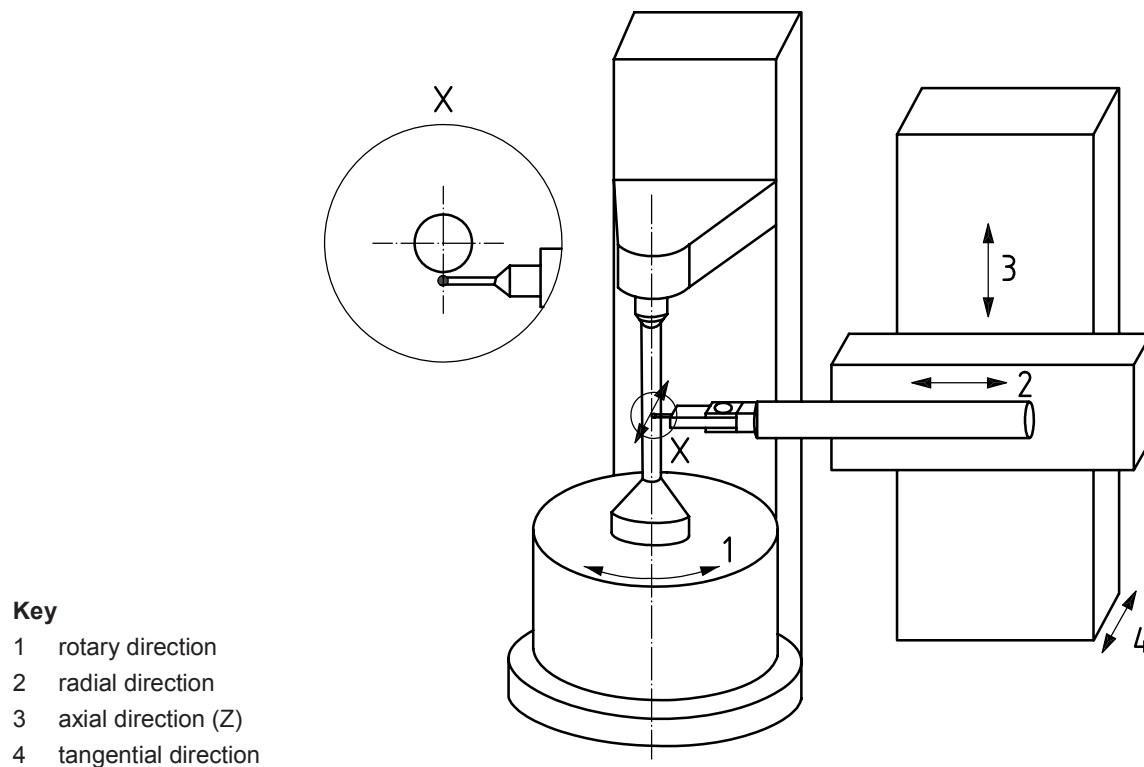


**Figure 5 — Z-axis to between-centres axis alignment verification
axial plane parallel to the measuring (base tangent) plane**

