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Gears — Evaluation of instruments for the measurement of individual gears

Engrenages — Évaluation des instruments de mesure des engrenages individuels

Reference number
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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.

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 18653 was prepared by Technical Committee ISO/TC 60, *Gears*.

Gears — Evaluation of instruments for the measurement of individual gears

1 Scope

This International Standard specifies methods for the evaluation of measuring instruments used for gear measurements of involute, helix, pitch and runout. It is applicable both to instruments that measure runout directly and to those that compute it from index measurements. It also gives recommendations for the evaluation of tooth thickness measuring instruments and, of necessity, includes the estimation of measurement uncertainty with the use of calibrated gear artifacts. It does not address the calibration of artifacts by laboratories accredited in accordance with ISO/IEC 17025; nor are its requirements intended as an acceptance specification of product gears (see ISO 1328-1, ISO 1328-2, ISO/TR 10064-1 and ISO/TR 10064-2). The estimation of product gear measurement uncertainty is beyond its scope (see ISO/TR 10064-5 for recommendations).

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

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

ISO/TR 10064-5[1)], *Cylindrical gears — Code of inspection practice — Part 5: Recommendations relative to evaluation of gear measuring instruments*

ISO 14253-1, *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/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

3 Terms, definitions and symbols

For the purposes of this document, the following terms, definitions and symbols (see Table 1) apply.

NOTE 1 The definitions, when applicable, conform to ISO 122-1, ISO 1328-1, ISO 1328-2 and ISO/TR 10064-1.

NOTE 2 The terms, definitions and symbols used in this document may differ from those used in other International Standards. The user needs to be certain of fully understanding them, as used here.

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1) Under preparation.

3.1
accuracy
closeness of agreement between a measured value and an accepted reference (or calibrated) value

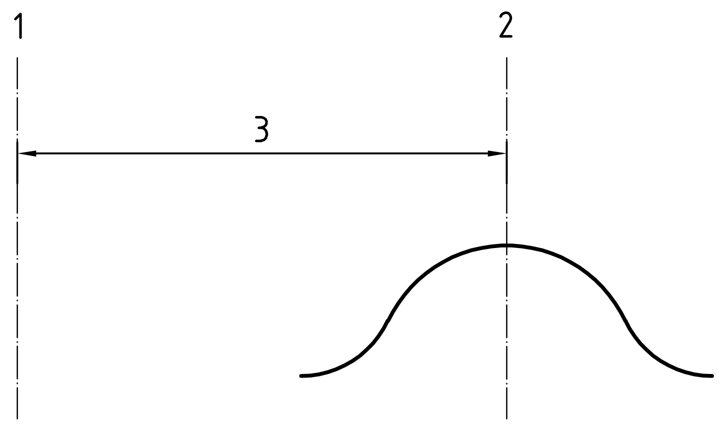
3.2
artifact
object of specific shape used to determine the accuracy of measuring devices

See Clause 7.

3.3
bias
difference between the observed average of measurements and the calibration value

See Figure 1.

NOTE Bias can be affected by systematic errors such as linearity or gain and can be different throughout the operating range of the measurement system.



Key

1 calibration value

2 observed average

3 bias

Figure 1 — Bias

3.4
calibration
set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system and the corresponding values realized by standards

3.5
gain
magnification factor between the input and the output

3.6
helix artifact
artifact having a calibrated helix form

3.7
involute artifact
calibrated artifact having an involute form determined by a specific base circle

3.8
measurand
particular quantity subject to measurement

3.9
pitch and runout artifact
artifact with calibrated index features for pitch or runout or both

3.10
repeatability (of measurement results)
closeness of the agreement between results of successive measurements of the same measurand carried out under the same conditions of measurement

3.11
reproducibility (of measurement results)
closeness of the agreement between results of measurements of the same measurand carried out under changed conditions of measurement

NOTE 1 A valid statement of reproducibility requires specification of the conditions changed.

NOTE 2 The changed conditions may include

— principle of measurement,

— method of measurement,

— observer,

— measuring instrument,

— reference standard,

— location,

— conditions of use, and

— time.

NOTE 3 Reproducibility may be expressed quantitatively in terms of dispersion characteristics of the results.

3.12
uncertainty (of measurement results)
parameter associated with the result of a measurement that characterizes the dispersion of the values that could be reasonably attributed to the measurand

NOTE 1 The parameter can be, for example, a standard deviation (or a given multiple of it), or the half-width of an interval having a stated level of confidence.

NOTE 2 Uncertainty of measurement comprises, in general, many components. Some of these components can be evaluated from the statistical distribution of the results of a series of measurements and can be characterized by experimental standard deviations. The other components, which also can be characterized by standard deviations, are evaluated from assumed probability distributions based on experience or other information.

