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Test code for machine tools —

Part 11: Measuring instruments suitable for machine tool geometry tests

Code d'essai des machines-outils —

Partie 11: Instruments de mesure compatibles avec les essais de géométrie des machines-outils

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 39, *Machine tools*, Subcommittee SC 2, *Test conditions for metal cutting machine tools*.

A list of all parts in the ISO 230 series can be found on the ISO website.

Introduction

The purpose of this document is to provide information for instruments and equipment for testing machine tools as specified in the ISO 230 series (except ISO 230-5 and ISO/TR 230-8), and in machine-specific standards of ISO/TC 39/SC 2, test conditions for metal cutting machine tools.

The main parts of this document have been transferred from ISO 230-1:1996, Annex A, which is no longer part of ISO 230-1. Newly developed measuring instruments, like special purpose measuring instruments in Clause 12, have been added to this document as well as special application examples in Clause 13.

The concept of measuring uncertainty has been implemented. Uncertainty contributors for measuring instruments and measuring procedures are listed in Annex D to improve reliability of test results. In addition, Annex A addresses checking devices for instruments applied in the workshop and Annex C addresses influences of supporting systems.

Additional information for existing ISO and national standards for measuring equipment is included in Annex B.

This document and ISO 230-1:2012 together cover the entire content of ISO 230-1:1996, with updated instruments and concepts.

Test code for machine tools —

Part 11:
Measuring instruments suitable for machine tool geometry tests

1 Scope

The aim of this document is to document the characteristics of precision measuring instruments for testing the geometric accuracy of machine tools, operating either under no-load or under quasi-static conditions.

Where necessary, reference is made to the appropriate International Standards.

The measuring instruments for operational testing of machine tools [vibrations (ISO/TR 230-8), noise (ISO 230-5), stick-slip motion of components, etc.] as well as instruments for checking of other characteristics of machine tools (speeds, feeds, temperature) are not covered in this document. The measuring instruments for checking of workpiece geometry (size, form, etc.) are not covered by this document either.

This document has list style construction for ease of search and identification of each instrument's characteristics.

Sources of uncertainty of instruments and measurements are described in this document for more accurate measurement procedures.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
calibration
operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties, and in a second step, uses this information to establish a relation for obtaining a measurement result from an indication

Note 1 to entry: A calibration may be expressed by a statement, calibration function, calibration diagram, calibration curve, or calibration table. In some cases, it may consist of an additive or multiplicative correction of the indication with associated measurement uncertainty.

Note 2 to entry: Calibration should not be confused with adjustment of a measuring system, often mistakenly called "self-calibration", nor with verification of calibration.

Note 3 to entry: Often, the first step alone in the above definition is perceived as being calibration.

[SOURCE: JCGM 200:2012, 2.39]

3.2
measuring range
set of values of measurands for which the error of a measuring instrument is intended to lie within specified limits

Note 1 to entry: Error is determined in relation to a conventional true value.

[SOURCE: ISO 14978:2006, 3.36]

3.3
accuracy
closeness of agreement between a measured quantity value and a true quantity value of a measurand

Note 1 to entry: The concept “measurement accuracy” is not a quantity and is not given a numerical quantity value. A measurement is said to be more accurate when it offers a smaller measurement error.

Note 2 to entry: The term “measurement accuracy” should not be used for measurement trueness and the term “measurement precision” should not be used for ‘measurement accuracy’, which, however, is related to both these concepts.

Note 3 to entry: “Measurement accuracy” is sometimes understood as closeness of agreement between measured quantity values that are being attributed to the measurand.

[SOURCE: JCGM 200:2012, 2.13]

3.4
linearity
degree of insignificance on deviation from the linear relation between the input signal and the output signal[20]

3.5
repeatability
measuring precision under a set of repeatability conditions of measurement

Note 1 to entry: These conditions include

— reduction to a minimum of the variations due to the observer,

— the same measurement procedure,

— the same observer,

— the same measuring equipment, used under the same conditions,

— the same location, and

— repetition over a short period of time.

Note 2 to entry: Repeatability can be expressed quantitatively in terms of the dispersion characteristics of the indications.

3.6
frequency response
a state where the amplitude ratio of an output signal to the input signal and the phase difference between the two are varied as a function of sinusoidal input signal frequency[20]

3.7
measuring force
<load> force applied by the stylus of an indicator or recorder to the feature being measured

3.8
operating environment
atmosphere or environment in which the object is placed during testing[20]

3.9
stability
property of a measuring instrument, whereby its metrological properties remain constant in time

Note 1 to entry: Stability may be quantified in several ways.

EXAMPLE 1 In terms of the duration of a time interval over which a metrological property changes less than a stated amount.

EXAMPLE 2 In terms of the change of a property over a stated time interval.

[SOURCE: JCGM 200:2012, 4.19]

3.10
correction
compensation for an estimated systematic effect

Note 1 to entry: See ISO/IEC Guide 98-3:2008, 3.2.3, for an explanation of “systematic effect”.

Note 2 to entry: The compensation value(s) can take different forms, such as a constant addition or multiplication, or multiple values obtained from a table.

[SOURCE: JCGM 200:2012, 2.53]

3.11
measuring instrument
device used for making measurements, alone or in conjunction with one or more supplementary devices

Note 1 to entry: A measuring instrument that can be used alone is a measuring system.

[SOURCE: JCGM 200:2012, 3.1]

3.12
measuring transducer
device, used in measurement, that provides an output quantity having a specified relation to the input quantity

[SOURCE: JCGM 200:2012, 3.7]

3.13
measuring system
set of one or more measuring instruments and often other devices, including any reagent and supply, assembled and adopted to give information used to generate measured quantity values within specified intervals for quantities of specified kinds

[SOURCE: JCGM 200:2012, 3.2]

3.14
sensor
element of a measuring system that is directly affected by the phenomenon, body or substance carrying the quantity to be measured

EXAMPLE Sensing coil of a platinum resistance thermometer, rotor of a turbine flow meter, Bourdon tube of a pressure gauge, float of a level-measuring instrument, photocell of a spectrometer, thermotropic liquid crystal which changes colour as a function of temperature.

Note 1 to entry: In some fields, the term “detector” is used for this concept.

[SOURCE: JCGM 200:2012, 3.8]

3.15
detector
device or substance that indicates the presence of a phenomenon, body, or substance when a threshold value of an associated quantity is exceeded

EXAMPLE Halogen leak detector, litmus paper.

Note 1 to entry: In some fields, the term “detector” is used for the concept of sensor.

[SOURCE: JCGM 200:2012, 3.9]

3.16
sensitivity
quotient of the change in the indication of a measuring system and the corresponding change in a value of a quantity being measured

Note 1 to entry: Sensitivity of a measuring system can depend on the value of the quantity being measured.

Note 2 to entry: The change considered in a value of a quantity being measured needs to be large compared with the resolution.

[SOURCE: JCGM 200:2012, 4.12]

3.17
resolution
smallest change, in a quantity being measured that causes a perceptible change in the corresponding indication

Note 1 to entry: Resolution can depend on, for example, noise (internal or external) or friction. It can also depend on the value of a quantity being measured.

[SOURCE: JCGM 200:2012, 4.14]

3.18
instrumental drift
continuous or incremental change over time in indication, due to changes in metrological properties of a measuring instrument

Note 1 to entry: Instrumental drift is related neither to a change in a quantity being measured nor to a change of any recognized influence quantity.

[SOURCE: JCGM 200:2012, 4.21]

3.19
optical measuring instrument
instruments, measuring physical, geometrical or material properties based on optical principles, such as photometry, interferometry, geometrical optics, holography, or refractometry[14].

EXAMPLE one-coordinate and multi-coordinate measuring machines, surface-measuring instruments, numerical measuring instruments for machine control, autocollimators, telescopes, contour-measuring instruments.

3.20
maximum permissible error
MPE
<for a metrological characteristic> extreme value of an error of a metrological characteristic permitted by specifications, regulations, etc. for a given piece of measuring equipment

[SOURCE: ISO 14978:2006, 3.21, modified — The domain has been added and “errors” has been changed to “error”.]

3.21
measuring precision
closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same or similar objects under specified conditions

Note 1 to entry: Measurement precision is usually expressed numerically by measures of imprecision, such as standard deviation, variance, or coefficient of variation under the specified conditions of measurement.

Note 2 to entry: The specified condition can be, for example, repeatability conditions of measurement, intermediate precision condition of measurement, or reproducibility condition of measurement (see ISO 5725-1. 1994).

Note 3 to entry: Measurement precision is used to define measurement repeatability, intermediate measurement precision, and measured reproducibility.

Note 4 to entry: Sometimes "measurement precision" is erroneously used to mean measurement accuracy.

[SOURCE: JCGM 200:2012, 2.15]

4 Preliminary remarks

4.1 Measuring units

The units for the following features are:

— displacement, distance and linear deviations: mm or µm;

— angles: degrees or a ratio;

— angular deviation: µm/m or ″ (arc seconds); and

— linear compliance: µm/N.

4.2 Uncertainty of measuring instrument

4.2.1 General

Uncertainty of measuring instrument is a component of combined measurement uncertainty (JCGM 200:2012, 4.24). The instrument uncertainty should be small enough to assess the system performance. The uncertainty of the measurement including the instrument uncertainty should be considered according to ISO 14253-1 ("decision rules") when it is used to check system performance against specifications. However, if the measurement uncertainty is less than 10 % of the specification limit, it is common industrial practice to decide on the conformance or non-conformance based on the indicated measurement value.

Measuring equipment should not be used until it has been allowed to stabilize at the ambient temperature, and stability maintained during the test procedure.

Care should be taken to prevent disturbance to the equipment caused by vibrations, magnetic fields, electrical interference, etc.

General uncertainty contributors are indicated in Table 1 (see also ISO 14253-2). Annex D describes relationship between the instruments and uncertainty contributors. Simple explanation of uncertainty contributors related to the measuring instruments and set-up procedures are described in the following clauses.

Table 1 — List of uncertainty contributors

1. Environment	**2. Measuring equipment**
Absolute temperature (4.2.2.1)	Stability (4.2.3.1)
Temperature spatial gradient (4.2.2.2)	Scale mark quality (4.2.3.2)
Temperature time variance (4.2.2.2)	Temperature expansion coefficient (4.2.3.3)
Vibration/noise (4.2.2.3)	Thermal conductivity (4.2.3.4)
Humidity (4.2.2.4)	Uncertainty of the calibration (4.2.3.5)
Contamination (4.2.2.5)	Resolution of the main scale (analogue or digital) (4.2.3.6)
Ambient pressure (4.2.2.6)	Time since last calibration (4.2.3.7)
Air composition (4.2.2.7)	Magnification, electrical or mechanical (4.2.3.8)
Air flow (4.2.2.7)	Wavelength error (4.2.3.9)
Gravity (4.2.2.8)	Zero-point stability (4.2.3.10)
Electromagnetic interference (4.2.2.9)	Measuring force stability/absolute force (4.2.3.11)
Supply air pressure (e.g. air bearings) (4.2.2.10)	Hysteresis (4.2.3.12)
Heat radiation (4.2.2.11)	Probe system, Tip radius, Form deviation of tip (4.2.3.13)
Instrument thermal equilibrium (4.2.2.12)	Stiffness/rigidity (4.2.3.14)
	Linear coefficient for thermal expansion (4.2.3.15)
	Temperature stability/sensitivity (4.2.3.16)
	Parallaxes (4.2.3.17)
	Interpolation system, error wavelength (4.2.3.18)
	Interpolation resolution (4.2.3.19)
3. Measurement setup and procedure	**4. Software and calculations**
Cosine errors and sine errors (4.2.4.1)	Rounding/Quantification (4.2.5.1)
Abbe principle (4.2.4.2)	Algorithms (4.2.5.2)
Temperature sensitivity (4.2.4.3)	Sampling (4.2.5.3)
Stiffness/rigidity (4.2.4.4)	Filtering (4.2.5.4)
Stiffness of the probe system (4.2.4.5)	Correction of algorithm/Certification of algorithm (4.2.5.5)
Optical aperture (4.2.3.6)	Interpolation/extrapolation (4.2.5.6)
Interaction between standard and setup (4.2.4.7)	
Warming up (4.2.4.8)	
Conditioning (4.2.4.9)	
Number of measurements (4.2.4.10)	
Order of measurements (4.2.4.11)	
Duration of measurements (4.2.4.12)	
Alignment (4.2.4.13)	
Choice of reference — reference item (standard) (4.2.4.14)	
Choice of apparatus (4.2.4.15)	
Strategy (4.2.4.16)	
Fixturing (4.2.4.17)	
Number of points (4.2.4.18)	
Probing principle and strategy (4.2.4.19)	

Table 1 *(continued)*

Alignment of probing system (4.2.4.20)	
Reversal measurements (4.2.4.21)	
Multiple redundancy, error separation (4.2.4.22)	

4.2.2 Environment factors

4.2.2.1 Reference temperature

Standard reference temperature for machine tool measurements is 20 °C (see ISO 1). Deviations from this temperature, either in absolute terms or due to temporal and spatial temperature gradients, results in linear expansion and/or bending of the measuring equipment, the measurement set-up and the object being measured. The influence of temperature deviations on the length is given by Formula (1).

$$\Delta L = \Delta T \times \alpha \times L \qquad (1)$$

where

ΔT is the relevant temperature deviation from 20 °C;

α is the temperature expansion coefficient of the material;

L is the effective length under consideration (see ISO 14253-2:2011, 8.4.8.1).

See also 4.2.3.3 and ISO/TR 16015.

4.2.2.2 Temperature gradient/variance

The existence of temperature gradients implies that portions of the environment will not be at the same mean temperature such that the consequences of mean temperatures other than 20 °C will be different in different locations in a room. Additional complexity is created when these temperature gradients change in time (see also ISO 230-3:2007, Annex D).

4.2.2.3 Vibration/noise

Vibration/noise from internal of machine tool system under test or from external sources causes relative displacement between the measuring instrument and the target machine surface. Such vibration also affects the supporting device of the instrument. Acoustic noise sometimes excites vibration that affects the instrument (see also ISO/TR 230-8).

4.2.2.4 Humidity

Length measurement using laser interferometer is affected by the change of the laser wavelength due to the change in the relative humidity of air, in which the laser beam passes. For example, 30 % change in relative humidity of air causes 1 µm/m change in length measurement.

4.2.2.5 Contamination

Dust, rust, oil, chemical materials and other unwanted small particles in the workshop can disturb precise contact between the instrument and target work surface. Surface contamination on optical parts can affect optical performance such as polarization, wavelength change, etc.

4.2.2.6 Ambient pressure

Length measurement using laser interferometer is affected by the change of the laser wavelength due to the change in pressure of air, in which the laser beam passes. For example, 330 Pa change in absolute air pressure causes 1 μm/m change in length measurement.

4.2.2.7 Air flow/air composition

The flow rate and velocity of the ambient air are of prime importance in the control of temperature variation and temperature gradients of the machine components. Also, such air characteristics affect the wavelength of the laser and, consequently, the length measurement when laser interferometer is used. The local air density change directly influences the length unit (see 4.2.2.4, 4.2.2.6 and also ISO 230-3:2007, Annex D).

4.2.2.8 Gravity

See 4.2.3.14.

4.2.2.9 Electromagnetic interference

Electromagnetic fields induced by surrounding power electronic facilities can contaminate the accuracy, stability and instrumental drift of an electronic measuring instrument. Sensors using magnetic effect such as scale, limit sensor, and inductive gauges can be influenced. It can affect sensor itself, connecting cable, amplifier and power source.

4.2.2.10 Supply air pressure (air bearing)

Air gauge, linear motion instruments with air bearing are operated by pressurized supply air in the workshop. The variance of air pressure can influence the air gauge stability, gap of air bearings, and motion accuracy. Content of moisture in the supply air can also induce rust.

4.2.2.11 Heat radiation

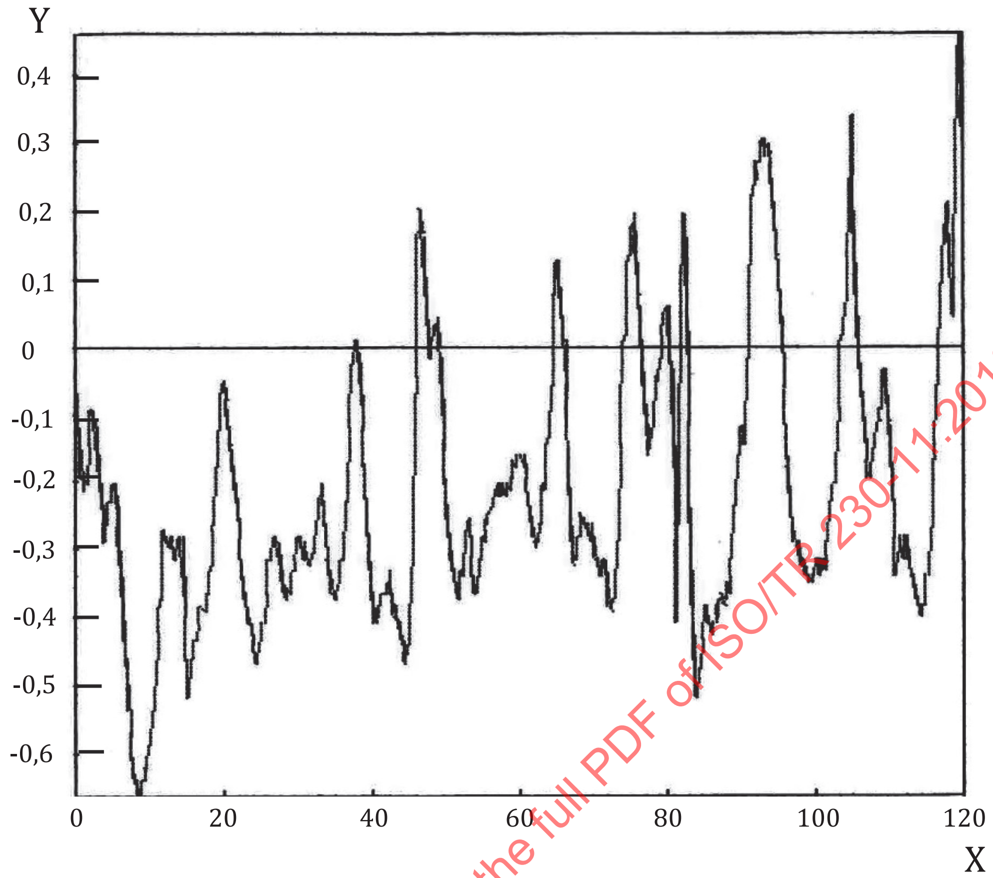
Heat generated by the machine environment can affect the measuring instrument and its supporting system. Such radiation can be guarded by a reflective material cover such as an aluminium sheet.