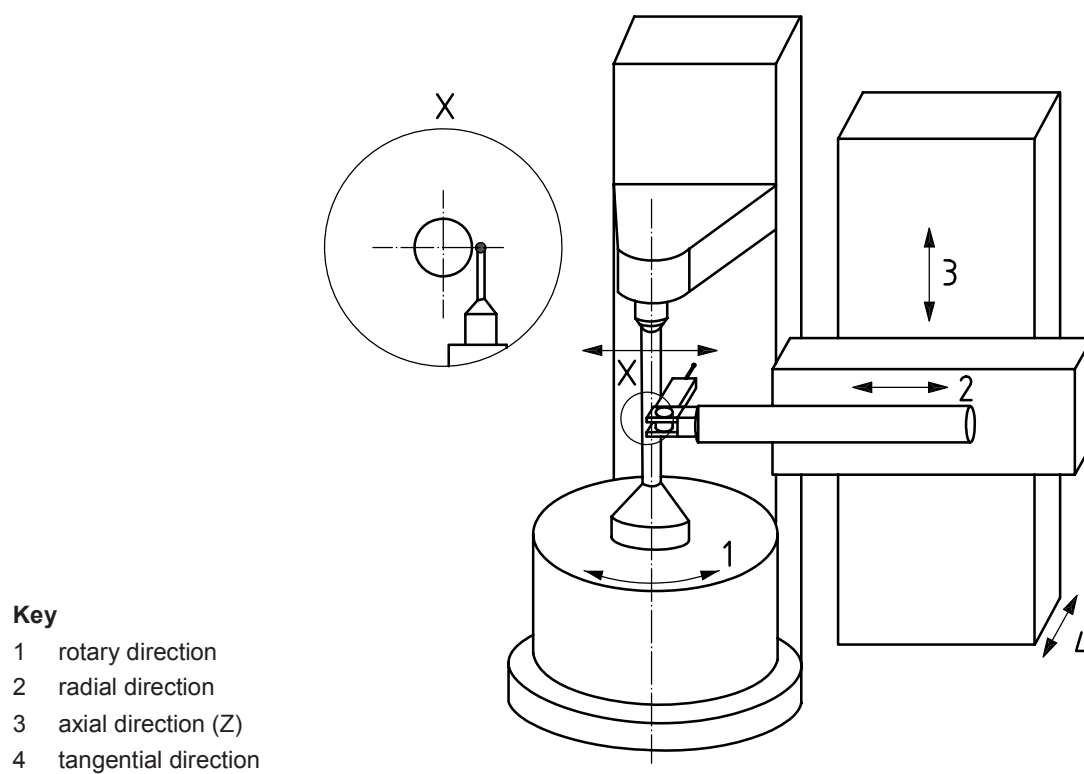


Figure 6 — Z-axis to between-centres axis alignment verification, perpendicular to measuring plane

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 centres. 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. Centring 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:

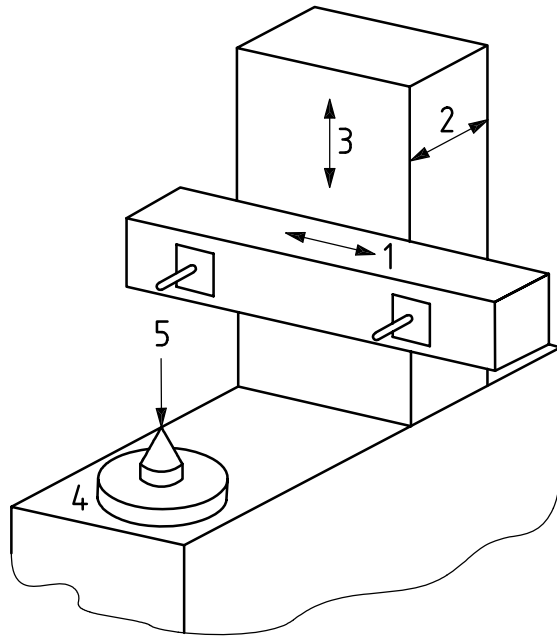
- a) the plane parallel with the measuring plane (the base tangent plane);
- b) the plane perpendicular to the measuring plane.

See Figures 5 and 6.

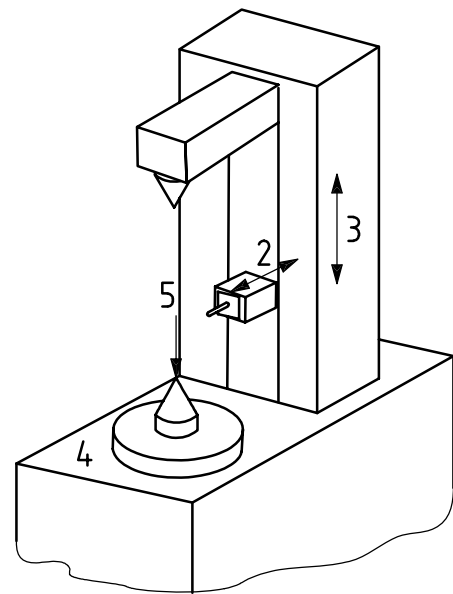
These measurements of axial measuring slide parallelism with the main spindle axis should be within the guidelines listed in Table 1. Two such guideline values are provided: one for observations parallel with the measuring plane, and one for those that are perpendicular to the measuring plane. These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

5.1.2.4 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.



a) Four-axis measuring instrument



b) Three-axis measuring instrument

Key

- 1 tangential
- 2 radial
- 3 axial
- 4 rotary
- 5 load

**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 centre 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.

- a) Load and secure a flat test gear on the measuring table.
- b) Check the helix of the test gear on a marked and designated tooth. Note the present deviations in alignment from the recording chart.
- c) 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.
- d) 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).