NOTE 3 It is understood that the result of the measurement is the best estimate of the value of the measurand, and that all components of uncertainty, including those arising from systematic effects, such as components associated with corrections and reference standards, contribute to the dispersion.

Table 1 — Symbols

Symbol	Definition	Unit	Where first used
E	Bias	µm	Eq. 1
k	Coverage factor	—	Eq. 1
n	Number of measurements	—	Eq. 2
U_{95}	Measuring uncertainty	µm	Eq. 1
U_{95c}	Uncertainty estimation	µm	Eq. 4
$U_{95(cal)}$	Measurement uncertainty stated in reference artifact calibration document	µm	Eq. 3
u_m	Standard uncertainty	µm	Eq. 1
u_n	Reference artifact calibration uncertainty	µm	Eq. 1
u_g	Geometry similarity influence	µm	Eq. 1
u_w	Workpiece characteristic influence	µm	Eq. 1
X_i	Individual measured value of parameter calibrated	µm	Eq. 2
$\bar{X}$	Mean of measured values	µm	Eq. 2

4 Application

4.1 General

The purpose of the tests prescribed in this standard is to estimate measurement uncertainty. It has been assumed that the gear-measuring instrument has been installed on site and a series of acceptance tests have been completed successfully. Prescribed tests may serve as interim checks to verify the measurement process.

The measurement and evaluation procedures may be used as part of acceptance tests for a new gear-measuring instrument, with prior agreement between customer and supplier. In this situation it is recommended that a series of traceably calibrated gear artifacts be used to verify the measurement uncertainty at specific points throughout the working volume of the instrument. These measurements should include provision for testing the machine with table loads that represent the weight of product gears being tested.

4.2 Traceability

The term traceability implies an unbroken calibration chain from measurements taken on shop floor inspection instruments to the primary artifacts at a national laboratory, see Figure 2. Traceability is transferred by calibrated gear artifacts. The primary laboratory has the lowest uncertainty, and uncertainty increases at each level as the traceability chain is transferred to shop floor measuring instruments. Minimizing the steps from the primary laboratory to a shop floor measuring instrument will reduce the measurement uncertainty.

4.3 Artifacts

The gear artifacts used for these tests shall be of similar size and geometry to product gears inspected on the measuring instrument. Artifacts shall be used to evaluate the accuracy of each parameter inspected: helix (lead), profile, pitch, runout and tooth thickness. Specific artifact requirements are given in Clause 7.

4.4 Measurement uncertainty

Conventional practice recommends the uncertainty of a measurement process be less than 10 % of the parameter tolerance measured, to ensure that the reliable interpretation of the measurement results is possible. However, this is not technically achievable when inspecting high accuracy gears.

For example, in gears with tolerances better than 10 µm, the best achievable uncertainty may be only 20 to 30 %. To determine the uncertainty, see Clause 8 and ISO/TR 10064-5. Recommendations for allowable measurement uncertainty are made in ISO/TR 10064-5.