4.2.2.12 Instrument thermal equilibrium

Temperature of the instrument placed on the target surface of the machine should be as close as possible to the machine temperature. The difference between these induces local deformation of instrument, thermally-induced changes in readings, etc.

4.2.2.13 EVE (Environmental Variation Error)

Environmental variation (such as temperature variation, air density variation, ground vibration) influences the measurement device and/or the machine tool under test causing environmental variation error (EVE) (see also ISO/TR 230-9:2005, C.2.5). This environmental variation error (EVE) can be checked by setting up the measurement equipment on the machine tool under test and looking at the change of readout during the time necessary to do the test. The location of EVE test is selected in order to recognize the largest influence from EVE on the geometrical test concerned. Figure 1 shows an example of EVE on laser angle measurement. The data indicate the variance within 120 seconds. The total EVE value is about 1 arc-second (see 4.2.2.2, 4.2.2.3, 4.2.2.6 and 4.2.2.7).



Key

X time: 0 s to 120 s

Y angle deviation in ″ (arc sec)

Figure 1 — Example of EVE by laser angle measurement

4.2.3 Measuring equipment factors

4.2.3.1 Stability

See 3.9.

4.2.3.2 Scale mark quality

The quality of a scale mark used for reading a value affects the accuracy. If the scale mark is not clear, the reading stability is contaminated and the total accuracy decreases (see also ISO 14978:2006, 3.28.11).

4.2.3.3 Coefficient of thermal expansion

This coefficient should be given as an "effective coefficient of thermal expansion" relevant to the effect of temperature on the geometrical characteristic represented by the material measured. The uncertainty of the stated value should also be provided (see ISO 14978:2006, 6.4.5).

4.2.3.4 Thermal conductivity

Differences of components' thermal conductivity can induce local deformation in the measuring instrument. Even if both temperature expansion coefficients are the same, the mass of components should be considered during temperature changes, as different mass can cause different temperature of components before reaching thermal equilibrium. It is possible thermal equilibrium not be reached if there is relevant environmental thermal variation and if the thermal time constants of elements engaged are significantly different.

4.2.3.5 Uncertainty of the calibration

Quality of calibration procedures should be high enough to minimize the uncertainty of measurement. Even if the resolution of an instrument is high, its reliability depends on the calibration integrity.

4.2.3.6 Resolution of the main scale (analogue or digital)

Resolution of the main scale should be fine enough to maintain the adequate sensitivity to change in measured value.

4.2.3.7 Time since last calibration

If the calibrated instrument is not stable, the calibration is valid only for a limited period of time. The latest calibration date should be clearly recorded and reported.

4.2.3.8 Magnification, electrical, mechanical, or optical

Small displacement values are magnified mechanically, electronically or optically to easily identify the values. Magnification accuracy of the measuring instrument influences the final reading.

4.2.3.9 Wavelength error

If a measuring instrument uses wavelength, i.e. optical, ultrasonic and electro-magnetic, as its length scale, wavelength error directly affects the measurement result. Calibration of wavelength should be conducted at certain intervals. It should be noted that the wavelength of the laser beam depends on the refractive index of the air through which it passes. Since the refractive index of air varies with temperature, pressure and relative humidity, the wavelength value used to compute, it can be necessary to compensate the measured length values for changes in these environmental parameters. For example, 1 °C change in ambient air temperature causes 1 µm/m error in length measurement.

4.2.3.10 Zero-point stability

Relative displacements are detected by movement of scale referring to zero-point or reference point. If zero-point moves from stationary position, this motion causes measurement uncertainty.

4.2.3.11 Measuring force stability / absolute force

Standard reference condition for machine tool measurements is zero measurement force. The effect on errors and uncertainty of length measurement by non-zero force is caused by elastic and, in some cases, also plastic deformation of the measurement equipment, the measurement set-up and the measuring object. Especially, the effect on the contact geometry between measuring equipment and measurement object should be investigated (see ISO 14253-2:2011, 8.4.8.2).

4.2.3.12 Hysteresis

It is the property of measuring equipment, or a characteristic whereby the indication of the equipment or value of the characteristic depends on the direction of the preceding stimuli. Hysteresis can also depend, for example, on the distance travelled after the direction of stimuli has changed (see ISO 14978:2006, 3.24).

4.2.3.13 Probe stylus system, tip radius, form deviation of the tip

In a contact-type measuring system, shape, form and size of the contact element affect real contact point calculation. These values are calibrated beforehand.

4.2.3.14 Stiffness/rigidity

If components that directly transfer displacement to the measuring transducer system lack stiffness or rigidity against force generated by displacement, linearity between real displacement and sensed value differs. In artefacts such as a straightedge, gravity and measuring force induce natural sag and deformation. These values induce form error of the reference artefacts.

4.2.3.15 Linear coefficient for thermal expansion

Materials used in measuring systems have unique thermal expansion coefficients. If the temperature of the instrument is different from 20 °C, components of the instrument that have different thermal expansion coefficients expand differently, and these differences induce different measuring transducer magnification values.

4.2.3.16 Temperature stability/sensitivity

If a measuring system uses material/design other than non-expansion material/design, the measuring system is affected by temperature changes induced by external or internal heat generation.

4.2.3.17 Parallaxes

If a measuring system has a user interface requiring human reading/interpretation of the output such as a vernier calliper or a micrometer, then the distance between master scale and the pointer generates a reading error due to the distance between human eyes.

4.2.3.18 Interpolation system

Basic scale pitch resulting from the wavelength generated by optical, magnetic, or electrical means has a limitation of not having adequate resolution. Therefore, these basic pitches are divided into smaller units by interpolation. Interpolation can be achieved optically, electronically or by using software. Such interpolation systems have their own limitation of linearity.

4.2.3.19 Interpolation resolution

Interpolation systems determine resolution by dividing the basic pitch by a number of equal units. If resolution is very fine, interpolation speed is low. Accuracy of interpolation is affected by system design.

4.2.4 Setup and procedure factors

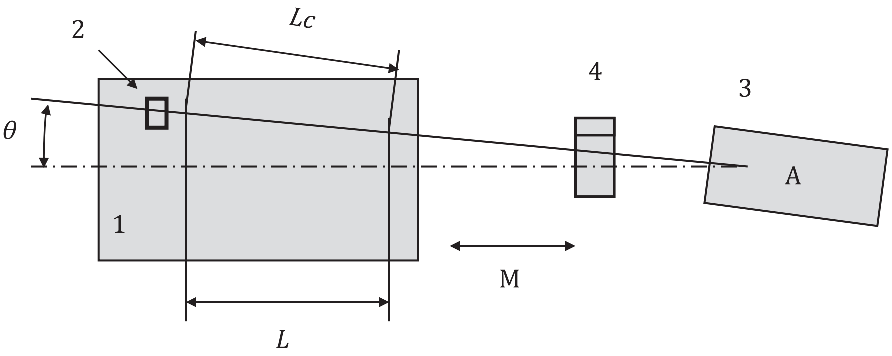
4.2.4.1 Cosine and sine errors

Misalignment of the scale of the measuring instrument (e.g. laser-beam path) with the axis of motion of the machine tool results in an error between the measured distance and the actual distance travelled. This misalignment error is usually referred to as cosine error, because the magnitude of the error is proportional to the term $(1 - \cos \theta)$, where θ is the angle of misalignment between the laser beam and the axis of motion.

When the measurement system is misaligned with the axis of machine travel, the cosine error causes the measured distance to be longer than the actual distance (see Figure 2).

The distance measured by the laser measurement system is Lc while the true distance travelled by the machine tool is L. By drawing an arc of radius D and centred at position A, one can easily see that L is shorter than Lc.

The only way to eliminate cosine error is to follow good alignment procedures during the set-up (see also ISO 230-2:2014, Annex A).



Key

1 machine table

2 retro reflector

3 laser head

4 interferometer

L actual machine travel

Lc measured machine travel

M direction of motion

θ angle of misalignment

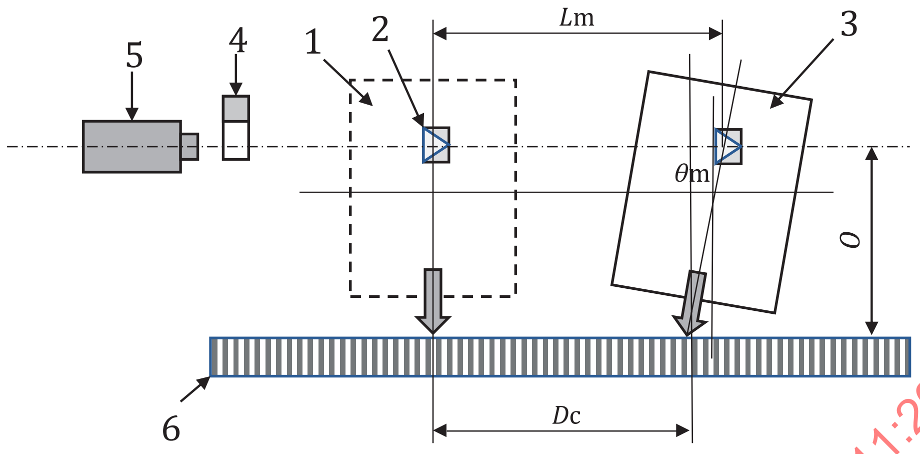
Figure 2 — Cosine error by laser interferometer measurement

4.2.4.2 Abbe principle

Referring to Figure 3, if a measurement is taken at a location 2 which is offset, *O*, from the machine tool displacement measurement system, 6, (e.g. ball screw, linear scale) any angular error motion (pitch and yaw error motion: *θ*) of the element introduces an error (*L*m − *D*c) (see A.2.3 and ISO 230-2:2014, Annex A).

A rule of thumb helpful in approximating the error attributable to an angular error motion: for each arc sec of angular error motion the error introduced is approximately 5 µm/m of offset. For a 200 mm Abbe offset and a 2 ″ (arc sec) angular motion, the error in the displacement measurement is 200 mm × 5 (µm/m) / (arc sec) × 2 ″ (arc sec) = 2 µm.

See also ISO 230-1:2012, 8.3.2.



Key

1 machine table at position 1
2 retro reflector
3 machine table at position 2
4 interferometer
5 laser
6 machine scale
O offset between machine scale and measuring position (Abbe offset)
*L*m measured length
*D*c machine command distance
*θ*m error motion angle

Figure 3 — Abbe offset error by laser interferometer measurement

4.2.4.3 Temperature sensitivity

A measuring system can be sensitive to the surrounding temperature change/gradients depending on its mechanical design and/or material used. Such influence affects the stability of the sensor reading.

4.2.4.4 Stiffness/rigidity

Simply supported (by two points) mechanical artefacts such as straightedge and taut wire are influenced by gravity. If straightness measurement is performed in the vertical direction, this deflection caused by gravity directly affects the measured straightness deviation. To minimize this effect, supporting points should be considered. In case of vertical direction measurement, distance between the support points should be $5L$ / 9 (where L is the working size of the artefact). Table 2 shows examples of supporting distance and estimated deflection.

Table 2 — Example of estimated deflection values

Working size, L (mm)	300	500	800	1 000	1 600
Supporting distance ($5L/9$) (mm)	190	300	465	575	910
Maximum Deflection (mm)	0,001	0,003	0,004	0,008	0,016

NOTE The natural deflection is proportional to the modulus of elasticity, E, of the material used. The deflection values given in the table correspond to straightedges made of ordinary cast iron: E = 98 kN/mm^2. In the case of steel, E = 196 kN/mm^2, the deflections are halved. In the case of heavy-duty cast iron, where, for example, E = 147 kN/mm^2, the deflection are 2/3 the values in the Table.

Supporting device stiffness check is required when the sensor is attached to the machine tool, see ISO 230-1:2012, 6.3.2). See also Annex C.

4.2.4.5 Stiffness of probing system

Bending stiffness affects the measuring position accuracy when applying probing extension bars. Such extension length should be as short as possible.

4.2.4.6 Optical aperture

When a laser length measuring system is applied to short distance displacement, reflected laser beam from reflector should be captured at exact point. However, optical aperture of beam detector has some area and it allows misalignment of setting. The return beam should always be aimed in the detector centre as good as possible, especially for short travels.

4.2.4.7 Interaction between standard and setup

If the reference artefact used is of significant weight or size, these features can affect the mechanical deformation of the setup construction. The temperature distribution, air flow and vibration conditions in the vicinity of the measurement setup can also be affected.

4.2.4.8 Warming up

Mechanical and optical instruments or those using electrical circuits generate heat during their operations. Warming up before measurement is necessary to minimize thermally-induced variations caused by such heat generation and target machine heat up (to reach thermal stability).

4.2.4.9 Conditioning

A series of filters and algorithms are used for generation of an image (value) of the measured physical quantity from the output of the sensor.

If sensors have nonlinear behaviours, such non-linearities can be corrected during the signal conditioning.

4.2.4.10 Number of measurements

A small number of measuring points along an axis can miss important errors. This increases the measurement uncertainty. The measuring point density should therefore be chosen sufficiently high.

A large number of repetitions does not decrease measurement uncertainty. It can decrease measurement uncertainty for any mean values if repeatability of measuring instrument is a significant contributor to measurement uncertainty.

4.2.4.11 Order of measurements

A measurement planning is used to define the order of measurement. For example, measurements along the directions of machine coordinate system should be carried out first.

4.2.4.12 Duration of measurement

Environment conditions can affect the object under test and/or the measuring equipment. Any measurement that needs a small amount of time diminishes the requirements for constant environmental conditions.

Any measurement that needs a large amount of time is more affected by changes of the environmental conditions.

4.2.4.13 Alignment

Alignment between the machine motion axis and the measurement axis (e.g. axis of the probe motion) should be carefully adjusted. Misalignments cause Abbe error and cosine error (see also 4.2.4.1 and 4.2.4.2).

4.2.4.14 Choice of reference artefact or feature

Selecting a suitable reference is necessary when the measurement is performed from the point of view of the specified tolerance. The ten percent rule should be adopted when a specified reference is not mentioned.

NOTE For many years, the 10 percent rule [23][24] has been applied for selecting measuring instruments. Today, the uncertainty due to the reference artefact (measuring instrument) is one of the contributors to the measurement uncertainty that is stated together with each measurement result. For proving conformance or non-conformance with specifications, ISO 14253-1 is applied. However, applying the 10 percent rule is still a sound rule of thumb for selecting a suitable reference artefact.

4.2.4.15 Choice of apparatus

Suitable apparatus must be selected when measurement is performed from point of view of resolution, working length, possible fixing method, possible placing area, etc.

4.2.4.16 Strategy of measurement

Strategies include the sequence of measurements, resolution of instruments used, selection of environments etc. These items directly influence data quality (i.e. accuracy, uncertainty).

4.2.4.17 Fixturing

All instruments used for measurement of relative displacement between tool side and work side are influenced by the motion of the machine tool. The instrument and its target are securely and properly fixed to the components of interest. Undesirable instrument or sensor mounting can generate undesirable deformation of the instrument or the target. When fixing the component of instrument, fixing torque/force should be considered not to deform the instrument. Improper fixing point also generates thermal deformation. Supports for dial gauges and electronic probes should be of sufficient stiffness to prevent unwanted deflections. See also Annex C.

4.2.4.18 Number of measuring points

The number of measuring points relate to the quality of extraction of error/deviation feature of the target. A too small number can result in a poor representation of the measurand. A too large number causes longer times to complete the measurement, and is therefore influenced by other conditions (e.g. thermal effects) as well as by the difficulty of data processing.

4.2.4.19 Probing principle and its strategy

Selection of probing principle such as contact/non-contact affects the results. Usually, non-contact probing can be useful for the measurement involving rapidly moving component. In case of evaluation of mechanical contact or interfacing items, the contact probing method can be a more suitable method for the measurement.

4.2.4.20 Alignment of probing system

The stylus of the dial gauge or electronic probe should be normal to the surface to be measured.