- e) Increase the incremental load, if possible, with a total of four increments, checking the test results at each incremental increase.
- f) 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.

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 probings 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 %).

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.

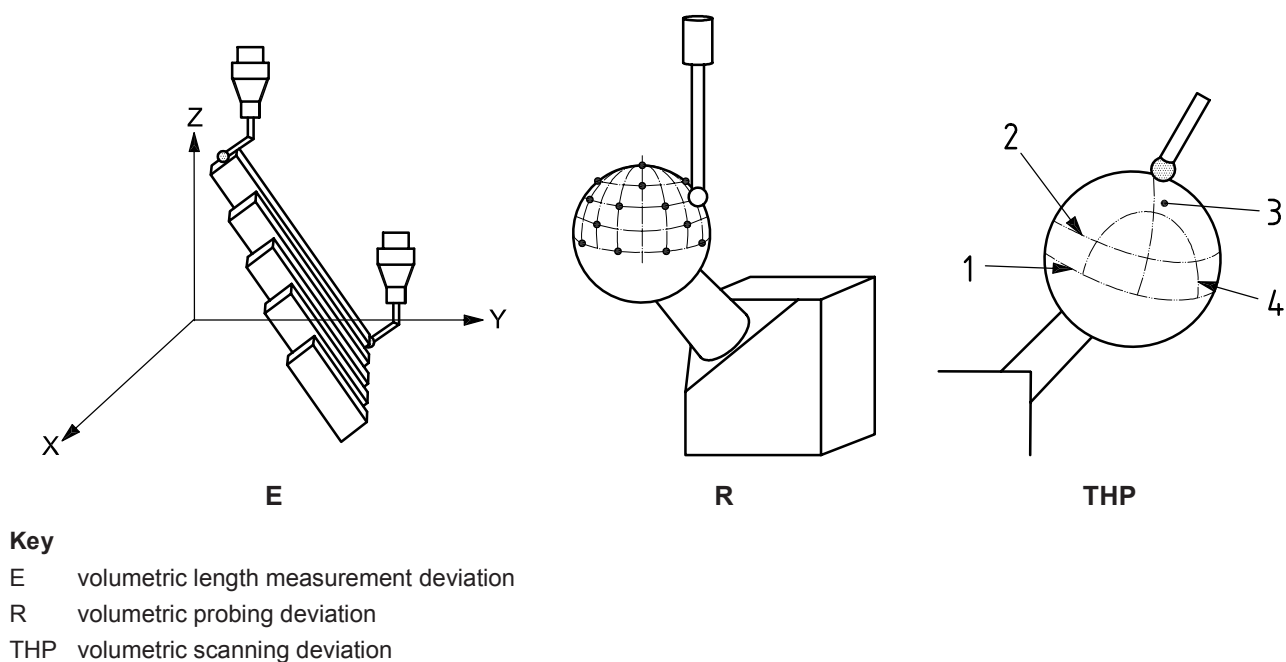


Figure 8 — CMM volumetric tests

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.