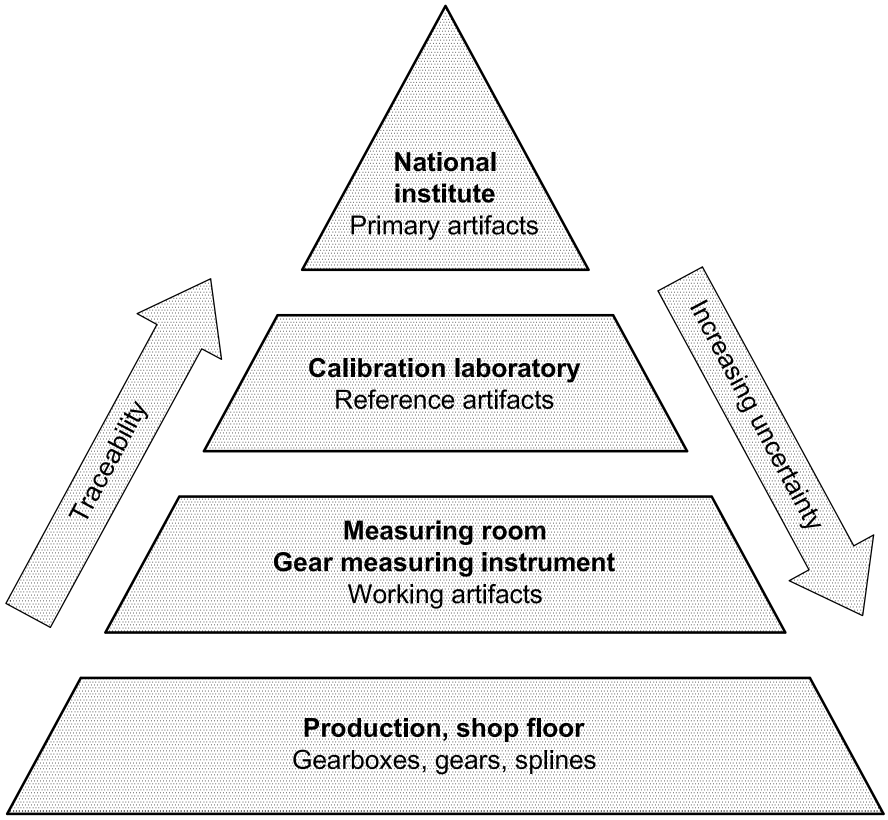


Figure 2 — Hierarchy of calibration

4.5 Sources of uncertainty

The verification of measurement uncertainty shall include, but not be limited to, the assessment of the principal contributions to uncertainty in gear measurement as follows:

- artifact data;
- calibration data;
- repeatability of the instrument;
- reproducibility of the instrument;
- probe system filtering, damping and dynamic response, and accuracy;
- environmental influence, including temperature, vibration;
- mechanical alignment;

- runout and mounting error measurement;
- servo control system;
- evaluation software;
- operator.

Refer to ISO/TS 14253-2 for further information on this subject.

4.6 Evaluation interval

The user shall establish the interval for evaluation of the measurement process. It is also recommended that interim tests be performed on a designated artifact. Data produced by the interim tests on calibrated gear artifacts can be used for measurement uncertainty.

5 Condition of the measurement system

5.1 System characteristics

Several characteristics of the measuring instrument and readout system should be checked or verified before proceeding with artifact measurement.

5.2 Suitability for calibration

The instrument should be suitable for calibration and representative of the normal operating conditions.

5.2.1 Instrument alignment

When the instrument manufacturer provides procedural checks for verification of alignments, these checks shall be made on a regular basis. Instrument alignment includes such things as runout of centres, whether the centres are coaxial, parallelism of centre axis to instrument ways, squareness of ways, etc. See ISO/TR 10064-5.

5.2.2 Readout condition

Meter movements and chart recorders should be checked to the manufacturer's specifications such as magnification, linearity, lost motion, and frequency response. See ISO/TR 10064-5.

5.3 Table load considerations

Instruments that are used to check very large gears (above 1 m) may deflect or change shape under the weight of the part being tested. This will cause deviations in measurement. Such instruments should be calibrated with a simulated load on the table. Gears with significant inertial mass can also cause measurement deviations. The effects of driving methods such as centre size, friction characteristics, live or dead centres, etc. should be considered.

5.4 Tooling and gauges

Any tooling or gauges used in the set up or calibration of a measuring instrument shall be calibrated at suitable intervals.

6 Environment

The stability of the environment will affect accuracy of the calibration process and measurement of production parts. The required environment specified by the instrument manufacturer shall be met during its evaluation and use. Calibration requires 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.

In particular, an adequate thermal equilibrium of the reference artifact and the instrument should exist. If measurements of the reference artifact are taken with an ambient temperature other than that of its calibration (normally 20 °C), either the calibrated value shall be adjusted to the actual operating temperature or the measured values shall be corrected to the calibration temperature. This procedure will add significant sources of uncertainty to the calibration process. See ISO/TR 10064-5 for details.

7 Artifacts

7.1 Artifact size and geometry

This clause describes artifacts for estimating measurement uncertainty. Artifacts are required for verifying every parameter measured by an instrument, namely helix (lead), involute, pitch, runout and tooth thickness. Artifacts may be work-piece-like, such as an accurate gear.

The specific requirements are prescribed in the following sections. Further recommendations, supporting information and artifact design details are presented in ISO/TR 10064-5.

The minimum requirement is that the artifact size shall be selected as near as practical to the centre of the measurement range over which the instrument is used.

Ideally, the geometry of the artifacts should represent the tooth number, module, helix angle, facewidth and weight of the product gear range. The artifacts should have left and right flank features. Single flank artifacts may be used inverted to simulate the opposite flank.

It is recommended that internal artifacts be used to verify instrument uncertainty where internal work pieces are measured.

A key characteristic of reference artifacts is their geometric stability. Adequate stability is an inherent requirement of the comparator method of measurement uncertainty determination. Since it is very difficult to detect stability problems in reference artifacts during usage, it is important to confirm that their design, manufacture and handling are carried out so as to minimize instability. Use of multiple artifacts is recommended to assist with detection of artifact instability. See ISO/TR 10064-5 for additional guidance.

7.1.1 Artifact calibration frequency

The user shall establish the artifact calibration interval. It is recommended that the interval be 3 years — or less, depending on the amount of usage and artifact material stability.