4.2.4.21 Reversal measurement

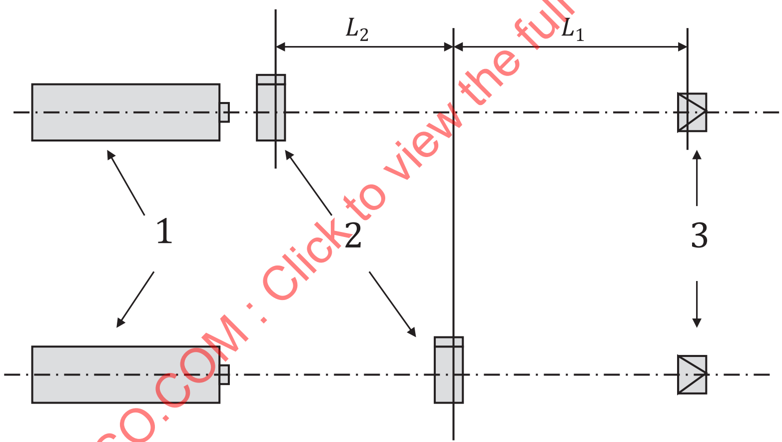
See A.2, ISO 230-1:2012, 8.2.2.1.1 and [25].

4.2.4.22 Multiple redundancy/error separation

A series of measurement data such as with different set up, different time can be applied to error reduction process. These data can include circumstances variance, operator error, set up, etc. These errors can be separated and reduced from original error.

4.2.4.23 Dead path error (laser interferometer)

Dead path is an error associated with changes in the environmental conditions during a measurement. In simple terms, it is an error due to an uncompensated length of laser-beam path, and it occurs when the atmospheric conditions surrounding the laser beam change (causing a change in the laser wavelength) and when the temperature in the material on which the optical interferometer and target reflector are mounted changes (causing the distance between the interferometer and retroreflector to increase or decrease). The dead path area of the laser measurement path is the distance between the optical interferometer and the reset (or 0) position of the measurement (L1). If there is no motion between the optical interferometer and the corner cube (retroreflector) and the environmental conditions surrounding the laser-beam path change, then the wavelength will change over the entire path (L1 + L2). If the velocity-of-light compensation value changes to correct for the new environmental conditions, the laser measurement system will correct for the laser-wavelength change over the distance L2, but no correction will occur over the dead path distance L1 (see Figure 4).



Key

1 laser head

2 interferometer

3 retro reflector

L_1 dead path distance

L_2 change over distance

Figure 4 — Dead path error

NOTE Software compensation also applicable to minimize this effect.

4.2.4.24 Other setup conditions

Specific setup and procedures specified by the instrument manufacturer, e.g. initialization or homing procedures, should be applied accordingly.

4.2.5 Software and calculation factors

4.2.5.1 Rounding/quantifications

The resolution of a measuring instrument (analogue or digital) or the step in last digit/decimal of a measured value or rounded measured value, whichever is largest, causes an uncertainty component, U_{XX}:

$$U_{\mathrm{XX}} \approx 0{,}3 \times d$$

where d is the resolution or the step in the last digit or decimal.

The uncertainty component, U_{XX}, is based on a rectangular distribution with limit value $a = 0{,}5 \times d$ (see ISO 14253-2:2011, 8.4.4).

4.2.5.2 Algorithms

Algorithms used for data processing should be suitable to the measurement items such as stable or dynamic, round part or flat part, etc. Misapplications of the software algorithms lead to completely different results.

4.2.5.3 Sampling

Depending on the nature of the measurement, data can be collected based on time or spatial intervals (called sampling period). Chosen sampling period influences the measurement results. For example, if the spatial sampling period on the surface is too large, captured data cannot indicate their true features on the surface. In the case of time-based measurement, sampling period directly influences the frequency response of the measurement.

4.2.5.4 Filtering

Filtering techniques can be applied when measurement data was contaminated by electrical or mechanical noise. The type of filtering, e.g. cut-off frequency, bandwidth, can sometimes distort original data.

4.2.5.5 Certification of algorithm

Certified test data can be used for certification of algorithms.

4.2.5.6 Interpolation/extrapolation

Digital equipment such as linear scales and rotary encoders include interpolation hardware/software to increase their resolution. Too much interpolation can generate non-linearity of the scale reading, and also reduces the frequency response.

4.3 Measuring equipment calibration (ISO 10012)

4.3.1 General

The measuring equipment should be calibrated at regular intervals against known reference standards, based on the metrological requirements. If necessary, calibration charts should be supplied to show the condition of the equipment. Recommended sequence is as follows:

a) regular calibration interval;

b) using calibration results for estimation of measurement uncertainty;

c) using calibration results (if necessary, calibration charts) to correct readings and, thus, reducing uncertainty due to instrument/artefact calibration uncertainty.

4.3.2 Manufacturer and supplier of measuring instruments

The manufacturer/supplier should calibrate the suggested metrological characteristics and document the conformance with the stated MPE values (see ISO 14978:2006, Clause 8).

4.3.3 User of measuring instruments

The metrological characteristics necessary for the intended use of the instrument should be chosen and should be verified by calibration (or verification tests). The calibrated value(s) of the metrological characteristic(s) should be stated with the related measurement uncertainty/uncertainties, and/or the calibrated values of the metrological characteristic should be proven to be in conformance with the actual MPE value(s).

NOTE In normal use of measuring instruments, it is often possible and appropriate to limit the number of requirements (different MPEs) and the extent of resources used to prove that the measuring instrument functions in accordance with the set-up requirements (MPLs and MPEs).

4.3.4 Measurement uncertainty

The acceptable amount of measurement uncertainty influences the number of points required to prove that a measuring instrument has a particular metrological characteristic function, and/or that this metrological characteristic is in conformance with a particular MPE value or function. A large number of points reduce the measurement uncertainty. A small number of points increase the measurement uncertainty. The required number of points therefore depends on the acceptability of the measurement uncertainty.

4.4 Comparison of measurement results by instruments using different measurement principles

There are multiple measuring instruments with different measurement principles that can be used to measure the same geometric errors. For example, squareness can be measured by square artefacts, laser angle interferometer and optical square with auto collimator. The measured results should be equal within a certain uncertainty level. When the measured results are compared, the compatibility should be checked using the following methods.

a) Absolute method: same reference artefacts are used for the comparison test. The same reference artefact is measured by the target instruments at the same time, and the results are compared. The artefacts used for this comparison should be calibrated and traceability to relevant International Standards should be guaranteed.

b) Relative method with calibrated devices at the same time: the accuracy of the device used for this test is checked by reference artefacts. Compatibility test should be performed simultaneously, and outputs are compared.

c) Relative method with calibrated devices at different times: the accuracy of the device used for this test is checked by reference artefacts. Compatibility tests are performed at different times, and its output compared.

d) Relative method with uncalibrated device at the same time: uncalibrated device such as real machine tool is applied to the test. Compatibility test is performed at same time, and outputs are compared.

e) Relative method with uncalibrated device at different times: uncalibrated devices are applied to the test. Compatibility test are performed at different times, and outputs are compared. Repeatability of the device is checked beforehand.

If measurement items of instruments to be checked include motion characteristics, then test speed, filtering, sampling rate, location of test, etc., should be (as much as possible) maintained constant and recorded.

Comparison test should be repeated at least ten times. Values of average and measurement uncertainties should be computed.

Comparison is performed for each different test parameter, e.g. in case of circular test, diameter, G*xx*, profile, etc., is tested and compared separately.

Figure 5 indicates the rule of judgment for the comparison.

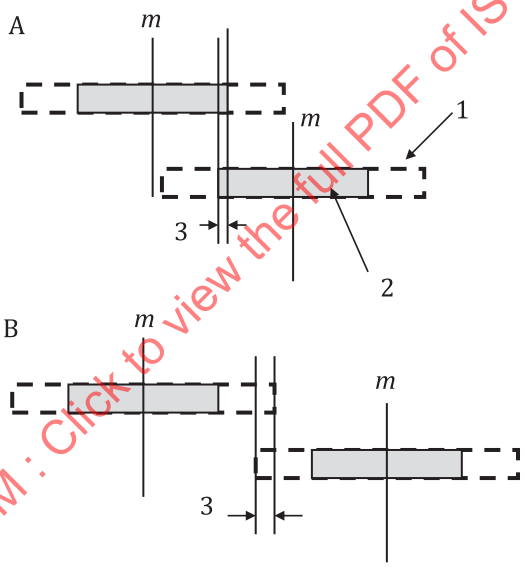
— If two specific conformance zones (see 2) are overlapped (see 3) as shown in Case 1, two results can be said to be identical and compatibility is satisfied, and can be used without any remarks.

— If two 2U (expanded measurement uncertainty) zones of specific instruments are overlapped (see 3) as shown in Case 2, compatibility is satisfied and results from two instruments can be used as same purpose.

— If there are no overlapping zones, then results from two instruments cannot be said to be compatible.

If different instrument types are applied without any comparison data, then agreement between manufacturer/supplier and user is necessary.

NOTE 2U zone can be obtained from preliminary experiences in the workshop.



Key

1 2U zone

2 specific conformance zone

3 overlap zone

m mean value

A case 1

B case 2

Figure 5 — Comparison between two different measuring instruments

5 Description of measuring instruments

Specific measuring instruments are described in this clause. Instruments are categorized and summarized in a table. Categorization method depends on its application and basic features as shown Table 3.

Table 3 — Instrument category and clause number

Clause number	Instrument category	Remark
6	Mechanical artefacts	Including length standard device
7	Length and displacement measuring instruments	From long range to short range measurement
8	Straightness measuring device	
9	Squareness measuring device	
10	Flatness measuring device	
11	Angle measurement instrument	
12	Special measuring device	

Each table indicates its name, size, measuring range, MPE, uncertainty of measurement, operating environment related standard, figure and remarks. An example of table is indicated in Table 4. The contents of tables are examples only, and are for machine tool measurements in the workshop. If there are some related standards for its specifications, contents are indicated as [recommended] or [typical].

Annex B indicates existing ISO and national standards for measuring equipment.

Table 4 — Example of the table format description

1	Name of artefact	Indication of instrument or measuring method name.
2	Description	Simple description of instrument or measuring method.
3	Size in mm	Example or recommended sizes are described.
4	Tolerance MPE	Example or recommended MPE is described.
5	Reduced (corrected) MPE at specific points in µm	If instrument or artefact is corrected by calibration, example or recommended improved MPE is described.
6	Surface finish	In case of artefacts, example or recommended surface quality at measuring point is indicated.
7	Surface hardness	In case of artefacts, example or recommended surface hardness at measuring point is indicated for each material used.
8	Operating environment	Remarks for operating environment such as temperature is described.
9	Long-term stability	—
10	Equivalent thermal expansion coefficient [µm/(m°C)]	Total thermal expansion coefficient is indicated.
11	Related standards	If there are standards for the instrument specification, it is described here.
12	Reference to the ISO 230 series	Application example in the ISO 230 series are indicated.
13	Uncertainty of measurement	Major clause numbers of uncertainty contributor name or descriptions are referred to in 4.2.
14	Remarks	Additional remarks are described.
15	Examples of figures	Appearance is indicated. Also refer to an example in ISO 230-1.

6 Mechanical artefacts for general use

6.1 General

A mechanical artefact is a reference material intended to define, realize, conserve or reproduce a unit or values of a quantity to serve as a reference in the machine workshop. Therefore, the artefact should be stable against any changes in conditions, and easy to mount on the machine tool side. An artefact is influenced by the gravity, therefore its supporting method influences the accuracy. Also, it is influenced by temperature change due to its thermal expansion. Therefore, the characteristics of thermal behaviour should be clearly stated. Internal thermal gradients of artefacts result in shape distortions and dimensional changes. The self-calibration method can be applied to most of mechanical artefacts (see ISO 230-1:2012, 8.2.2.1.1). For uncertainty contributors, see Table D.1.

Table 5 indicates quick references for mechanical artefacts.

Table 5 — Quick references for mechanical artefacts

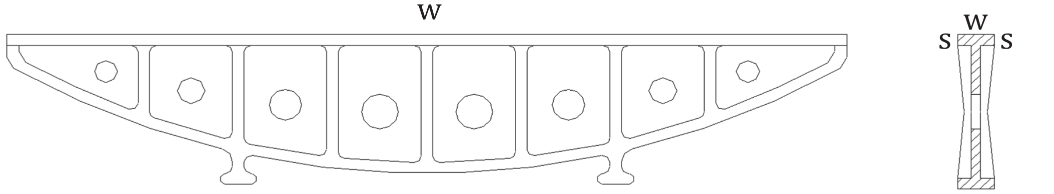
Name of artefacts		Property of measurement								
		Straightness	Parallelism	Squareness	Roundness	Radial offset	Flatness	Profile	Position	Positioning
Reference straightedge		+	+				+			
Test mandrels	with taper shanks	+	+			+				
	7/24 taper shanks	+	+			+				
	between centres	+	+			+				
Reference square	plane and edge	+		+						
	cylindrical square	+	+	+						
	block-type square	+	+	+						
Reference cube		+	+	+			+			
Reference surface plate		+	+				+			
Reference sphere			+		+	+		+	+	
Reference 1D ball array		+								+
Reference 2D ball array		+	+	+						+
Reference step gauge										+
Reference gauge block									+	

NOTE “+” indicates applicable property of motion.

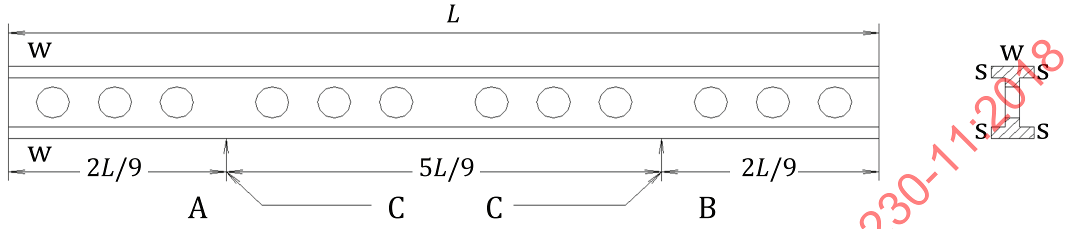
6.2 Reference straightedge

1	Name of artefact	Reference straightedge					
2	Description	A straightedge is a material representation of a straight reference line, with a particular MPE, by reference to which deviations from straightness or flatness can be determined. There are two principal types of straightedge: — the bow-shaped straightedge with a single working surface [see Figure 6 a)]; — the straightedge with two parallel working surfaces [see Figure 6 b)]. The latter type can be: — uniform-section with a solid or lightened web [see Figure 6 c)]. — of plain rectangular cross-section.					
3	Recommended size	Measuring length + 40 mm					
4	Recommended measuring length, *L*, in mm	300	500	1 000	1 500	2 000	3 000
5	Recommended straightness MPE and flatness MPE of working surfaces in µm: less than (2 + *L*/250) µm local tolerance, 5 µm for >300 mm	3	4	6	8	10	14
6	Recommended parallelism MPE of working surfaces in µm less than 1,5(2 + 0,01 *L*) µm	5	10	15	25	30	45
7	Recommended straightness of side surfaces in µm less than 10(2 + 0,01 *L*) µm	30	50	100	150	200	300
8	Recommended parallelism of side surfaces in µm less than 15(2 + 0,01 *L*) µm	45	70	150	220	300	450
9	Example of reduced (corrected) straightness MPE at specific points in µm	0,1 to 1	0,5 to 2	1 to 2	2 to 4	2 to 5	3 to 5
10	Permissible natural deflection	0,01 mm per 1 000 mm, when resting on two supports situated at the extreme ends. Exact maximum value should be marked on one of the faces.					
11	Recommended squareness MPE of side faces to working surfaces	5 µm for a measuring length of 10 mm					
12.1	Recommended surface finish	Less than 0,8 µm roughness, R_t. Finely ground, lapped or scraped.					
12.2	Recommended surface hardness	Hv490 to Hv620					
13	Operating environment	Workshop conditions (see ISO 230-3:2007, Table C.1)					
14	Long-term stability	—					

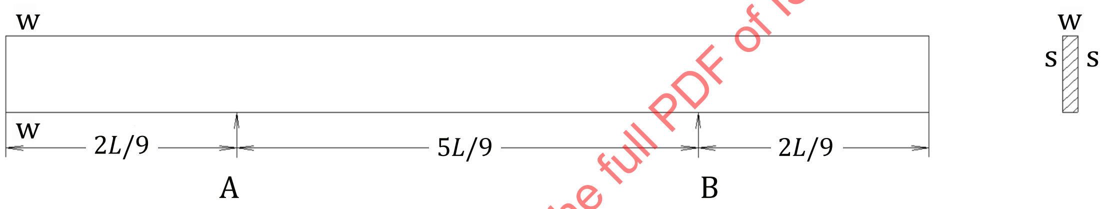
15	Equivalent thermal expansion coefficient [µm/(m°C)[(influences the bending in case of thermal gradients)	Depends on material used: steel: 11; ceramics: 8; ultra-low expansion (ULE) glass: 0,1.
16	Related standards	BS 5204, DIN 874, JIS B7514
17	Reference to ISO 230 series	ISO 230-1:2012, 8.2.2.1, 10.3.2.3, 12.2.3.1 and 12.2.3.2
18	Measurement uncertainty	Major contributors: See Table D.1
		EXAMPLE: —
19	Remarks	When the straightedge is used with a level, the width of the working faces should not be less than 35 mm. In case of vertical direction measurement, support distance should be 5 *L*/9. Table 6 indicates recommended supporting condition of straightedge.
20	Example of figures	See Figure 6



a) Bow-shaped



b) With two parallel surfaces with lightened web



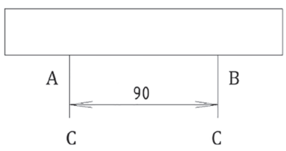
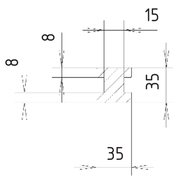
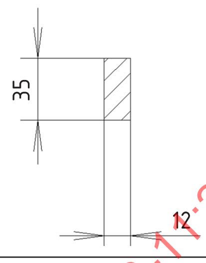
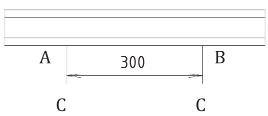
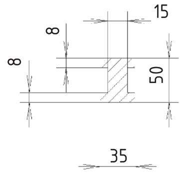
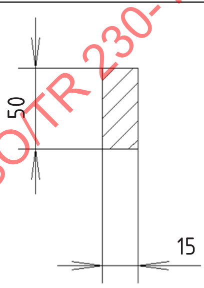
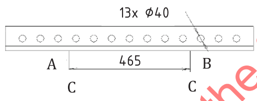
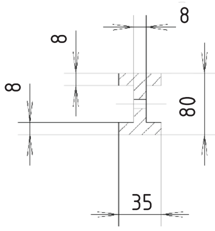
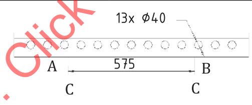
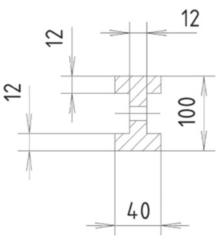
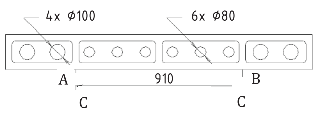
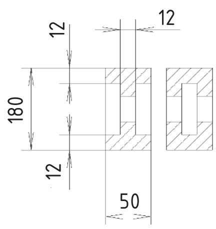
c) Plain rectangular section

Key

A, B support points
C best supports
L working length
W working surface
S side surface

Figure 6 — Examples of straightedge

Table 6 — Supporting condition of straightedge

No.	Length in mm		Diagram	Broad type		Normal type	
	Working	Total[a]		Section	Mass[b] kg	Section	Mass[b] kg
1	300	340			2		1
2	500	540			4		3
3	800	840					5
4	1 000	1 040					12
5	1 600	1 640					33

[a] The total length is a little greater than the working length, so that inspection can be made without having to use the ends of the straightedge, which are more difficult to machine accurately.