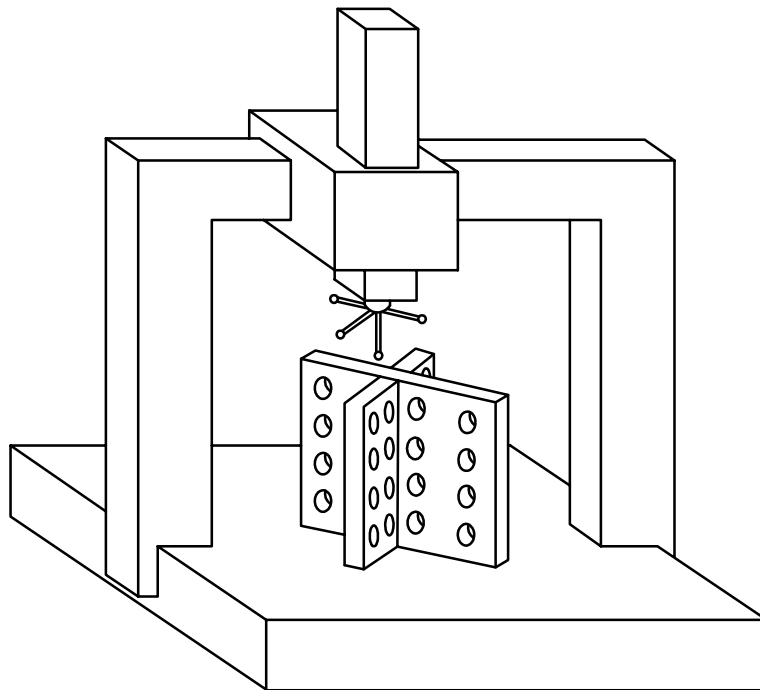


Figure 9 — Ball plate tests

5.2.3 Rotary tables

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

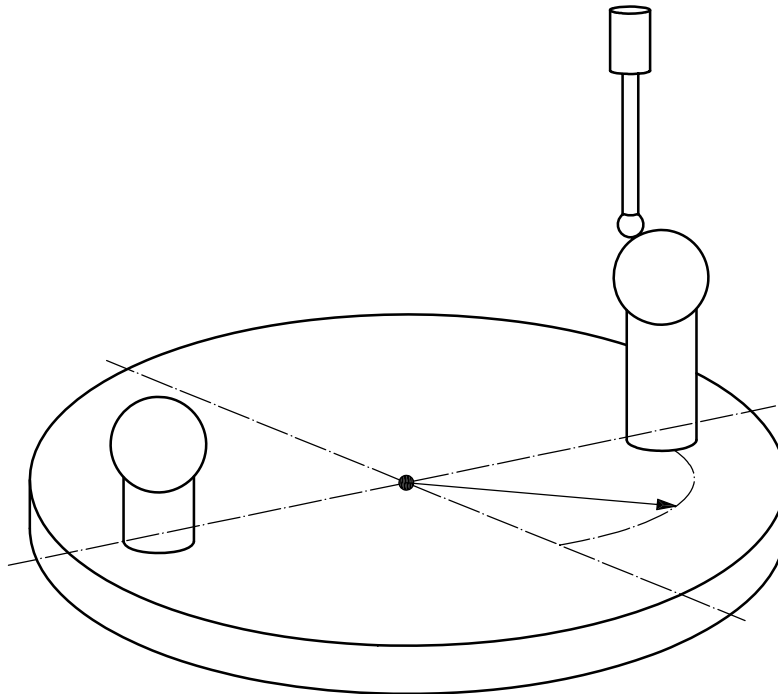


Figure 10 — Rotary table tests

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.

Generative instruments measure 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 centre 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 involute profile 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 CMMs 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 be tested in both directions. Also note that the dynamic characteristics are not verified with this test procedure.

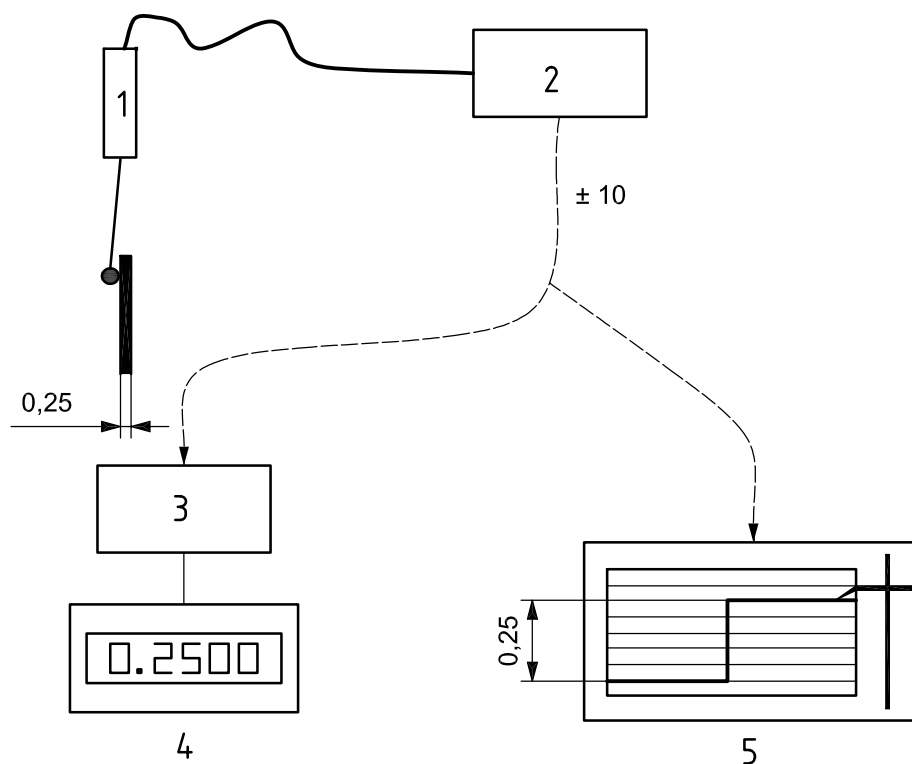
Table 2 — Probe system guidelines

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 gauging 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 micrometre, 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.