7.1.2 Artifact calibration certificates

Artifacts used for evaluation purposes shall have a valid traceable calibration certificate that has been issued by a laboratory and which complies with the requirements specified in ISO/IEC 17025.

The calibration certificate shall contain sufficient information to enable a comparison of calibration data and measurement data from the instrument being evaluated. Specific details regarding the calibration method and the interpretation of results shall be unambiguously reported. Annex A contains a list of the specific requirements.

7.1.3 Artifact mounting

The method used to mount the artifact shall be identical to the method used for mounting work pieces.

Some instruments use software to define the measurement axis on work pieces. The evaluation procedure for these instruments shall include the use of this software.

7.1.4 Artifact deviations

Artifacts with minimum deviations from true form may be used to identify local errors on instruments. Artifacts with large deviations are used to perform functional tests on instruments, but care should be taken to ensure that small changes in measurement position do not affect the validity of measurement data.

Artifacts with minimum deviations may be measured with different reference geometry, thus generating large deviations (see ISO/TR 10064-5). Appropriate calibration data shall be provided for comparison purposes with the modified reference data on the calibration certificate.

It is recommended that artifacts be manufactured with deviations less than Grade 5 in accordance with ISO 1328-1, and with a measurement surface roughness of 0,4 µm Ra or better.

7.1.5 Calibrated parameters

The calibrated parameters shall be defined and evaluated in accordance with ISO 1328-1, including slope and form, with the exception that the evaluation range shall be the entire surface certified for measurement on the artifact. The data density for CMM measurement of involute should be equidistant along a base tangent. See Annex A for further information.

7.1.6 Artifact calibration datum surfaces

The datum surfaces for determining the reference axis of measurement shall be specified. The calibrated artifact datum surfaces shall be identical to those used to verify the measuring instrument to minimize measurement uncertainly. Artifact datum surfaces shall have runout and form deviations in accordance with ISO/TR 10064-3.

7.1.7 Measurement location

To minimize the effects of form deviation, the measurement shall be restricted to the position, path and limits as defined in the calibration certificate. This may be particularly desirable on artifacts manufactured with significant deviations from the nominal form.

7.1.8 Artifact material

It is recommended that artifacts be manufactured of a stable tool steel material, of minimum hardness 60 HRC. Less stable forms of material may be used, but the recalibration interval shall be reduced to take into account material instability.

7.1.9 Additional artifacts

It is recommended that additional artifacts be used to verify the instrument throughout the size range of the work pieces tested.

7.2 Involute artifacts

An involute artifact is a calibration artifact that provides a feature of involute form. The involute feature is certified relative to the theoretical involute associated with a specific base circle (see Figure 3).

Additional artifacts of involute or non-involute form may be used. These are discussed in ISO/TR 10064-5.

7.3 Helix artifacts

A helix artifact is a calibration artifact that provides a feature of helical form. The helix feature is certified relative to the theoretical helix associated with a specific lead (see Figure 4).

It is recommended that the artifact be of involute form.

Figure 3 — 115 mm base circle diameter involute artifact

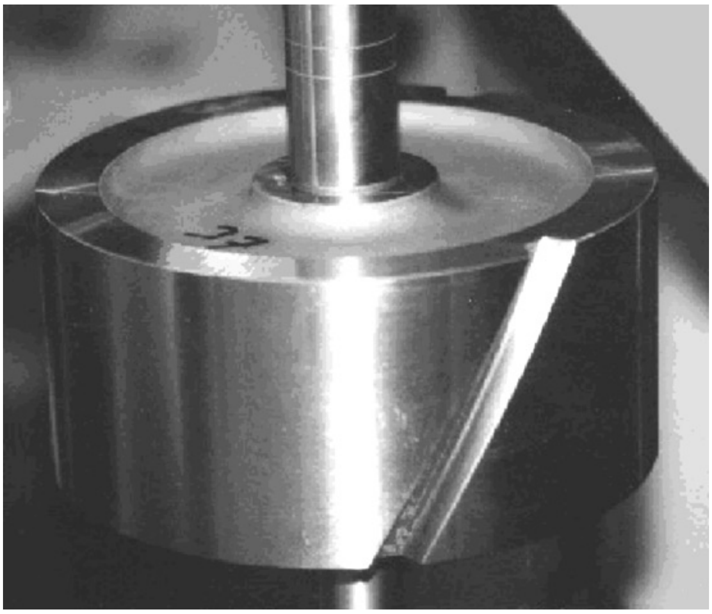


Figure 4 — Helix artifact with involute form

7.4 Pitch artifacts

A pitch artifact is a calibration artifact that provides a series of features of the same form arranged in equally spaced angular positions around the periphery of the artifact. Index features are calibrated relative to theoretical angular positions of features determined by division of a circle by the number of index features provided.