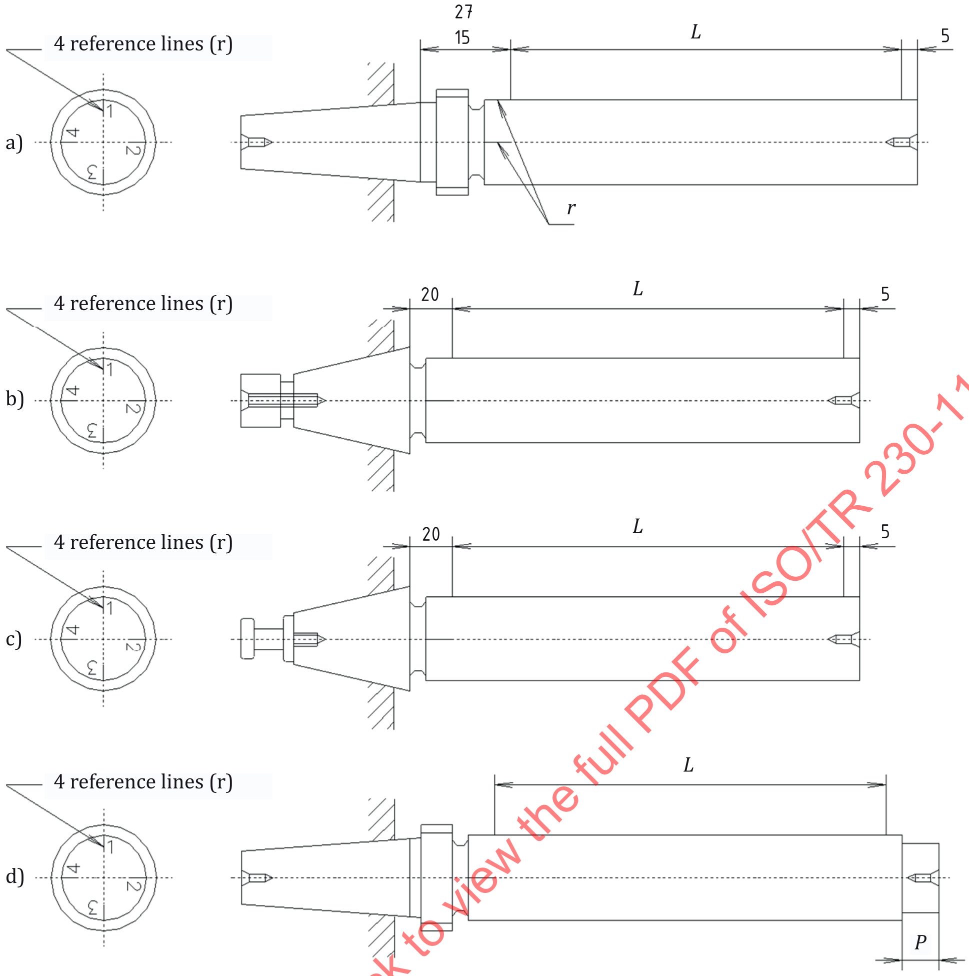
[b] Masses are relative to plain cast iron; they are slightly greater than steel.

6.3 Test mandrels with taper shanks

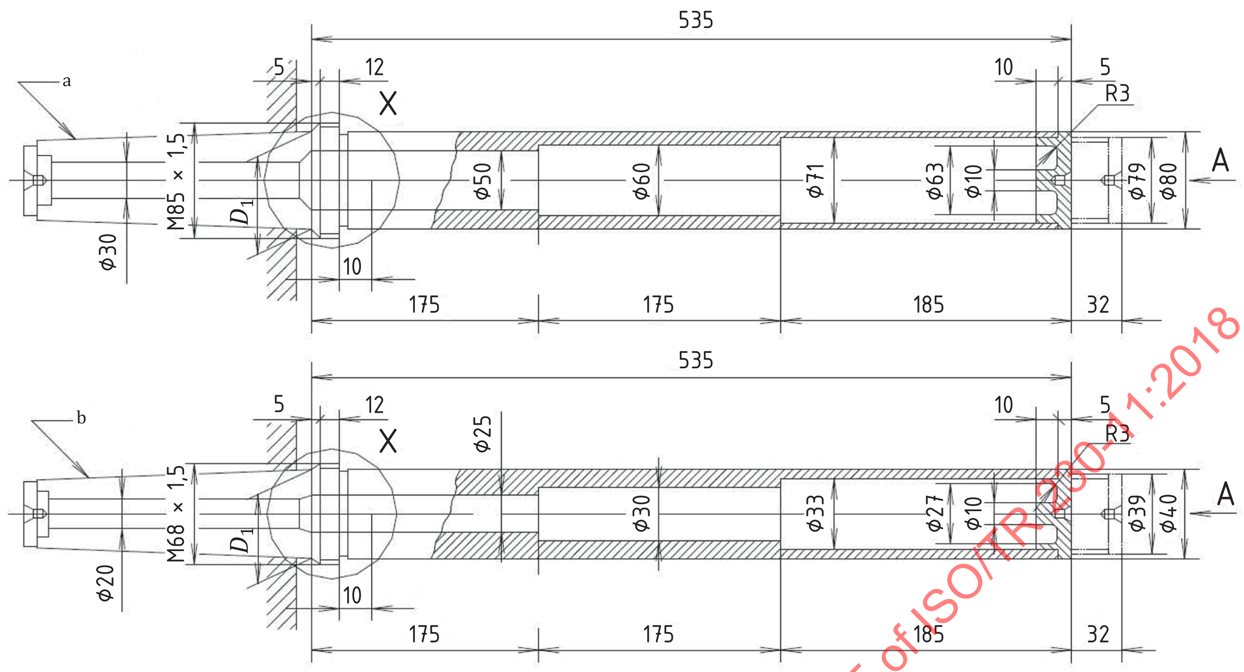
1	Name of artefact	Test mandrel with taper shank				
2	Description	A test mandrel represents, within given limits, the axis which is to be checked, either for run-out or for location (position and orientation) in relation to other components of the machine. Test mandrels have a tapered shank for inserting in the socket of the machine to be tested, and a cylindrical body which is used as a reference for the measurements.				
3	Recommended size in mm	Measuring length + 40 mm + taper shank length				
4	Recommended measuring range (length of straight part) in mm	75	150	200	300	500
5	Recommended natural deflection (Morse taper) in µm	0,65	1,5	1,8	3,3	5,8
6	Recommended straightness MPE (Morse taper) in µm	1,6	2,1	2,5	4	6,2
7	Recommended total run-out along entire length in µm	2	2	3	3	3
8	Recommended maximum variation in diameter of cylindrical part in µm	2	2	3	3	3
9	Example of reduced (corrected) straightness MPE at specific points in µm	0,8	0,8	1,0	1,0	1,5
10.1	Recommended surface finish	less than 0,8 µm roughness, R_t				
10.2	Recommended surface hardness	Hv490 to Hv620 plated or un-plated				
11	Recommended materials	Hardened and stabilized steel				
12	Operating environment	Workshop conditions				
13	Long-term stability	Stress free heat treatment required				
14	Equivalent thermal expansion coefficient in µm/(m °C)	Depends on material used: steel: 11; ceramics: 8.				
15	Related standards	JIS B7545				
16	Reference to ISO 230 series	ISO 230-1:2012, 10.1.2 to 10.1.5, 10.2, 10.4.4, 12.3.2.4, 12.3.2.6, 12.3.3, 12.3.4, 12.4.6 and 12.5				

17	Uncertainty of measurement	Major contributors: see Table D.1 EXAMPLE: –
18	They are made of hardened and stabilized steel, either un-plated or plated with hard chromium. They also have the following characteristics: a) ground and lapped centres, recessed for protection at the ends, for purposes of manufacture and inspection; b) four reference lines are spaced at 90° (1, 2, 3 and 4); c) in the case of relatively slow Morse and metric tapers, the mandrels are self-holding in the socket, see Figure 7 a) a. A threaded portion is provided to receive a nut for extracting the mandrel from the socket; d) in the case of relatively steep tapers [see Figure 7 a) b], a tapped hole is provided for fixing the mandrel by means of a threaded retaining bar, or a retention knob as used with an automatic tool-changing device [see Figure 7 a) c]. Finally, in order to avoid the mandrel being reversed end for end when grinding, the instrument can also be fitted with an extension P of a length from 14 mm to 32 mm and a diameter slightly smaller than that of the cylindrical part [see Figure 7 a) d]. Figure 7 b) to Figure 7 e) shows, as examples, a series of suitable mandrels. The external dimensions (diameter and length) and the profile of the bore of these mandrels have been determined such that (with the exception of those with Morse tapers No. 0 and No. 1) the deflection at the free end, due to the overhanging weight of the mandrel and the deflection caused by the pressure of a dial gauge on it, is minimized when testing with these instruments. The deflections have been calculated for E = 206 kN/mm^2; even for somewhat smaller values (E = 176 kN/mm^2 to 186 kN/mm^2) the deflections are still negligible. In the case of the 7/24 taper, table indicates the correspondence between the cylindrical portions and the dimensions of the cone. If the mandrels with dimensions differing from those in Figure 7 are used for checking alignment, their deflection should be distinctly marked on them and taken into account when testing machines. Finally, attention is drawn to the fact that mandrels above 5 kg in mass tend to cause deflection of a horizontal spindle into which they are inserted. NOTE The cone is perfectly fit within the socket. This is checked carefully, for example with Prussian blue. To measure the run-out, the mandrel should be successively inserted in the spindle in four positions, each at 90° to the previous, and the mean of the four results taken. To check the accuracy of the lateral position of a component or of parallelism, the test should be made successively on two opposite reference lines on the cylindrical surface of the mandrel, turning the mandrel and the spindle through 180° (see ISO 230-1:2012, 8.2.2.1.1). After inserting a mandrel in a spindle, time should be allowed to elapse for dissipating the heat of the hand of the operator and to allow the temperature to stabilize. In the case of mandrels with Morse tapers No. 0 and No. 1, it is necessary to take into account their natural deflection. They should only be used with a dial gauge reading to 0,001 mm and having a force not exceeding 0,5 N. The dial gauge should preferably be applied to the underside of the mandrel so as to oppose its natural sag Table 7 indicates test mandrel cylindrical parts of 7/24 taper shanks. Figure 7 e) indicates HSK type shank. For details on dimensions, see ISO 12164-1.	
19	Example of figures	see Figure 7 a), b), c), d) and e)

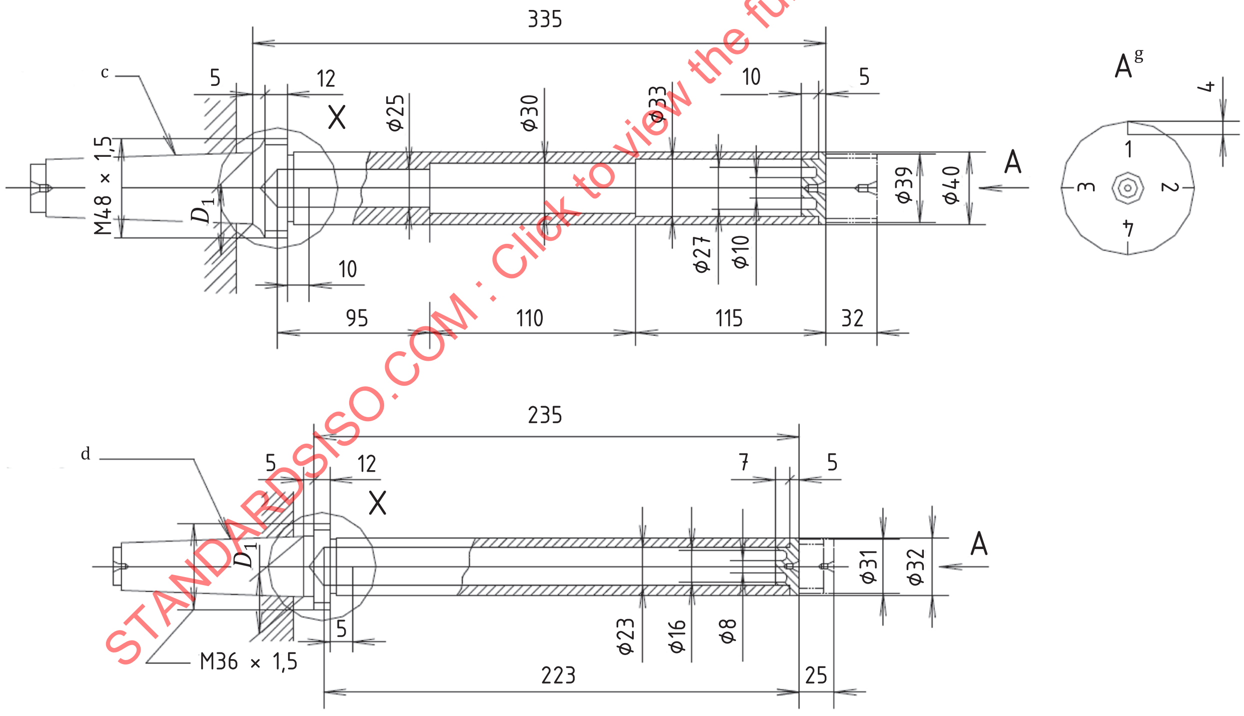
Dimensions in millimetres (mm)



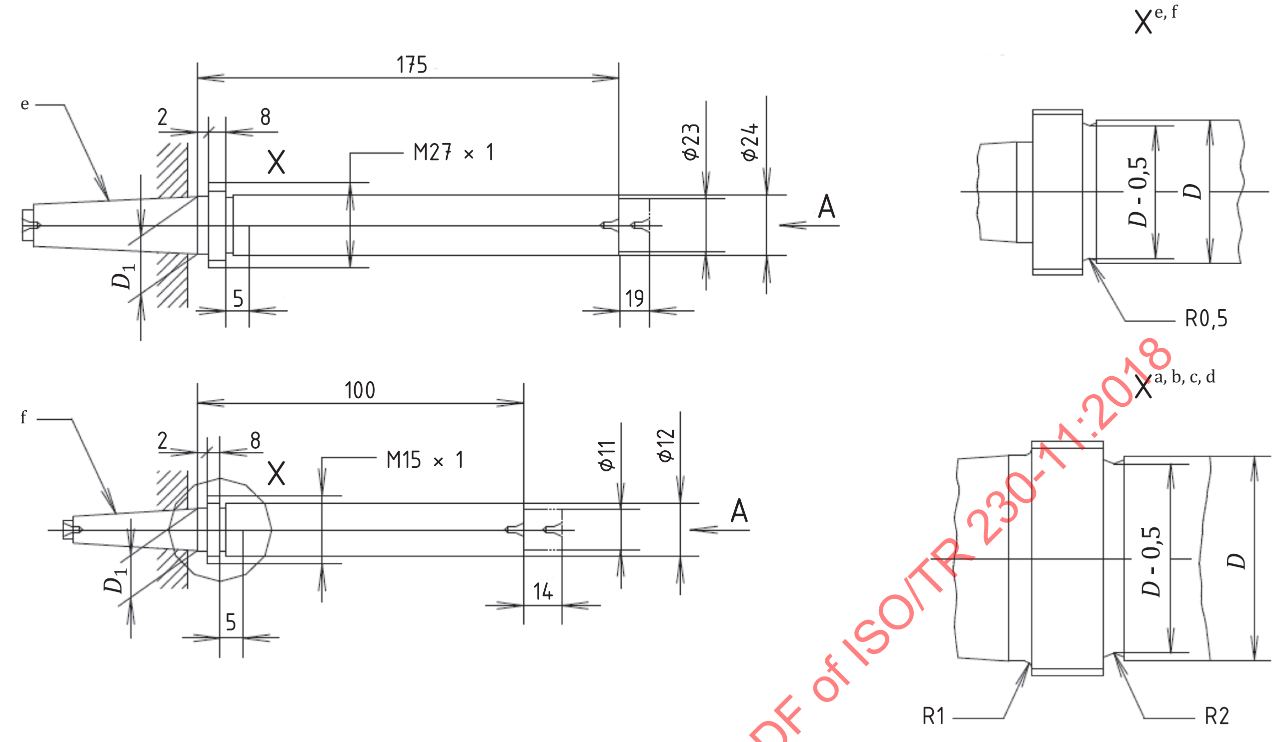
a) Small size taper shank mandrels [a) to d)]