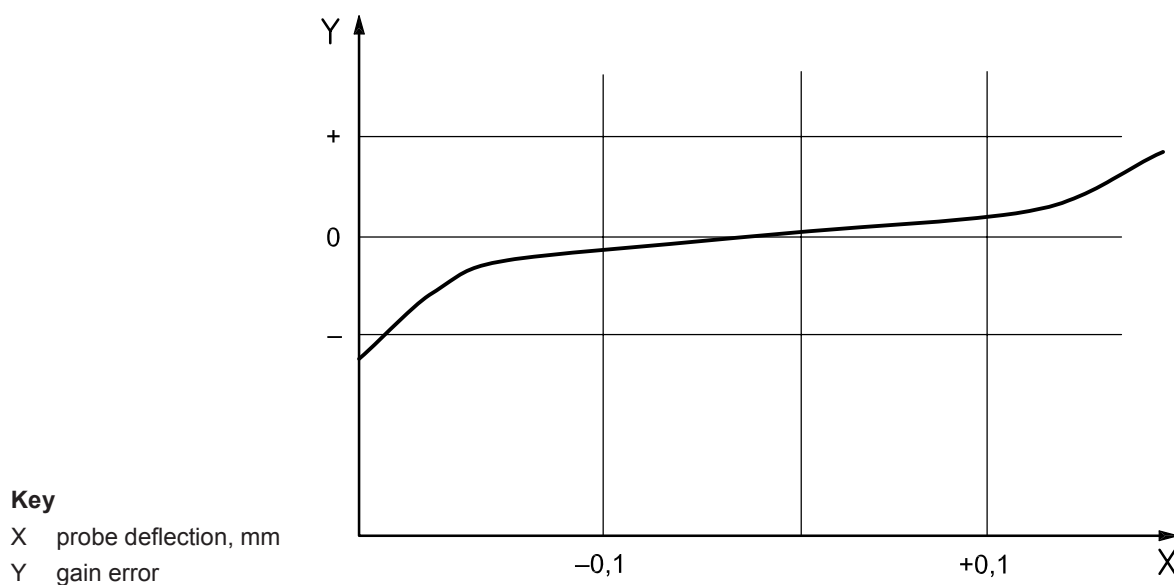
Dimensions in millimetres

**Key**

- 1 LVDT measuring probe
- 2 probe amplifier (analog)
- 3 analog to digital converter
- 4 final readout device — digital
- 5 final readout device — strip chart

Figure 11 — Gauging 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.

**Key**

- X probe deflection, mm
- Y gain error

Figure 12 — LVDT system linearity

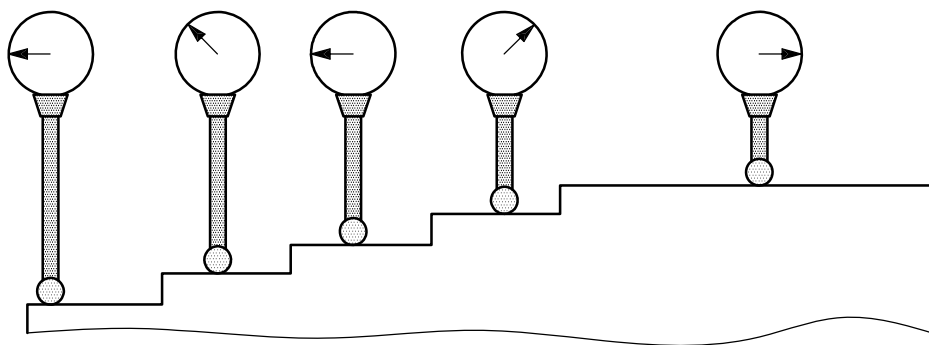


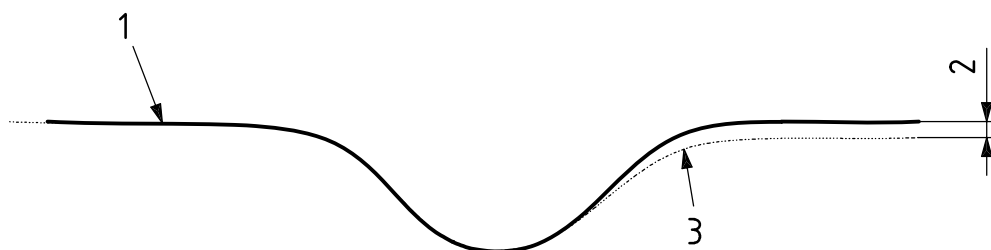
Figure 13 — Linearity with step gauge

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. Second, 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.