It is recommended that the artifact be of involute form.

Pitch artifacts with identical left and right involute flank forms may be used as runout artifacts (see Figures 5, 6 and 7).

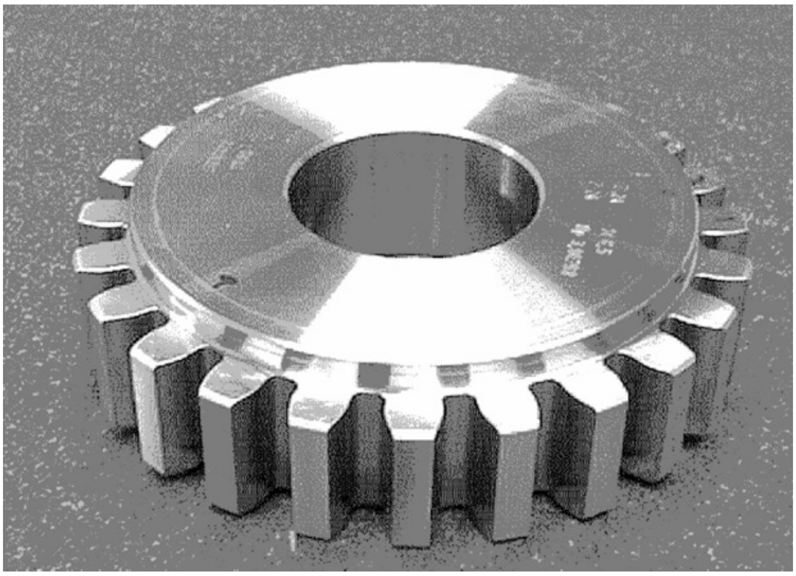


Figure 5 — Involute form pitch artifact

Figure 6 — Master gear artifact

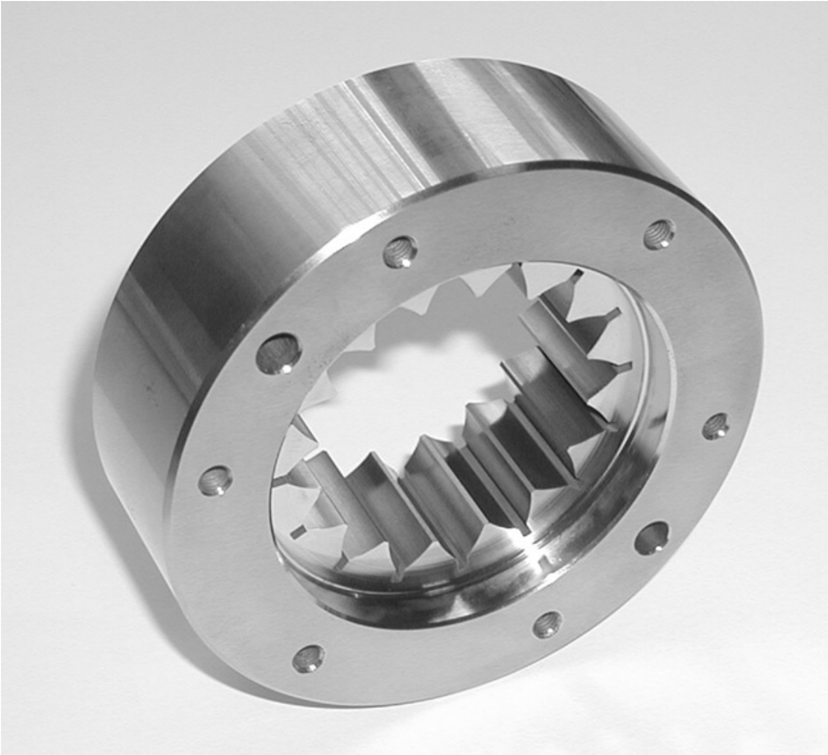


Figure 7 — Internal gear artifact

7.5 Runout artifacts

A runout artifact is a calibration artifact that provides a series of teeth of involute form arranged in equally spaced angular positions around the periphery of the artifact. The runout artifacts are calibrated as the deviation of the radial position of a sphere of specified diameter located within the tooth spaces so as to establish simultaneous contact with both flanks.

A gear provided with an appropriate calibration certificate can serve as a runout calibration artifact. This type of artifact can also serve as an involute form pitch calibration artifact with both left and right flank features.

7.6 Tooth thickness artifacts

A tooth thickness artifact is a calibration artifact that provides some teeth or gaps of involute form with both right and left hand flank features. See Figure 8.