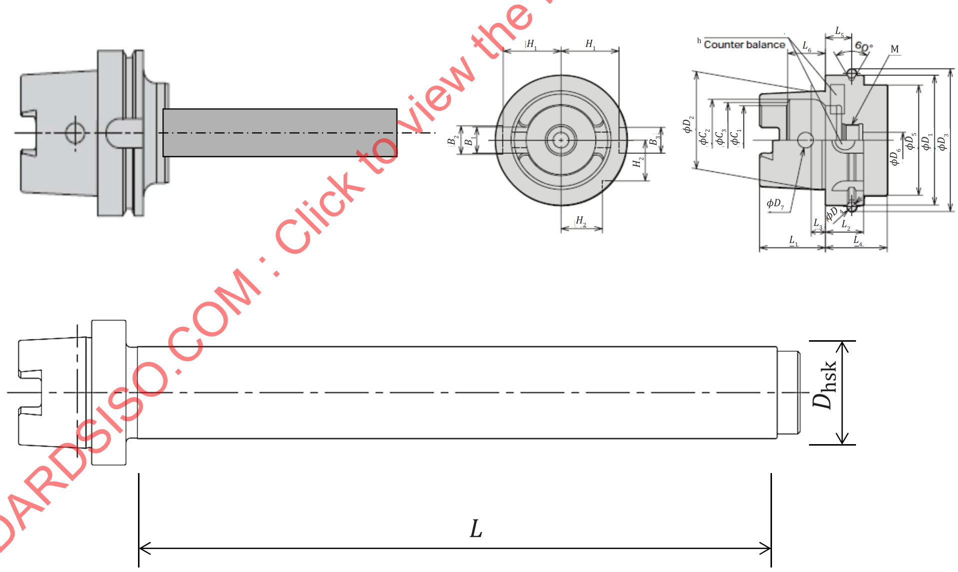
b) Larger metric and Morse taper shank mandrels



c) Morse 3, 4 and 5 taper shank mandrels



d) Morse 0 to 2 taper shank mandrels



e) HSK type mandrel

Key

L effective length

P cylindrical extension

r reference lines

a Metric 80 and larger.

b Morse 6.

c Morse 4 and 5.

d Morse 3.

e Morse 2.

f Morse 0 and 1.

g Partial.

h Counter balance.

Example of size, L, and diameter, D_{hsk}

D_{hsk}	32	40	40	63
L	150	200	300	300

NOTE The four lines 0,1 mm wide, spaced at 90° marked on the cylindrical parts, are reproduced in alignment and numbered 1 to 4 on the mandrel end.

Figure 7 — Examples of test mandrel

An extracting nut should be supplied with each mandrel.

For particulars of the tapered shank, refer to the ISO specification, e.g. D1.

The mandrel should have a ground and lapped centre of the protected type at each end.

The part indicated in dashed line is that of the mandrel shown in Figure 7 a): this extension, P, has been added to assist manufacture. The total length will be increased by this amount, as also that of the first bore, the end plug being unchanged.

Special shape such as cone and taper can be applicable for reference plane.

Table 7 — Test mandrel Cylindrical parts of 7/24 taper shanks

Taper 7/24 No.	30	40	45	50	
				Short mandrel	Long mandrel
Measuring length in mm	200	300	300	300	500
Mandrel Morse No. to which cylindrical part is adapted	3	4 and 5	4 and 5	4 and 5	6

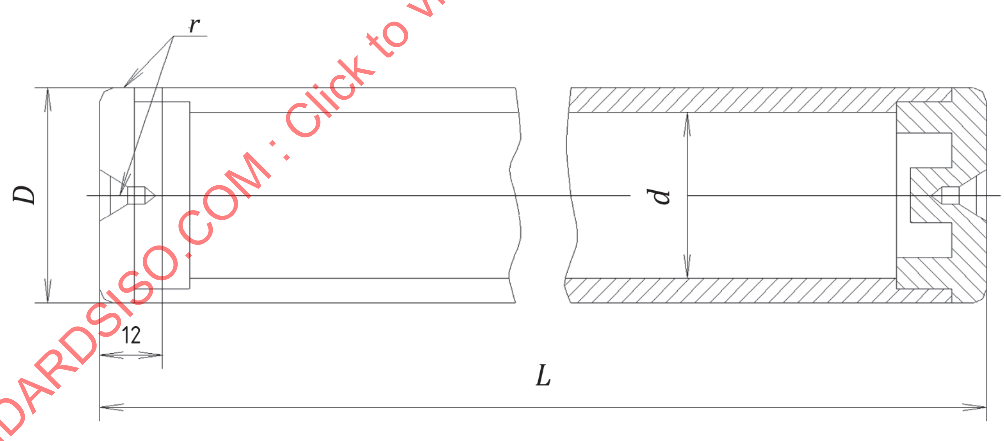
6.4 Mandrels between centres

1	Name of artefact	Mandrel between centres			
2	Description	While a test mandrel with a taper shank serves as a material representation of an axis of rotation, a mandrel mounted between centres represents simply a straight line passing between two points. The axis of such a mandrel should be straight and its exterior surface truly cylindrical. It has, at each end, four reference marks located in two perpendicular axial planes, and centres recessed for protection.			
3	Recommended size in mm	300	500	1 000	1 600
4	Recommended outside diameter in mm	40	63	80	125
5	Recommended inside diameter in mm	0	50	61	105
6	Recommended mass without end plugs in kg	1,5 to 3	2,7 to 4,5	8,3 to 16,5	28,2 to 45
7	Recommended maximum diameter variation in µm	3	3	4	5
8	Recommended straightness MPE in µm	1	2	2	2
9	Recommended cylindricity MPE in µm	4	4	5	6
10	Recommended maximum run out in µm	3	3	7	10

Table 7 *(continued)*

11	Example of reduced (corrected) straightness MPE at specific points in µm	2	2	3	3
12	Recommended maximum natural deflection in µm E = 206 kN/mm^2	0,02 to 0,04	0,1 to 0,7	0,5 to 8	3 to 19
13.1	Recommended surface finish	Less than 0,8 µm roughness, R_t			
13.2	Recommended surface hardness	The cylinder should be hardened and can be hard chrome-plated to increase its resistance to wear. HV490 for steel, Hv600 for ceramics.			
14	Recommended materials	Steel or Al_2O_3.			
15	Operating environment	Workshop conditions.			
16	Long-term stability	Weld-free hot-drawn tubes are used for the material, therefore, it is stabilized before final grinding.			
17	Equivalent thermal expansion coefficient in µm/(m°C)	Depends on material used: steel: 11; ceramics: 8.			
18	Related standards	JIS B7545			
19	Reference to ISO 230 series	ISO 230-1:2012, 10.2.1			
20	Uncertainty of measurement	Major contributors: see Table D.1.			
		EXAMPLE: —			
21	Example of figures	see Figure 8			

Dimensions in millimetres



Key

D external diameter

d internal diameter

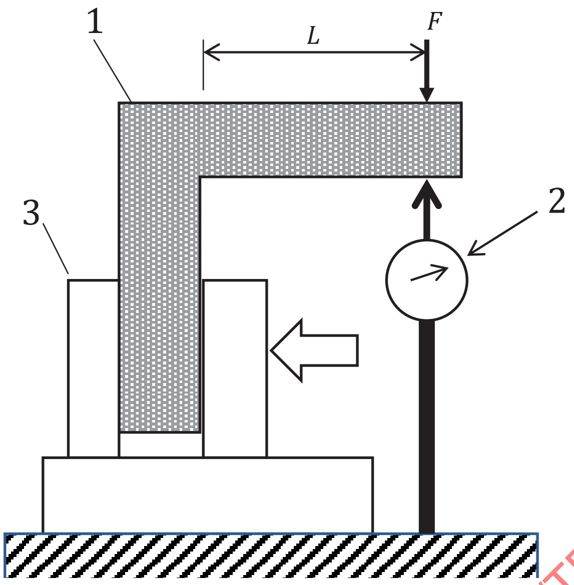
L total length

r reference marks

Figure 8 — An example of mandrel between centres

6.5 Reference squares

1	Name of artefact	Squares
2	Description	The principal types of squares are: 1) the square represented by a plane and an edge at right angles, with or without a reinforcing rib [Figure 10 a)], 2) the cylindrical square, represented by an axis perpendicular to a plane [Figure 10 b)], 3) the block-type square with or without reinforcing ribs [Figures 10 c) and d)].
3	Recommended size in mm	Generally not to exceed 500 mm. For cylindrical squares, not to exceed 1 200 mm.
4	Recommended flatness MPE (of arms) and straightness MPE in µm	(2 + 0,01 L), where L is working length in millimetres
5	Recommended MPE of squareness in µm	— (2 + L/200) µm for cylindrical squares; — (1 + L/200) µm for two arms type; or — 5 µm for any measuring length of 300 mm. where L is the working length in millimetres. The angle can be either smaller or larger than 90°.
6	Example of reduced (corrected) squareness MPE at specific points in µm	0,5
7	Recommended surface finish	Less than 0,8 µm roughness, R_t Finely ground, lapped or scraped.
8	Recommended surface hardness	More than Hv360 for hardened steel For un-hardened steel, more than HV170
9	Operating environment	Workshop conditions
10	Long-term stability	Stress free heat treatment required
11	Equivalent thermal expansion coefficient in µm/(m°C)	Depends on material used: Steel: 11; cast iron: 10; ceramics: 8; granite: 10
12	Tolerance on deflection of squares with two arms	Deflection d = 0,7 L(1/2)/1 000 mm Test method, see Figure 9.
13	Related standards	JISB 7526, B 7539, BS 939
14	Reference to ISO 230 series	ISO 230-1:2012, 10.3.2.2 and 12.4
15	Uncertainty of measurement	Major contributors: see Table D.1 EXAMPLE: —
16	Remarks	Reversal measuring method should be applied for improved measuring accuracy (see ISO 230-1) – measure at the centre
17	Examples of figures	see Figures 10 a), b), c)



Key

F apply force: 2,5 N

L working length in millimetres

1 target square

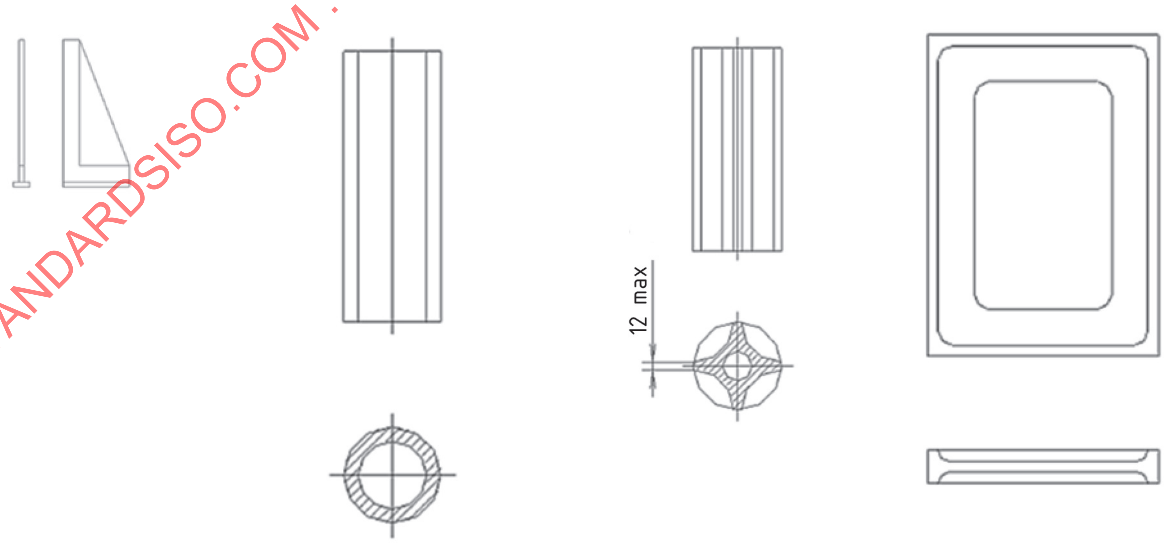
2 dial gauge

3 clamping device

Deflection: $d = 0{,}7\ L(1/2)/1\ 000$ mm

Figure 9 — Deflection test method of two arms square

Dimensions in millimetres

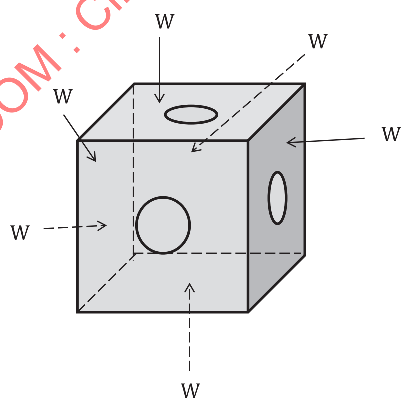


a) Plane **b) Cylindrical** **c) Block type** **d) Block square**

Figure 10 — Examples of squares

6.6 Reference cube

1	Name of artefact	Precision cube, reference cube
2	Description	Precisely manufactured cube that is used for the reference of square, straightness and position. Commercially available cubes are also applicable to use.
3	Recommended size in mm	Generally 100 mm to 500 mm square
4	Recommended squareness MPE	2 µm for any measuring length of 300 mm
5	Recommended flatness/parallelism MPE	2 µm in flatness/parallelism
6	Example of reduced (corrected) MPEs at specific points (µm)	Squareness: 1 µm; Straightness: 1 µm; Flatness: 2 µm
7	Recommended surface finish	Less than 1 µm roughness, It.
8	Recommended surface hardness	HB200 < Cast iron: HB200; Stone: Hs70; Ceramics: Hv1600
9	Operating environment	Workshop conditions
10	Long-term stability	Stress free heat treatment required for steel.
11	Equivalent thermal expansion coefficient in µm/(m °C)	Depends on material used; Steel: 11; ceramics: 8; stone: 10
12	Related standards	None
13	Reference to ISO 230 series	None
14	Uncertainty of measurement	Major contributors: see Table D.1 EXAMPLE: —
15	Remarks	Calibrated dimension, flatness, straightness and squareness artefact can be obtained.
16	Examples of figures	See Figure 11



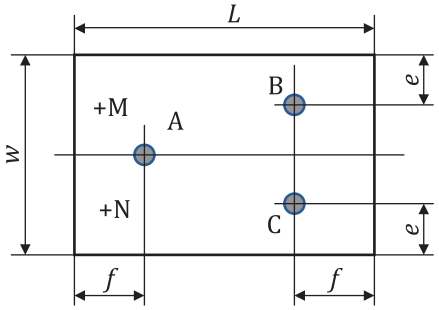
Key

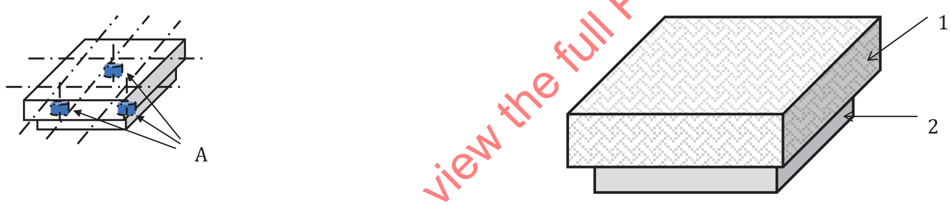
W working surface

Figure 11 — Reference cube

6.7 Surface plates

1	Name of artefact	Surface plate											
2	Description	Surface plate is a reference flat plane in workshop. It is applied to centring, assemble and measurement of work. Its top surface is finished by scraping or lapping to achieve good surface accuracy.											
3	Recommended size in mm	160 mm × 100 mm to 2 500 mm × 1 600 mm											
4	Recommended size, X,Y in mm	160 × 100	250 × 160	400 × 250	630 × 400	1 000 × 630	1 600 × 1 000	2 000 × 1 000	2 500 × 1 600	250 × 250	400 × 400	630 × 630	1 000 × 1 000
5	Recommended flatness MPE for ISO grade 0 (ISO 8512) in µm	3	3,5	4	5	6	8	9,5	11,5	3,5	4,5	5	7
6	Example of reduced (corrected) MPE at specific points in µm	0,5	0,5	0,5	0,5	1,0	1,0	1,0	1,5	0,5	0,5	0,5	1,0
7.1	Recommended surface finish	Finely scraped, ground or lapped											
7.2	Recommended surface hardness	Cast iron: HB200; stone: Hs70; ceramics: Hv1600											
8	Operating environment	Workshop conditions											
9	Long-term stability	Stress free heat treatment required for cast iron											
10	Equivalent thermal expansion coefficient in µm/(m°C)	Cast iron: 11; stone: 10; ceramics: 8											
11	Related standards	ISO 8512, DIN 876, JIS B7513, ISIRI 10137.1/2											
12	Reference to ISO 230 series	ISO 230-1:2012, 10.5.1, and 12.2.2											
13	Uncertainty of measurement	Major contributors: See Table D.1											
		EXAMPLE: —											