Key

- 1 tooth surface with depression
- 2 lost motion
- 3 readout displayed deviation

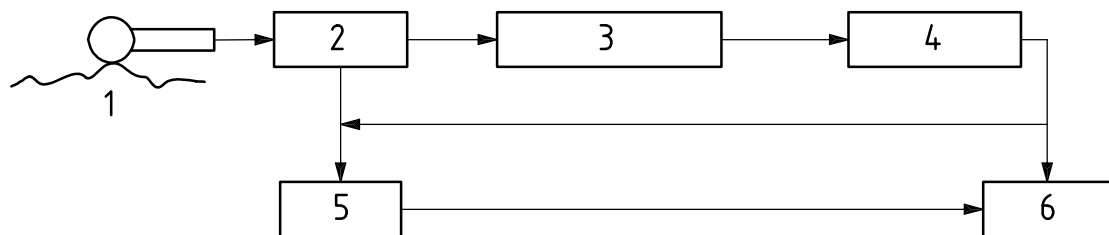
Figure 14 — Gauging system lost motion

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 ensure 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. A filter that reduces 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.



Key

- 1 probe tip shape — mechanical filtering
- 2 analog probe amplifier — electronic or mechanical filtering
- 3 analog to digital converter — input signal may be conditioned with active low-pass electronic filter
- 4 software digital filter — after conversion of deviation to numeric values, software may apply digital filtering
- 5 analog display — input signal may be conditioned by the electromechanical filtering of the display
- 6 digital display — additional digital filtering may apply to both samples

Figure 15 — Types of filtering

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 cut-off. All data at frequencies significantly higher than the cut-off 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.

5.5 Uncertainty estimation

The final procedure is to estimate the uncertainty of the measurement process. Use of artifacts such as those described in Clause 6 and measurement uncertainty estimation procedures such as those described in Clauses 7, 8 and 9 are recommended. Guidance on the determination of measurement process fitness-for-use, and recommendations for reducing measuring uncertainty, are provided in Clause 11.

6 Artifacts

A reference artifact is any suitable object having an unbroken chain of traceable calibrations with proper treatment of measurement uncertainties at each step in the chain. Reference artifacts normally comprise high-quality reference surfaces to establish a reference axis and high-quality test surfaces representative of involute helicoid gear tooth flank geometry. The reference artifacts should be similar in size and geometry to the production gears inspected on the measuring instrument. Artifacts should be stored in the same environmental conditions as the gear measuring instrument and protected from damage or corrosion.

A key characteristic of reference artifacts is their geometric stability. Adequate stability is an inherent requirement of the comparator method of measurement uncertainty estimation. Since it is very difficult to detect stability problems in reference artifacts during usage, it is important that their design, material, manufacture, and handling minimise instability.

Features of an artifact such as flank and tooth identification should be in accordance with ISO/TR 10064-1.

6.1 Mounting reference features

Artifacts are normally mounted between centres on the test instrument. This is convenient and acceptable, as are a variety of other possible configurations. However, since the physical orientation of the artifact to the instrument can affect test results, artifacts should be provided with appropriate reference surfaces to permit confirmation of proper mounting. Typically, this requirement is addressed by identifying datum diameter locations toward either end of the artifact. The amplitude and angular orientation of the runout characteristics of these reference surfaces must be included in the artifact certification data and confirmed as part of the involute profile test instrument calibration procedure.

Artifacts may also be constructed without provision for mounting between centres on the test instrument. Such artifacts must be provided with either two datum diameter locations near either end of the artifact or one datum diameter location and a datum band located on one face. Careful positioning of the artifact so as to minimize runout of the reference surfaces is required for this type artifact. Artifacts of this type must have a circular chart documenting the amount and orientation of runout of these reference features included with the certification statement.

6.2 Suggested master artifacts

As indicated in ISO 18653, there are many methods and artifacts which can be used for calibration. Suggested artifact designs which use an actual involute tooth form are given in 6.2.2 to 6.2.5.