Figure 8 — Tooth thickness artifact

The tooth thickness or space width is calibrated directly by measuring the length of a circular arc on the reference circle between the left and right flank. This length is dependent on the reference axis of the artifact. Therefore, this axis shall be defined.

Measurement of the dimension over two pins or balls in opposing gaps is an indirect method of calibration of the space width of an artifact. The resulting dimension is independent of the reference axis of the artifact.

There can be differences in the results of both measuring methods (especially on helical artifacts). Therefore, the artifact should be calibrated in the same way as it is used. It is recommended that an artifact always have teeth or gaps on the opposite side and the number of teeth should be even, so that both measuring and calibration methods can be used. The use of gaps instead of teeth on the artifacts has advantages, because the stiffness of the geometry is increased and the flanks are secured against damage.

7.7 Workpiece-like artifacts

An accurate gear, workpiece-like artifact, with appropriate calibration data, can serve as a calibration artifact with both left and right flank features (see Figure 9). Workpiece-like artifacts shall have appropriate datum surfaces in accordance with ISO/TR 10064-5.

A workpiece-like artifact offers the advantage that it can serve as an involute, helix, pitch (index) or runout calibration artifact. Workpiece-like artifacts are recommended where instrument operators require frequent use of the artifact.

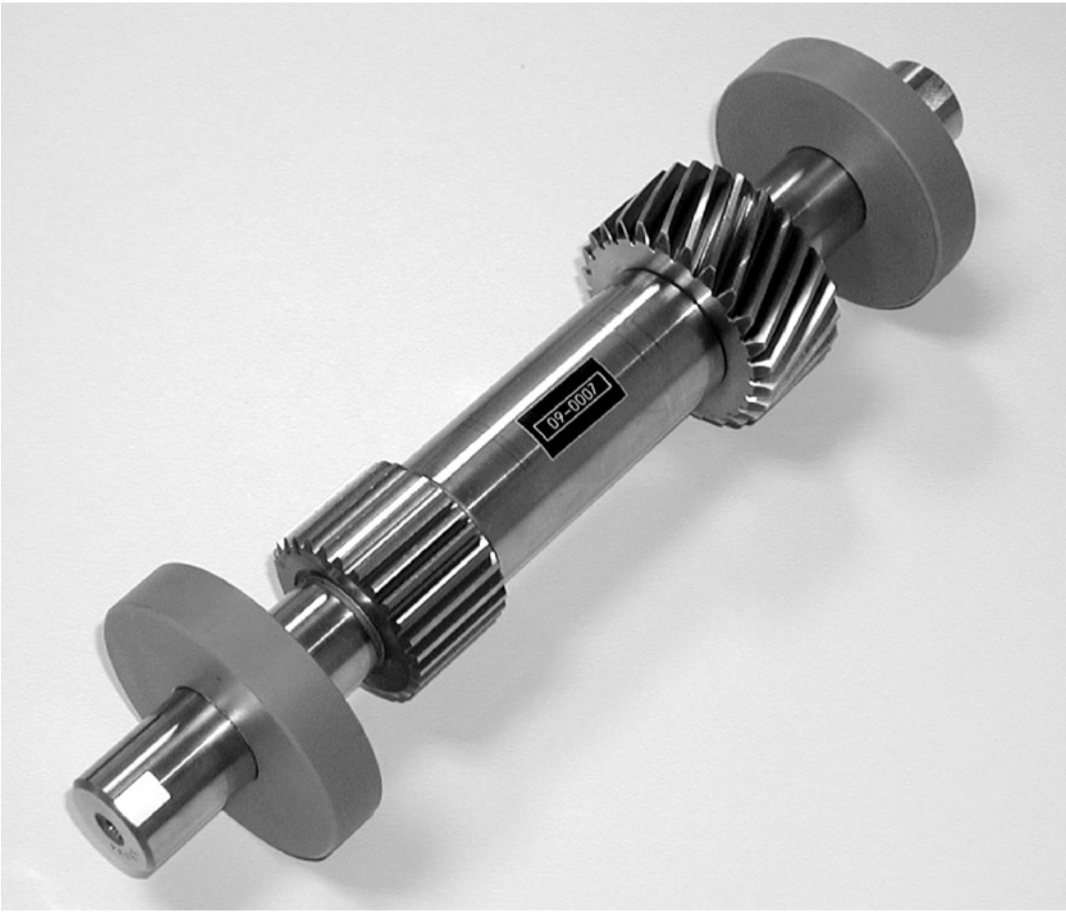


Figure 9 — Workpiece-like artifact

8 Method for estimating measurement uncertainty

The purpose of evaluating measurement uncertainty is to estimate how errors from the various sources combine to affect measurement processes. When a calibration document or inspection report states a measurement uncertainty (U_{95}), it is stating that there is a 95 % probability that the true value lies within the range defined by the uncertainty. There is a 5 % probability it lays outside that range.