14	Remarks	For large size surface plate:  Distribution rule for support points	**Key** *L* length *w* width A,B,C supporting points M,N safety support points $e = 2\ w/9$ $f = 2\ L/9$ If the operating area exceed 400 mm × 250 mm, compliance should be smaller than 1 µm/200 N at the centre position.
15	Example of figures	See Figure 12	



a) Cast iron surface plate **b) Granite surface plate**

Key

A three support points

1 granite surface plate

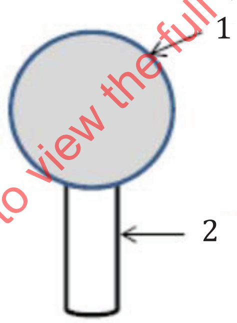
2 supporting unit

Figure 12 — Surface plate

6.8 Reference sphere

1	Name of artefact	Precision ball (sphere), reference sphere
2	Description	Precisely manufactured ball that is used for the reference of position and rotation. Commercially available balls are also applicable to use.
3	Recommended size in mm	Generally 16 mm to 30 mm diameter.
4	Recommended form tolerance (sphericity)	0,2 µm or less
5	Recommended size tolerance	0,3 µm in diameter if the diameter is referenced.
6	Example of reduced (corrected) MPE at specific points in µm	—

7.1	Recommended surface finish	Less than 0,1 µm roughness, R_t
7.2	Recommended surface hardness	HV1600 (Ceramics), HV800 (Steel)
8	Operating environment	Workshop conditions
9	Long-term stability	Stress free heat treatment required for steel.
10	Equivalent thermal expansion coefficient in µm/(m °C)	Depends on material used: Steel: 11; ceramics: 8; granite: 10; quartz: 1
11	Related standards	None
12	Reference to ISO 230 series	ISO 230-1:2012, 10.1.4.4, 10.4.4, 11.2.5.1 and 11.4 ISO 230-10
13	Uncertainty of measurement	Major contributors: See Table D.1
		EXAMPLE: —
14	Remarks	If ball is used to check spindle rotation accuracy, concentricity between ball centre and shank can be required
15	Example of figures	See Figure 13



Key

1 ball

2 support bar

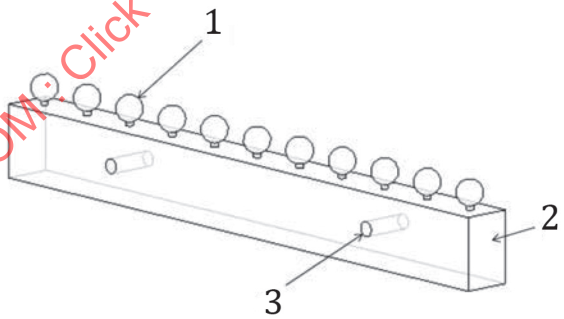
Figure 13 — Reference sphere

6.9 1D ball array

1	Name of instrument	1-D ball array or ball beam
2	Description	A series of precision balls are fixed to a beam structure and calibrated on a CMM, used for determining the relative positions of the centre points of the precision balls. Such artefact is stable and is mounted on a machines workpiece table stress-free in order to avoid stresses and strains (deteriorating the validity of its calibration).
3	Typical length	250 mm to 2 000 mm
4	Typical beam material	Carbon Fibre (CF), Silicon Carbide (SiC), Steel

5	Typical beam size ($L \times w \times H$)	500 × 50 × 70 mm (CF) 500 mm × 40 mm × 40 mm (SiC)
6	Typical beam shape	rectangular, square, triangular or cylindrical
7	Typical ball diameter	16 mm to 30 mm
8	Typical ball material	Ceramic (Al_2O_3, Si_3N_4) or steel
9	Typical ball hardness	>HV1650 (Al_2O_3)
10	Typical Form tolerance (spherity) MPE	<0,3 µm
11	Typical surface roughness	<0,1 µm roughness, R_t
12	Thermal expansion coefficients in µm/(m °C)	CF = −0,8; SiC = 4,5; Steel = 11; Al_2O_3 = 8,5
13	Typical weight	2,5 kg (CF ball array, 500 mm length) 1,6 kg (SiC ball array, 500 mm length)
14	Typical calibration uncertainty	U (k = 2) = (0,14 + 0,6·L) µm with L in m
15	Re-calibration interval	Once a year
16	Related standards	None
17	Reference to ISO 230 series	ISO 230-1, 11.6.2 (1-D ball array), ISO 230-2, ISO 230-6 (diagonal tests)
18	Uncertainty of measurement	Major contributors: See Table D.1 EXAMPLE: —
19	Example of figures	See Figure 14
20	Applications	a) Axis parallel 1-D ball array is used in combination with a probing system to sense the ball's positions (i.e. linear displacement sensors, 3D sensor nest, touch-trigger probe, 3D probe head, etc.). The 1-D ball array is mounted nominally axis parallel enabling the determination of: Positioning errors (i.e. E_{XX}) Straightness deviations (i.e. E_{YX} and E_{ZX}) b) Diagonal tests 1-D ball array can also be measured in a face and/or body diagonal of the machine's working volume for inspecting the volumetric accuracy.

21	Remarks	a) To maintain its stability the 1-D ball array should be handled with care and shocks should be avoided. b) When applied the 1-D ball array is preferably mounted on a machine tool in the same way as during its calibration to cancel sag effects. Sag effects are also minimised by supporting the 1-D ball array on its Bessel points (which equals 2L/9 from the beams ends, 5L/9 separated) which is recommended. c) Due to manufacturing tolerances, the balls are not exactly positioned in a straight line but typically vary ±0,1 mm in 3D space. Therefore, the balls are not exactly separated equidistantly. Three linear machine axes are usually required to measure such 1-D ball array even when it is mounted axis parallel. Sometimes, offset balls are applied to facilitate the determination of the roll orientation of the 1-D ball array better, necessary when both straightness errors are determined simultaneously. d) The size of the 1-D ball array should match with the machine's working volume. For very large machines, the 1-D ball array can be moved stepwise along a machine's axis and measurements can be combined/stitched provided there is sufficient overlap.



Key

1 reference balls

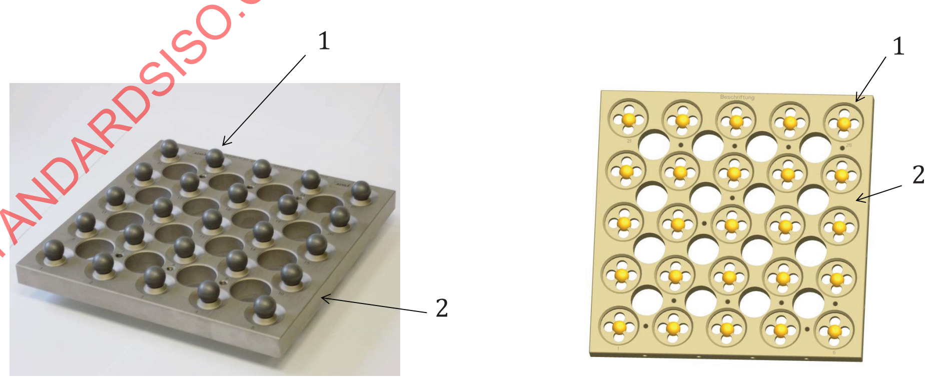
2 support unit (base)

3 support points (holes)

Figure 14 — 1-D ball array

6.10 2D ball array

1	Name of instrument	2-D ball array, Ball plate
2	Description	Series of precision balls are fixed on the plate. Their positions are precisely calibrated. This is used for the calibration of two dimensional machine positioning accuracy. This is also applicable to measure the straightness and squareness error of motion.
3	Example size	500 mm × 500 mm × 100 mm
4	Example measuring range	400 mm × 400 mm
5	Example MPE or linearity	2 µm
6	Example of reduced (corrected) MPE at specific points in µm	0,6 µm
7	Resolution	—
8	Repeatability	Depends on position sensor
9	Frequency response	—
10	Measuring force or load	Depends on position sensor
11	Operating environment	Workshop conditions
12	Long-term stability of reading	—
13	Equivalent thermal expansion coefficient	Based on frame material Steel: 11
14	Related standards	None
15	Reference to ISO 230 series	ISO 230-1:2012, 11.5.2 ISO 230-2
16	Uncertainty of measurement	Major contributors: see Table D.1
		EXAMPLE: —
17	Remarks	Application of reversal methods
18	Example of figures	See Figure 15



a) Type A(balls on stem)

b) Type B (balls in natural plane)

Key

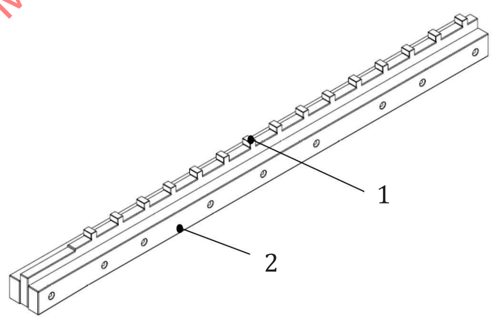
1 reference balls

2 base plate

Figure 15 — 2-D ball array

6.11 Step gauge

<table>
<tr><td>1</td><td>Name of gauge</td><td colspan="4">Step gauge</td></tr>
<tr><td>2</td><td>Description</td><td colspan="4">The step gauge is one of end standard gauge. It consists of a lot of short gauge blocks and a base steel bar. Solid type (manufactured from single material block e.g. ceramics, steel and glass) are also possible.</td></tr>
<tr><td>3</td><td>Example size</td><td colspan="4">From 300 mm to 1 500 mm</td></tr>
<tr><td>4</td><td>Example measuring range</td><td colspan="4">According to size, 0 mm to 1 000 mm</td></tr>
<tr><td rowspan="2">5</td><td rowspan="2">Example pitch MPE in µm</td><td>0 to 310</td><td>310 to 610</td><td>610 to 1 000</td><td>1 010 to 1 050</td></tr>
<tr><td>5</td><td>7</td><td>10</td><td>16</td></tr>
<tr><td>6</td><td>Example block pitch</td><td colspan="4">20 mm (10 mm + 10 mm)</td></tr>
<tr><td>7</td><td>Material</td><td colspan="4">The material used are steel and zirconia ceramics.</td></tr>
<tr><td>8</td><td>Measuring force or load</td><td colspan="4">According to reading instrument.</td></tr>
<tr><td>9</td><td>Operating environment</td><td colspan="4">Workshop conditions</td></tr>
<tr><td>10</td><td>Long-term stability of reading</td><td colspan="4">—</td></tr>
<tr><td>11</td><td>Equipment thermal expansion coefficient in µm/(m°C)</td><td colspan="4">Steel: 11; ceramics: 8</td></tr>
<tr><td>12</td><td>Related standards</td><td colspan="4">None</td></tr>
<tr><td>13</td><td>Reference to ISO 230 series</td><td colspan="4">ISO 230-2</td></tr>
<tr><td rowspan="2">14</td><td rowspan="2">Uncertainty of measurement</td><td colspan="4">Major contributors: see Table D.1</td></tr>
<tr><td colspan="4">EXAMPLE: —</td></tr>
<tr><td>15</td><td>Example of figures</td><td colspan="4">See Figure 16</td></tr>
<tr><td>16</td><td>Remarks</td><td colspan="4">The step gauge is set up on the machine, and its position is read with lever type dial gauge or electric micrometer. In some cases, the gauge blocks are used instead of step gauge.</td></tr>
</table>



Key

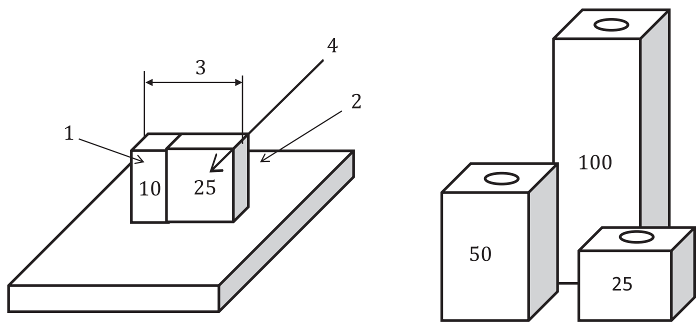
1 step gauge

2 base support

Figure 16 — Step gauge

6.12 Gauge block

1	Name of artefact	Gauge block, reference gauge block
2	Description	Precisely manufactured series of blocks that are used for the reference of length, distance and position. Desired length can be generated by wringing two or more different blocks. Rectangular type, square block with hole are applicable to use.
3	Example size in mm	0,5 mm to 1 000 mm
4	Example measuring range	Depends on the number of assembling.
5	Example MPE	0,24 µm (10 mm) to 4,00 µm (1 000 mm) depending on the class and size
6	Example of reduced (corrected) MPE at specific position in µm	0,05 µm (100 mm)
7	Recommended surface finish	Less than 20 nm roughness, R_t
8	Example of material	Gauge steel, WC, ceramics, glass ceramics
9	Recommended surface hardness	HV800
10	Operating environment	Workshop conditions
11	Long-term stability	Stress free heat treatment required for steel.
12	Equivalent thermal expansion coefficient in µm/(m°C)	Depends on material used Steel: 11,5; ceramics: 8; glass ceramics: 0
13	Related standards	ISO 3650, BS 4311, DIN 861, ISIRI 2606
14	Reference to ISO 230 series	ISO 230-1
15	Uncertainty of measurement	Major contributors: See Table D.1
		EXAMPLE: —
16	Remarks	Any size can be created by wringing procedures.
17	Example of figures	See Figure 17



a) Rectangular type

b) Square block type

Key

1 gauge block 1
2 gauge block 2
3 created size by wringing 1 and 2
4 indication of nominal size

Figure 17 — Gauge block

7 Length and displacement measuring instruments

7.1 General

Length and displacement measuring instruments are classified as follows:

a) for long range (laser);

b) for medium range (reference linear scale, standard scale, digital probe with scale);

c) for short range (contact sensor, non-contact sensor, touch probe).

Basic specification or characteristics requirements for the length and displacement measuring instruments are:

— size;

— measuring range;

— MPE or linearity;

— resolution;

— repeatability;

— frequency response;

— measuring force;

— operating environment;

— long-term stability of readings; and

— equivalent thermal expansion coefficient.

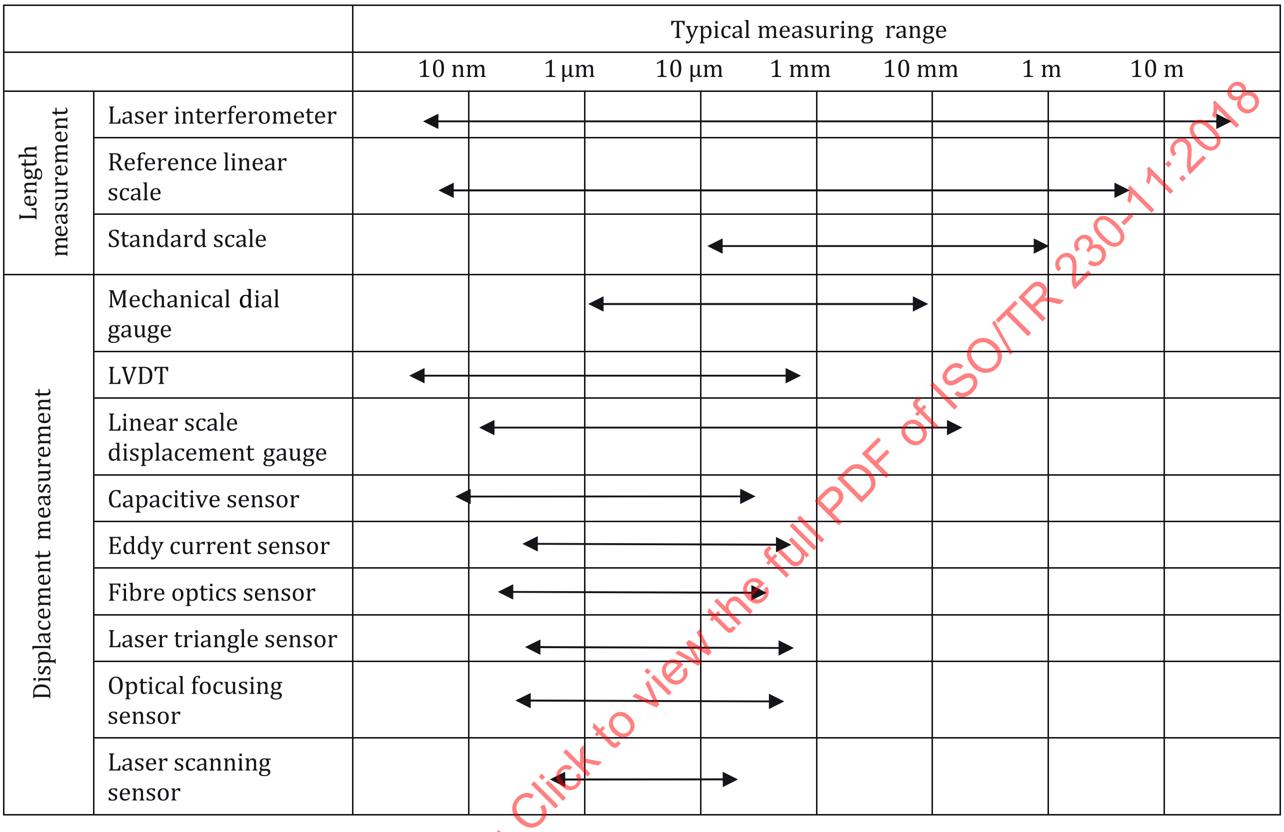
These requirements are included in the tables describing the instrument characteristics.

