TECHNICAL REPORT

ISO/TR 10064-5

First edition
2005-04-15

Cylindrical gears — 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

Reference number
ISO/TR 10064-5:2005(E)

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Published in Switzerland

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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is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.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 *Cylindrical gears — 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 $11{,}5 \times 10^{-6}$ 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:

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

b) Calculate the slope change due to the temperature difference:

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

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

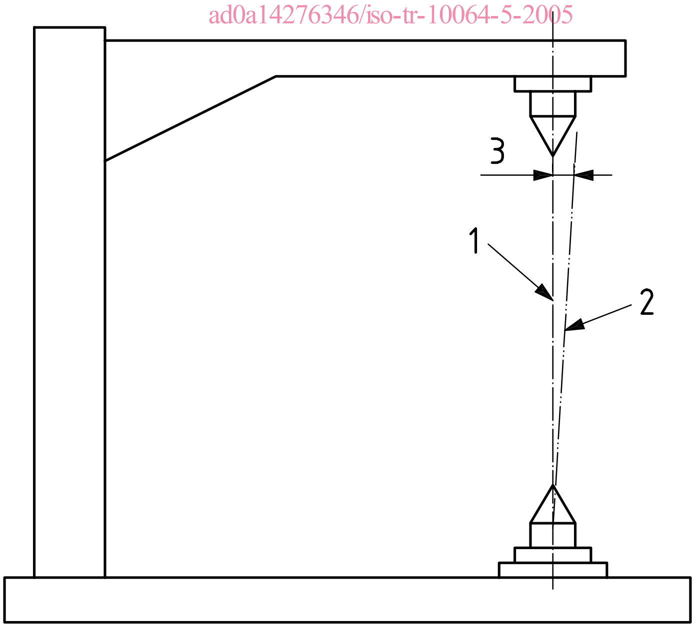
Proper operation of important components of gear measuring instruments can be verified by the procedures outlined in the following. This verification procedure should begin with a visual inspection of the instrument to assure that no obvious detrimental conditions exist that would impair proper operation. 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 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 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

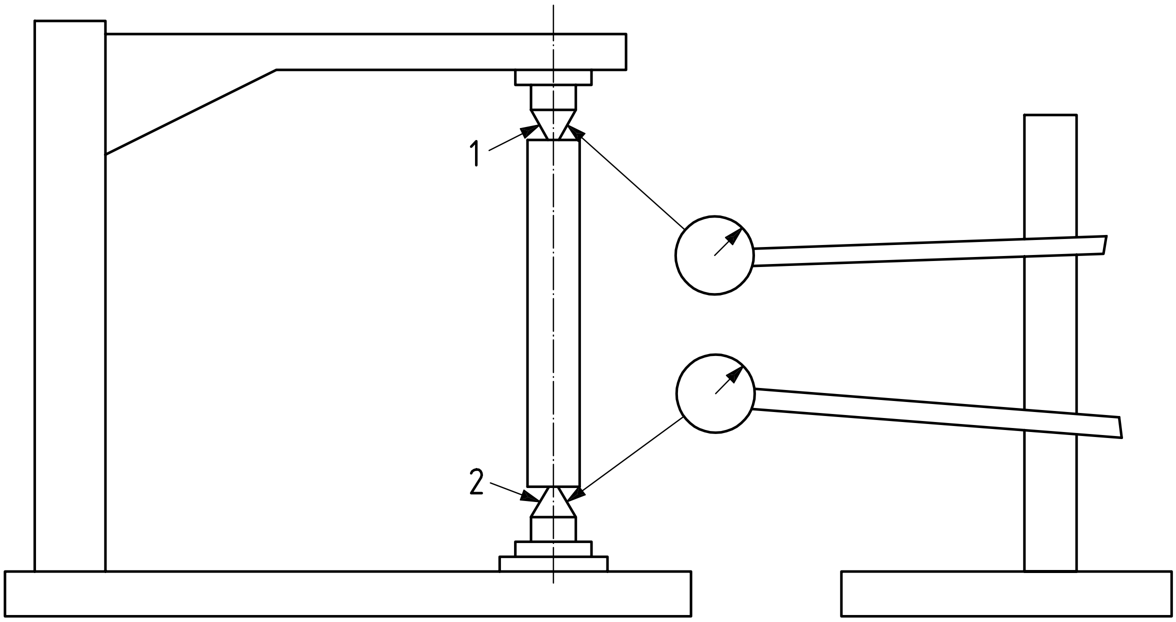
[a] The guidelines are for multi-purpose instruments. Single-purpose instruments may only require one or more of the parameters.

[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

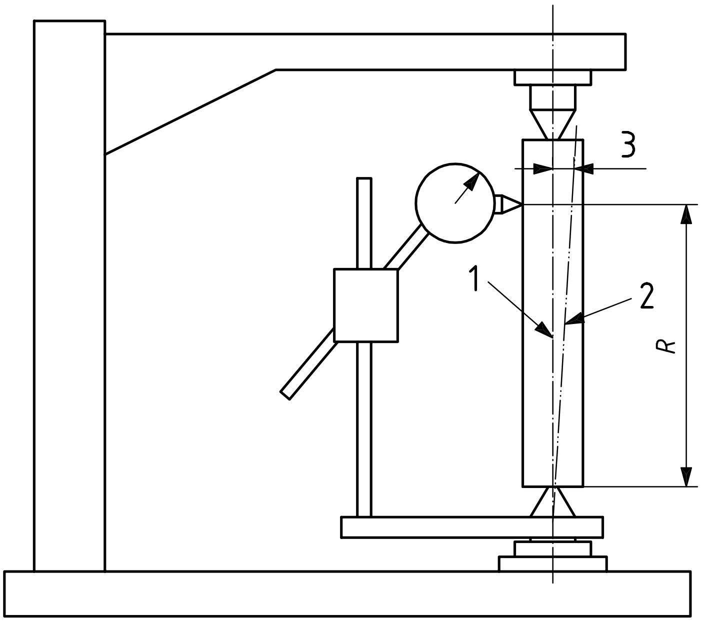
A testing practice often called sweeping can be used to effectively evaluate the position of the tailstock centre relative to the main spindle axis. Sweeping the tailstock centre at only one location on the tailstock slide verifies its positioning for testing gears at that location only. Sweeping the 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 µm or the table tolerance per 200 mm of the length, R, in Figure 4.