The determination of measurement uncertainty is closely tied to an instrument calibration; it could be said that an instrument has been calibrated once its measurement uncertainty has been determined. However, it is important to understand that many factors beyond performance of the given instrument can influence the uncertainty of a measurement process. Often the contribution of the instrument is small compared to other sources. Therefore, it is better to refer to the uncertainty of a measurement process rather than to the uncertainty of an instrument.

Any document stating the results of an instrument calibration or measurement process uncertainty determination shall provide the associated limitations of applicability, including the parameters measured, size of the measuring envelope, configurations of instrument hardware and software, and environmental conditions.

8.1 Methods

There are a number of common methods for determining uncertainty in the measurement of gears and gear artifacts. Each method differs considerably in complexity, time to implement and cost. Selection is usually determined by the application:

— the decomposition and surrogate methods are generally applied in national and primary calibration facilities;

— the uncertainty budgeting method outlined in *GUM* is often applied in secondary calibration laboratories or industrial facilities that require a more accurate estimate of their measurement process capability;

— the comparator method is generally used by the gear industry to verify the measuring instrument performance.

A combination of the methods is often used in practice.

This standard provides a procedure using the comparator method for estimating gear measurement uncertainty.

8.2 Comparator method

The comparator method evaluates the measurement process by use of a calibrated artifact with gear tooth geometry.

Sometimes an extrapolated comparator method is used to determine measurement uncertainty of an object that is similar, but not identical, to the reference artifact that was used to calibrate the measurement process. This is considered valid, so long as the differences between the object and the reference artifact are within specified limits.

The comparator method is sometimes extended still further to include the measurement of work pieces that are significantly different from the artifact used to calibrate the measurement instrument. This disparity between reference artifact and measured work pieces can take two general forms. One is called geometry similarity influence, u_g, and includes consideration for differences such as diameter, module, and face width. The other is called workpiece characteristic influence, u_w, and includes differences associated with such items as material characteristics, surface finish and form. These differences necessitate the application of more complex variations in the uncertainty determination and usually result in larger uncertainty values.

For guidance concerning the expanded and extended comparator methods, see ISO/TR 10064-5.

8.3 Calculation of U_{95} measurement uncertainty

Equations used for calculation of U_{95} measurement uncertainty vary considerably. The general form of the uncertainty equation for comparator methods is shown in Equation 1:

$$U_{95} = \left[k \left(u_m^2 + u_n^2 + u_g^2 + u_w^2 \right)^{0,5} \right] + |E| \qquad (1)$$

Depending on the particular method being used, the following components, which represent sources of measurement uncertainty, may be included in the given uncertainty calculation, or set to zero.

— Measuring uncertainty, U_{95}: the expanded uncertainty of the given measurement process with a 95 % confidence level; expressed in micrometers.

— Coverage factor, k: Usually set to $k = 2$, thereby producing an expanded uncertainty value with a confidence level of 95 %.

— Standard uncertainty, u_m: The variability of a series of measurements (reproducibility) made on the same work piece by the given instrument; expressed in micrometers.

— Reference artifact calibration uncertainty u_n: it should be clearly stated as one half of the $U_{95(cal)}$ value on the reference artifact calibration document; expressed in micrometers.

— Geometry similarity influence, u_g: uncertainty associated with dissimilarity between reference artifact and measured work piece geometry; expressed in micrometers.

— Work piece characteristic influence, u_w: uncertainty associated with dissimilarity between reference artifact and measured work piece such as material characteristics, surface finish and form; expressed in micrometers.

NOTE Values for u_g and u_w will not be given in this standard, see ISO/TR 10064-5. The measurement uncertainty determination methods given in this standard are limited by required characteristics of the measured work piece for validity.

— Bias (accuracy), E: the offset of the average value of a series of measurements made by the given instrument from the calibrated value of the measured reference artifact, in some cases it will in practice be adjusted out of the measurement process — either by adjusting the instrument or compensating the results; expressed in micrometers.

8.4 Procedure

8.4.1 Operating conditions

All equipment used for measurement uncertainty estimates shall be traceably calibrated to a national standard (see 4.2).

Before starting measurements leading to estimation of uncertainty, confirm the operational and environmental conditions set forth by the instrument manufacturer, the user manual or ISO/TR 10064-5.

Carry out a preliminary visual inspection of the instrument, required apparatus and reference artifacts in order to confirm the absence of detrimental dirt or wear. The condition, runout and positioning of mounting should be checked on instruments so equipped with a rotary table. Initialize the instrument and carry out required procedures such as probe qualification, in accordance with normal instrument operating procedures.