Table 8 indicates typical measuring range of length/displacement measuring instruments. For uncertainty contributors, see also Table D.2.

NOTE 1 Minimum measuring range is about 10 times greater than the resolution of the instrument.

NOTE 2 Indicated measuring ranges consider the conditions for machine tool testing in the workshop.

Table 8 — Typical measuring range of length/displacement measuring instruments



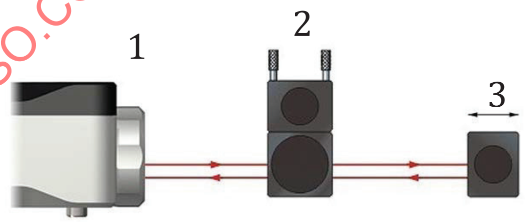
7.2 Instruments for large and medium range linear displacements

7.2.1 Laser interferometer

1	Name of instrument	Laser interferometer
2	Description	The development of the laser interferometer has provided the machine tool industry with a high-accuracy standard which can be used on machine tools of all types and sizes. The frequency stabilized helium-neon laser currently represents the state of the art in laser length standards, and in practical terms has become the accepted length standard for workshop measurement.
3	Example size	200 mm × 300 mm × 100 mm (Laser source)
4	Example measuring range	Up to 40 m
5	Example MPE or linearity	The MPE of the interferometer is determined by the laser wavelength, and is better than 0,5 parts per million, if air temperature, machine temperature, air humidity, and air pressure are constant.
6	Example resolution	1 nm to 10 nm
7	Example repeatability	Depends on circumstances (see remarks)

8	Example frequency response	100 kHz to 100 MHz at interface port signals	
9	Measuring force or load	None	
10	Operating environment	Workshop conditions	
11	Long-term stability of reading	8 × 10^{-9}/m (Laser beam only)	
12	Equivalent thermal expansion coefficient in µm/(m °C)	Laser wavelength is affected by not only air temperature, but also air pressure, humidity and composition. EXAMPLE: if air temperature changes 1 °C, it corresponds to 1 µm/m measuring length.	
13	Uncertainty of measurement	Major contributors: ISO 230-2:2014, Annex A and ISO/TR 230-9. See Table D.2 and also 17.	
		Even air condition can be measured and compensated, influence of uncertainty of sensors such as temperature, pressure remains. In case of precision application, refractometer should be applied to increase measurement accuracy. Check of total environment influence by environmental variation test, with description of test (see ISO 230-3).	
		a) Environmental error (4.2.3.9)	Moving pockets of warm and cold air cause air turbulence. As these pockets of warm and cold air move through the measurement laser beams, the laser wavelength within the pockets varies. If this pocket is 0,1 °C warmer than the surrounding air and 1 m across, then this would cause the linear reading to change by 0.1 µm. To minimize this effect, air surrounding the laser beam should be either very stable or mixed by fans. The actual influence of the environment should be checked by an EVE test. (see ISO 230-2:2014, Annex A)
		b) Machine surface temperature (4.2.3.15, 4.2.3.4,)	For machine tools that use a steel lead screw to determine carriage position, this effect represents an expansion of approximately 11 µm/m for a 1 °C rise in the lead screw temperature. If the total carriage travel is 1 000 mm, this effect represents a potential change in the considered length of lead screw of 0,011 mm per °C change in temperature. (see ISO 230-2) The material temperature sensors should be placed correctly to detect the table surface temperature. The obtained temperature values apply to compensate the thermal expansion of target part.
		c) Dead path error	See 4.2.4.23
		d) Cosine error	See 4.2.4.1
		e) Abbe offset error	See 4.2.4.2
14	Related standards	None	

15	Reference to ISO 230 series	ISO 230-1:2012, 8.3.2.1, ISO 230-2, ISO 230-3 and ISO/TR 230-9
16	Example of figures	See Figure 18
17	Remarks	The laser interferometer can be used for five of the six degrees of freedom: linear positioning, horizontal straightness, vertical straightness, pitch and yaw, as well as squareness between two axes. Other degrees of freedom are of equal importance since positioning errors, resulting from tilt error motion (pitch and yaw error motion) can be potentially larger than the errors of the linear positioning system of machine tool axes. Other sources of error to be considered before commencing measurements are indicated in application remarks In setting up a laser measurement system to evaluate a machine tool, three basic guidelines should be followed: a) choose the correct set-up to measure the desired parameters; b) minimize the potential error sources (alignment, compensation, deadpath, etc.); (see ISO 230-2:2014, Annex A. See also 13 a), b) ,c); c) simulate the working conditions of the machine tool as closely as possible. Each individual set-up should be carefully analysed to ensure that measurements of machine tool errors represent workpiece errors. Measurements should reflect the relative motions of the cutting tool and the workpiece. It should always be arranged to mount one optical component where the cutting tool would be situated and the other optical component at the workpiece position. The laser should be located to maximize the number of measurements that can be made without repositioning the laser head. Although laser system measurements are extremely accurate, bear in mind that their correctness depends on the initial set-up and elimination of potential errors. A kind of optical measuring instrument.



Key

1 laser head

2 interferometer

3 retro reflector

Figure 18 — Typical setup of laser interferometer for linear displacement

7.2.2 Reference linear scale

1	Name of instrument	Digital linear scale
2	Description	Digital scales use a sliding head to create position signals from stationary scale consisted of optically or magnetically produced digital markings with equal in-between spacing. These markings are manufactured precisely as length standards. The signals are interpolated to achieve finer resolution.
3	Typical size	From 50 mm to 3 000 mm (steel/ glass) More than 10 000 mm (tape scale)
4	Example measuring range	Depends on the size
5	Typical MPE or linearity	6 µm in full reading range (1 000 mm, JIS class 0) or (3 + 3 L/1 000) µm where L is the effective measuring length
6	Example of reduced (corrected) MPE at specific points	0,5 µm
7	Typical resolution	0,01 µm to 1 µm
8	Example repeatability	0,2 µm
9	Frequency response	Depends on interpolation system and electronics devices
10	Measuring force or load	—
11	Operating environment	Workshop conditions
12	Long-term stability of reading	Depends on circumstances
13	Equivalent thermal expansion coefficient in µm/(m °C)	11 for steel, 8 for glass material, 1 for Inver and 0 for Ultra-low expansion (ULE) glass scale
14	Related standards	JIS B7450, ZBJ 42036
15	Reference to ISO 230 series	ISO 230-1:2012, 8.3.2.2
16	Uncertainty of measurement	Major contributors: see Table D.2 EXAMPLE: —
17	Example of figures	See Figure 19
18	Remarks	Digital scales used for machine tool calibration are mounted on the special rig for easy handling and placing on the machine table. The reading head is placed with linear guiding system to keep constant gap between scale surface and reading head.

Key

1 digital linear scale

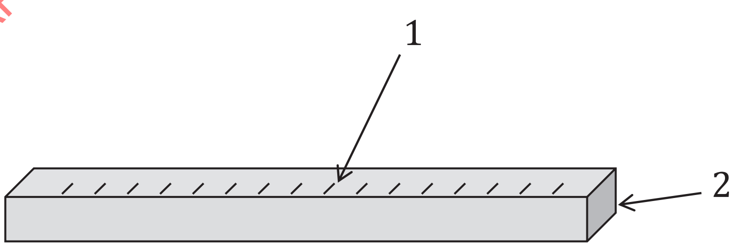
2 mounting base with guide

3 reading head

Figure 19 — Reference linear scale

7.2.3 Standard scale

<table>
<tr><td>1</td><td>Name of instrument</td><td colspan="7">Standard scale</td></tr>
<tr><td>2</td><td>Description</td><td colspan="7">Standard scale has ruled, engraved or etched markings with equal in-between spacing. The line pitch and total distance are calibrated.</td></tr>
<tr><td>3</td><td>Typical size</td><td colspan="7">From 100 mm to 1 500 mm (steel/glass)</td></tr>
<tr><td>4</td><td>Typical measuring range</td><td colspan="7">Depends on the size</td></tr>
<tr><td rowspan="2">5</td><td>Size in mm</td><td>100 to 200</td><td>200 to 300</td><td>300 to 400</td><td>400 to 500</td><td>500 to 600</td><td>600 to 800</td><td>800 to 1 000</td></tr>
<tr><td>Typical MPE or linearity in µm</td><td>1,2</td><td>1,3</td><td>1,4</td><td>1,5</td><td>1,6</td><td>1,8</td><td>2,0</td></tr>
<tr><td>6</td><td>Example of reduced (corrected) MPE at specific points in µm</td><td colspan="7">0,5</td></tr>
<tr><td>7</td><td>Example scale line pitch</td><td colspan="7">1 mm</td></tr>
<tr><td>8</td><td>Example repeatability</td><td colspan="7">0,2 µm (according to reading device)</td></tr>
<tr><td>9</td><td>Materials</td><td colspan="7">The material used are nickel, stainless steel, steel, normal glass and low expansion glass</td></tr>
<tr><td>10</td><td>Measuring force or load</td><td colspan="7">None</td></tr>
<tr><td>11</td><td>Operating environment</td><td colspan="7">Workshop conditions</td></tr>
<tr><td>12</td><td>Long-term stability of reading</td><td colspan="7">Depends on circumstances</td></tr>
<tr><td>13</td><td>Equivalent thermal expansion coefficient in µm/(m°C)</td><td colspan="7">11 for steel, 8 for glass material, 1 for Invar and 0 for Ultra Low Expansion glass scale</td></tr>
<tr><td>14</td><td>Related standards</td><td colspan="7">JIS B7541</td></tr>
<tr><td>15</td><td>Reference to ISO 230 series</td><td colspan="7">ISO 230-1:2012, 8.3.2.2</td></tr>
<tr><td rowspan="2">16</td><td rowspan="2">Uncertainty of measurement</td><td colspan="7">Major contributors: see Table D.2</td></tr>
<tr><td colspan="7">EXAMPLE: —</td></tr>
<tr><td>17</td><td>Example of figures</td><td colspan="7">See Figure 20</td></tr>
<tr><td>18</td><td>Remarks</td><td colspan="7">The line positions are read by microscope with reticule line, CCD with reference line and photo-electric microscope. Reading accuracy is affected by supporting point. It is recommended to support with Bessel points (distance = 0,559 L) to minimize the distortions.</td></tr>
</table>



Key

1 line (scale)

2 base unit

Figure 20 — Standard scale

7.3 Instruments for short range linear displacements

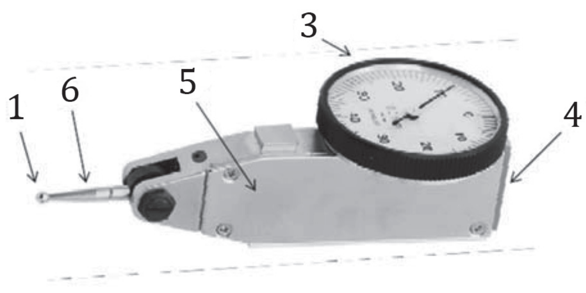
7.3.1 Contact-type sensors

7.3.1.1 Dial gauges

1	Name of measuring transducer	Dial gauge, lever type dial gauge
2	Description	Dial gauge is a small, compact instrument for use on machines, surface plate, for numerous other purposes. This instrument has a linear travelling plunger and dial that indicates displacement. The linear plunger travel is converted to rotation motion, e.g. by gears or twisted strips, that is indicated by pointer
3	Typical size	50 mm diameter. 50 mm plunger length.
4	Typical measuring range	2 mm, 10 mm
5	Typical MPE or linearity	14 µm in full reading range
6	Typical resolution	2 µm
7	Typical repeatability	1 µm (single direction) 3 µm (bidirectional)
8	Frequency response	less than 5 Hz
9	Typical Measuring force or load	0,4 N
10	Operating environment	Workshop conditions
11	Long-term stability of reading	Depends on circumstances
12	Equivalent thermal expansion coefficient in µm/(m °C)	11
13	Related standards	ISO 463, JIS B 7503,BS 907,DIN 878, NFE 11-050, ISIRI 9675,14526 JIS B 7533
14	Reference to ISO 230 series	—
15	Uncertainty of measurement	Major contributors: see Table D.2
		EXAMPLE: —
16	Example of figures	See Figures 21 a) and b)

17	Remarks	For details of dial gauges, reference should be made to ISO 463. Ordinary tests can be made with 0,01 mm dial gauges, but for more precise tests (e.g. run-out of a spindle functional surfaces of a machine tool), dial gauges with 0,001 mm resolution should be employed. It is emphasized that the principal characteristics of these instruments are: a) the error tendency such a linear, concave, convex and sin wave; b) the maximum value of hysteresis; c) the extreme values of the measuring force at the beginning and end of the stroke of the stylus; d) the maximum local variation of the measuring force (this force generally has different values for the in-and-out movements of the plunger at every position in the stroke); and e) the repeatability when used upside down. It is recommended that the dial gauges used have a short stroke, low hysteresis and a light contact force. For lever type dial gauges, it is emphasized that the alignment between the lever action direction and displacement to be measured should be parallel. Otherwise, cosine error is generated. When the dial gauges are applied to measurement with motion, the motion direction should be the correct direction that does not harm pivot action of the lever.

a) Dial gauge



b) Lever type dial gauge

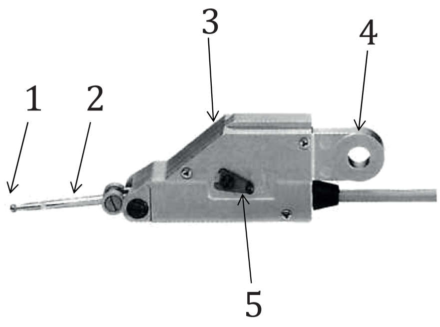
Key

1 contact point
2 plunger
3 reading dial
4 support
5 body
6 lever

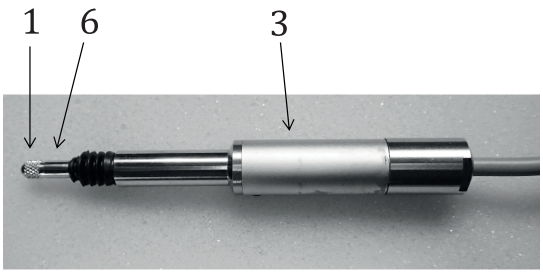
Figure 21 — Dial gauges

7.3.1.2 Linear variable differential transformer (LVDT)

1	Name of measuring transducer	Linear variable differential transformer (LVDT)
2	Description	Linear variable differential transformer produces an output which is proportional to the displacement of a movable core within the field of several coils. As the core moves from its null position, the voltages induced by the coils change, producing an output representing the difference in induced voltages. The LVDT gauge head can be either a cartridge or a lever-head type.
3	Typical size	8 mm diameter; 90 mm length (linear probe) 15 mm × 17 mm × 90 mm (lever type)
4	Typical measuring range	4 mm (linear type); 0,6 mm (lever type)
5	Example MPE or linearity	4 % of full scale (lever type)
6	Typical resolution	0,01 µm to 0,1 µm
7	Example repeatability	0,02 (linear type) 0,1 µm (Lever type)
8	Frequency response	approximately 20 Hz
9	Typical measuring force or load	1 N (linear type) 0.1 N (lever type)
10	Operating environment	–10 °C to +75 °C
11	Long-term stability of reading	Depends on circumstances
12	Equivalent thermal expansion coefficient in µm/(m °C)	11
13	Related standards	JIS B 7536
14	Reference to ISO 230 series	—
15	Uncertainty of measurement	Major contributors: see Table D.2
		EXAMPLE: —
16	Remarks	Equivalent thermal behaviour can be changed by the clamping position and the method.
17	Example of figures	See Figure 22



a) Lever type



b) Plunger type

Key

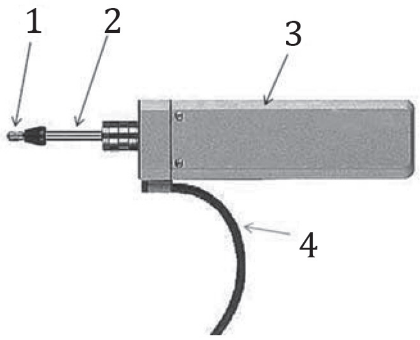
1 contact point lever
2 lever
3 body
4 support plate
5 direction change lever
6 plunger

Figure 22 — Linear variable differential transformer

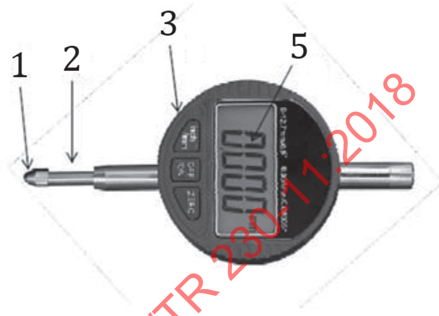
7.3.1.3 Linear scale displacement gauge

1	Name of measuring transducer	Linear scale displacement gauge
2	Description	This type of gauge consists of small linear digital scale, linear displacement guide and contact probe. Reading range (travel range) is greater than the LVDT, normally 5 mm to 30 mm range with 1 µm to 0.1 µm resolution. Applied digital scales are capacitive, magnetic and photo-electric scale. In the capacitive scale type, possible response speed is limited. Dial gauge type can be obtained (see example Figure 23)
3	Typical size	12 mm diameter, 50 mm length
4	Typical measuring range	5 mm to 50 mm
5	Typical MPE or linearity	0,4 % of full scale
6	Example of reduced (corrected) MPE at specific points in µm	2 digit
7	Typical resolution	0,01 µm to 1 µm
8	Repeatability	Depends on circumstances
9	Frequency response	approximately 1 kHz (depending on interpolation system and electric device)
10	Typical measuring force or load	2 N
11	Operating environment	0 °C to 50 °C
12	Long-term stability of reading	Depends on circumstances
13	Equivalent thermal expansion coefficient in µm/(m °C)	8 (glass)
14	Related standards	none
15	Reference to ISO 230 series	—