8.4.2 Measurement procedures

Mount the reference artifact on the instrument and measure the calibrated feature(s) in the same way and under the same conditions stated in the calibration certificate.

The minimum number of measurements shall be 10. Improved validity could be achieved by additional measurements, to a point of diminishing returns at about 30. These measurements should be made at a number of different positions on the instrument, covering the range of positioning of test piece measurements that will subsequently be used. Different positions may mean different angular positions on a rotary table, or different positions in the measuring volume. The reference artifact shall be removed from the instrument between each measurement.

If the measurements are to estimate the uncertainty of a new instrument or following an instrument service, then the random error components of measurement uncertainty will not include environmental or reproducibility error sources. These shall be clearly stated when reporting the results.

It is recommended that measurement data be gathered over longer periods of time, for example, from measurements taken during routine weekly checks on instrument performance. This data will include environmental variation and reproducibility data and will thus be a better representation of the day-to-day performance of the measuring process.

8.4.3 Estimation of measurement uncertainty

This U_{95c} uncertainty estimation will quantify the uncertainty of measurements made with the calibrated gear artifact, or an identical artifact, under the identical measurement conditions of position and environment. See ISO/TR 10064-5 for guidance on estimating product gear measurement uncertainty.

The procedure shall be carried out as follows.

a) Perform a series of measurements on the calibrated reference artifact, following the procedure given in 8.4.2. The minimum number of measurements is 10.

b) Determine the mean value, $\bar{X}$, of the results produced in a). Then find the bias, E, by subtracting the calibrated value of the reference artifact from the mean value of the results.

c) Determine the standard uncertainty, u_m, of the results produced in a) using Equation 2:

$$u_m = \left(\sum_{i=1}^{n} \frac{\left(X_i - \bar{X} \right)^2}{n-1} \right)^{0,5} \tag{2}$$

where

u_m is the standard uncertainty;

X_i is an individual measured value of the parameter calibrated;

$\bar{X}$ is the mean of measured values;

n is the number of measurements.

d) Determine the standard uncertainty, u_n, associated with the calibration of the reference artifact using Equation 3:

$$u_n = \frac{U_{95(cal)}}{2} \tag{3}$$

where

u_n is the reference artifact standard uncertainty;

$U_{95(cal)}$ is the U_{95} measurement uncertainty stated in the reference artifact calibration document.

e) Determine U_{95c} measurement uncertainty for this specific series of measurements using Equation 4, which is the specific application of Equation 1 for the direct comparator method:

$$U_{95c} = \left[2\left(u_m^2 + u_n^2 \right)^{0,5} \right] + \left| E \right| \tag{4}$$

8.4.4 Examples for the estimation of uncertainty

See ISO/TR 10064-5 for examples of gear measurement instrument estimation of uncertainty.

Annex A
(normative)

Artifact calibration certificate requirements

Artifacts used for verification purposes shall have a valid calibration certificate that has been issued by a laboratory in compliance with ISO 17025.

The calibration certificate shall contain sufficient information to enable a comparison of calibration data and measurement data. Specific details shall be unambiguously reported. This should include, but not be limited to,

- a title, e.g. “Calibration Certificate”,
- the name and address of the calibration laboratory,
- a unique identification of the certificate, e.g. a serial number, printed on each page of the certificate,
- a page numbering system which clearly indicates a page is recognizable as part of a certificate, e.g. “page 3 of 6”,
- the name and address of the client,
- a description of, or reference to, the method used,
- a description of, condition of and unambiguous identification of the item calibrated,
- the date(s) of calibration of the item,
- the environmental conditions under which calibrations were made that influence the results,
- the calibration results and the units of measurement,
- the uncertainty of measurement,
- a statement of traceability,
- the orientation and the calibrated flank definition and numbering, if applicable,
- the definition of the datum surfaces used and the runout of the datum surfaces, if appropriate, or a statement that the datum surfaces were used to define the datum axis of the calibration item, and
- the position where measurements were made and the evaluation range, if appropriate.

Where statements of compliance are made, the certificate should clearly identify which clauses of the specification are met or not met, and give due consideration of the effect of measurement uncertainty in accordance with ISO 14253-1:

- the name and signature of the person authorizing the calibration certificate;
- the date of issue of the certificate.

Information should be included that enables the conditions of calibration to be duplicated. This could include, but not be limited to,

- mounting arrangement,

- the size and geometry of the stylus,
- the stylus force,
- the scanning speed used, or a statement that the data was gathered statically,
- the number of measurement points gathered,
- the definition of filter(s) used, if any, prior to evaluation,
- reference to the relevant standard used to evaluate the results, e.g. “ISO 1328-1”, and the definition of ± deviation used, and
- graphical representation of the parameters measured.

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