16	Uncertainty of measurement	Major contributors: see Table D.2
		EXAMPLE: —
17	Example of figures	See Figure 23 a) and b)



a) Plunger type



b) Dial gauge type

Key

1 contact point
2 plunger
3 body with linear scale
4 output cable
5 digital reading display

Figure 23 — Linear scale displacement sensor

7.3.2 Non-contact sensors

7.3.2.1 Capacitive displacement sensor

1	Name of measuring transducer	Capacitive displacement transducer
2	Description	Capacitive gauge; Capacitive displacement measurement systems are based on the functioning of ideal plate capacitors. If the distance between the two capacitor electrodes varies, the voltage value of the capacitor will change accordingly. In a non-contact displacement measurement application the two plate electrodes consist of the sensor and the target. The gage head can be either contact or non-contact type.
3	Typical size	5 mm diameter; 50 mm length
4	Typical measuring range	0,2 mm (depending on resolution)
5	Example MPE or linearity	0,4 % of full scale
6	Typical resolution	0,01 µm to 0,1 µm (corrected frequency bandwidth can change)
7	Repeatability	Depends on circumstances
8	Typical frequency response	Approximately 100 kHz (Resolution can change. See item 5)
9	Measuring force or load	Non-contact
10	Operating environment	0 °C to 50 °C

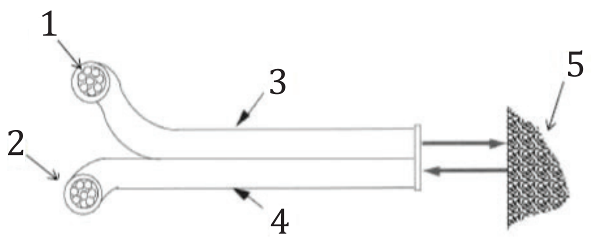
11	Long-term stability of reading	Depends on circumstances
12	Equivalent thermal expansion coefficient in µm/(m °C)	As same with case materials
13	Related standards	None
14	Reference to ISO 230 series	ISO 230-3, ISO 230-7
15	Uncertainty of measurement	Major contributors: see Table D.2
		EXAMPLE: —
16	Remarks	Applicable displacement range is small, normally 0,1 mm to 0,2 mm depending on maximum resolution and bandwidth. If maximum resolution becomes 10 nm level, then possible range is generally 100 µm.
17	Example of figures	—

7.3.2.2 Eddy current displacement probe

1	Name of measuring transducer	Eddy current displacement transducer
2	Description	An electric a.c. current in the reference coil creates an electromagnetic field, which combines with the field produced in the active coil. The resultant electromagnetic field interacts with a conductor producing a current flow on the surface and within the target. The induced current produces a magnetic field which opposes and reduces the intensity of the original field. This changes the effective impedance of the active coil, which is detected by the signal conditioning electronics. This change is used as a displacement sensor.
3	Typical size	5 mm diameter, 20 mm length
4	Typical measuring range	0,5 mm
5	Typical MPE or linearity	0,1 % to 0,5 % of full scale
6	Typical resolution	0,1 µm
7	Typical repeatability	0,2 µm
8	Example frequency response	50 kHz
9	Measuring force or load	non-contact
10	Operating environment	0 °C to 50 °C Sensitive to the target materials, grain size, heat treatment.
11	Example long-term stability of reading	0,15 µm per month
12	Equivalent thermal expansion coefficient	Nearly same with steel
13	Related standards	None
14	Reference to ISO 230 series	—
15	Uncertainty of measurement	Major contributors: see Table D.2
		EXAMPLE: —
16	Example of figures	—

7.3.2.3 Fibre optic displacement sensors

1	Name of measuring transducer	Fibre optics displacement sensor
2	Description	The distance of an object from the face of a fibre optic bundle consisting of source and receiving fibres can be determined based on the intensity of reflected light that is sensed. When the sensor is very close to the surface, the light cannot be reflected into the receiving fibres. The receiving fibres transmit the reflected light back to a photodiode, which measures the intensity.
3	Typical size	3 mm to 5 mm diameter
4	Typical measuring range	0 mm to 0,5 mm
5	Typical MPE or linearity	5 % of full scale
6	Typical resolution	10 nm
7	Repeatability	Depends on circumstances
8	Typical frequency response	100 kHz
9	Measuring force or load	Non-contact
10	Operating environment	Workshop conditions
11	Long-term stability of reading	Depends on temperature stability
12	Equivalent thermal expansion coefficient in µm/(m °C)	Nearly equal to fibre materials (glass or plastics)
13	Related standards	—
14	Reference to ISO 230 series	—
15	Uncertainty of measurement	Major contributors: see Table D.2
		EXAMPLE: —
16	Remarks	Sensitivity is depending on its bundle patterns (see 15). A kind of optical instrument.
17 a)	Example of figures	See Figure 24
17 b)	Pattern of fibres	Half type, Random type, Coaxial type



Key

1 light source connected to the cable

2 detector connected to the cable

3 transmission leg

4 receiving leg

5 target

Figure 24 — Fibre optics displacement sensor

7.3.2.4 Laser triangulation displacement sensor

1	Name of measuring transducer	Laser triangle displacement sensor
2	Description	Light from the laser makes a spot on the surface of the target and a lens is used to focus scattered light onto the surface of a photodetector. The output of the photodetector is proportional to the position of the centre of intensity of the focused image.
3	Example size	100 mm × 150 mm × 50 mm (scan head)
4	Example measuring range	5 mm to 50 mm
5	Example MPE or linearity	4 % of full scale
6	Example resolution	0,02 % of full scale range
7	Repeatability	0,05 % of full scale
8	Example frequency response	2,5 kHz
9	Measuring force or load	Non-contact
10	Operating environment	0 °C to 40 °C; Workshop conditions
11	Long-term stability of reading	—
12	Equivalent thermal expansion coefficient in µm/(m °C)	—
13	Related standards	—
14	Reference to ISO 230 series	—
15	Uncertainty of measurement	Major contributors: see Table D.2
		EXAMPLE: —
16	Remarks	A kind of optical instrument
17	Example of figures	—

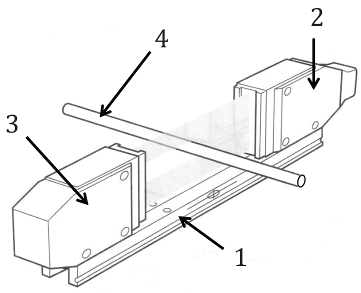
7.3.2.5 Optical focusing displacement sensor

1	Name of measuring transducer	Optical focusing displacement sensor
2	Description	Light spot emitted by laser diode is focused on the target surface. The reflected light spot is focused on photo diode. Focus is controlled by changing the distance between sensor and target by servo control system. This control signal is proportional to the distance change.
3	Example size	50 mm × 65 mm (sensing head)
4	Example measuring range	1 mm
5	Example MPE or linearity	1 µm of full scale
6	Example resolution	0,01 µm
7	Repeatability	—
8	Example frequency response	1 kHz
9	Measuring force or load	Non-contact
10	Operating environment	Workshop conditions
11	Long-term stability of reading	—
12	Related standards	—
13	Reference to ISO 230 series	—

14	Uncertainty of measurement	Major contributors: see Table D.2
15	Remarks	A kind of optical instrument
16	Example figure	—

7.3.2.6 Laser scanning micrometer

1	Name of measuring transducer	Laser scanning micrometer
2	Description	There are two types of scanning microscope, one is mechanical beam scanning system, and other is steady beam band light with CCD detector. This instrument was originally designed to measure wire and tube diameters. The system consists of a laser light source, beam scanning prism, rotation angle measuring system, time base and two coupled CCD arrays that detect the beam position. The target diameter and its centre position are calculated from the beam position and prism rotating speed. One system can measure both the centre position of the wire and its diameter, so that it is possible to detect the machine straightness.
3	Typical size	40 mm × 100 mm × 340 mm (depends on heads distance)
4	Typical measuring range	0,3 mm to 30 mm
5	Typical MPE or linearity	5 % of full scale
6	Typical resolution	0,01 µm to 100 µm
7	Typical repeatability	0,3 µm
8	Typical frequency response	Depends on averaging cycles. Total data treatment times are: — for average number N = 1; 3 ms; — for average number N = 128; 60 ms; and — for average number N = 2 048; 870 ms. [at sampling frequency: 2 400 times/sec]
9	Measuring force or load	Non-contact
10	Operating environment	0 °C to 50 °C
11	Long-term stability of reading	0,5 µm (0 °C to 50 °C)
12	Equivalent thermal expansion coefficient in µm/(m °C)	—
13	Related standards	—
14	Reference to ISO 230 series	ISO 230-1:2012, 8.2.2.2
15	Uncertainty of measurement	Major contributors: see Table D.2 EXAMPLE: —
16	Remarks	The instrument can be used for taut wire measurement and thermal displacement measurement. A kind of optical instrument.
17	Example of figures	See Figure 25



Key

1 base plate
2 light scanning head
3 light receiver
4 measured object

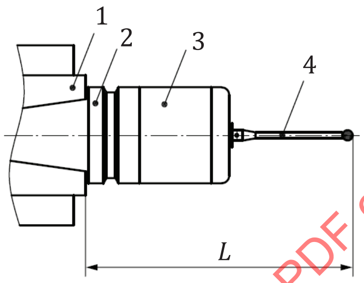
Figure 25 — Laser scanning micrometer

7.3.3 Contact probing system

7.3.3.1 1D probe (discrete point)

1	Name of instrument	Touch-Trigger probe
2	Description	Touch probe is a sensor that detects the relative position between target and probe holding device with contacting the probe tip. Touch probe consists of connection device between probe system and machine tool, probe housing that include electric sensing device, probe bar and contact tip. The sensor detects the contact between the probe tip and target by mechanical deflection, vibration, etc. Probe system is carried by the moving component until tip hits the target surface. The signal from the probe generates the stopping command of moving component. The moving component stops after getting this command. There are some over travelling distance caused by this delay. The over travelling distance is affected by the motion speed, trigger system delay, and mechanical hysteresis of the probe construction. There are two major types of probe, one only detects the contact, and the other continuously detects the relative displacement between the target and probe system. This type of probe only detects contact position between target and probe.
3	Example size and weight:	—
4	Example measuring range	—
5	Example MPE or linearity	—
6	Resolution	—
7	Example repeatability	0,1 µm to 1 µm
8	Example frequency response	100 Hz
9	Measuring force or load	0,5 N
10	Operating environment	Workshop conditions

11	Long-term stability of reading	—
12	Equivalent thermal expansion coefficient in µm/(m°C)	11
13	Related standards	—
14	Reference to ISO 230 series	ISO 230-3, ISO 230-10
15	Uncertainty of measurement	Major contributors: see Table D.3
		EXAMPLE: —
16	Remarks	—
17	Example of figures	See Figure 26



Key

1 spindle

2 tool holder

3 probe

4 stylus

L probing tool length

Figure 26 — Touch-Trigger probe

7.3.3.2 1-D probe (scanning)

1	Name of instrument	1-D probe (scanning)
2	Description	1-D probe is a sensor that detects the relative position between target and probe holding device with contacting the probe tip. 1-D probe consists of connection device between probe system and machine tool, probe housing that include electric sensing device, probe bar and contact tip. The sensor detects the displacement between the probe tip and target by scale, mechanical deflection, vibration, etc. Probe system is carried by the moving component until tip hits the target surface.
3	Example size and weight:	—
4	Example measuring range	5 mm
5	Example MPE or linearity	—
6	Resolution	0,1 µm
7	Example repeatability	0,1 µm to 1 µm
8	Example frequency response	100 Hz
9	Measuring force or load	0,5 N

10	Operating environment	Workshop conditions
11	Long-term stability of reading	—
12	Equivalent thermal expansion coefficient in µm/(m °C)	11
13	Related standards	—
14	Reference to ISO 230 series	ISO 230-3, ISO230–10
15	Uncertainty of measurement	Major contributors: see Table D.3 EXAMPLE: —
16	Remarks	—
17	Example of figures	See Figure 26

7.3.3.3 2-D probe (touch trigger)

1	Name of instrument	Touch-Trigger probe
2	Description	Touch probe is a sensor that detects the relative position between target and probe holding device by contacting the probe tip. Touch probe consists of connection device between probe system and machine tool, probe housing that include electric sensing device, probe bar and contact tip. The sensor detects the contact between the probe tip and target by mechanical deflection, vibration, etc. Probe system is carried by the moving component until tip hits the target surface. The signal from the probe generates the stopping command of moving component. The moving component stops after getting this command. There are some over travelling distance caused by this delay. The over travelling distance is affected by the motion speed, trigger system delay, and mechanical hysteresis of the probe construction. There are two major types of probe, one only detects the contact, and the other continuously detects the relative displacement between the target and probe system. This type of probe only detects contact position between target and probe.
3	Example size and weight:	—
4	Example measuring range	—
5	Example MPE or linearity	—
6	Resolution	—
7	Example repeatability	0,1 µm to 1 µm
8	Example frequency response	100 Hz
9	Measuring force or load	0,5 N
10	Operating environment	Workshop conditions
11	Long-term stability of reading	—
12	Equivalent thermal expansion coefficient in µm/(m°C)	11
13	Related standards	—
14	Reference to ISO 230 series	ISO 230-3, ISO 230-10

15	Uncertainty of measurement	Major contributors: see Table D.3
		EXAMPLE: —
16	Remarks	—
17	Example of figures	See Figure 26

7.3.3.4 2-D probe (proportional)

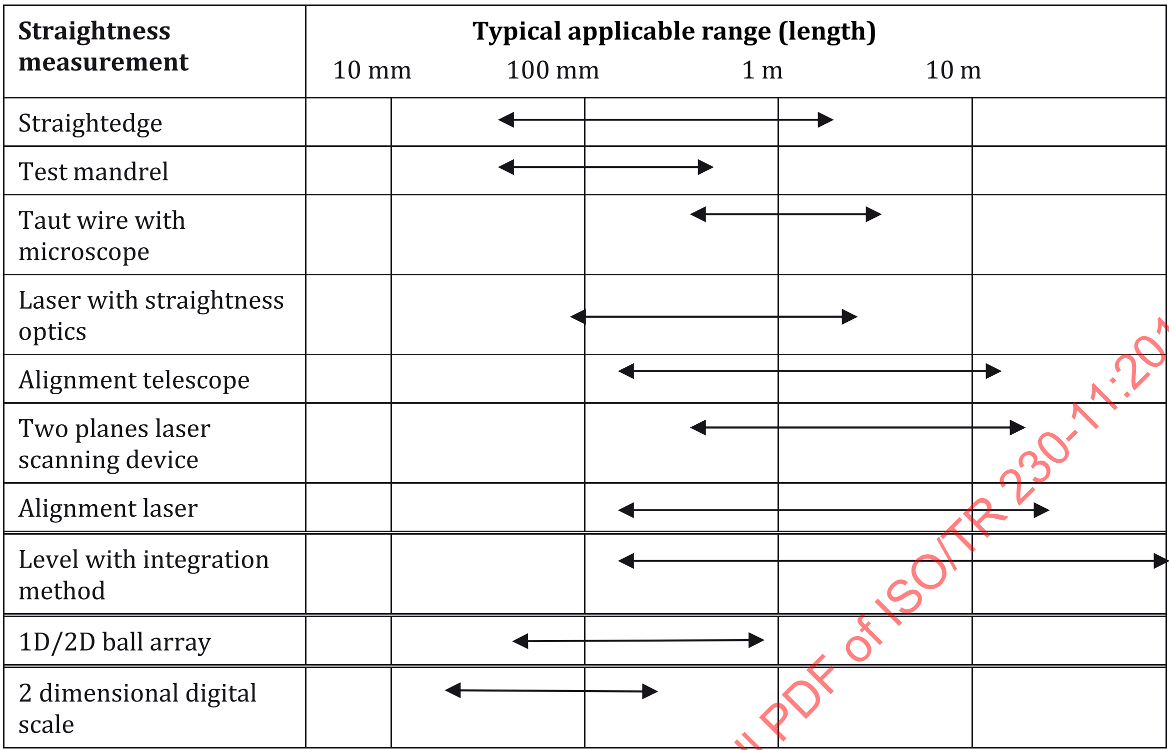
1	Name of instrument	2-D probe
2	Description	—
3	Example size and weight:	—
4	Example measuring range	—
5	Example MPE or linearity	—
6	Resolution	0,1 µm
7	Example repeatability	0,1 µm to 1 µm
8	Example frequency response	100 Hz
9	Measuring force or load	0,5 N
10	Operating environment	Workshop conditions
11	Long-term stability of reading	—
12	Equivalent thermal expansion coefficient in µm/(m °C)	11
13	Related standards	—
14	Reference to ISO 230 series	ISO 230-3, ISO 230-10
15	Uncertainty of measurement	Major contributors: see Table D.3
		EXAMPLE: —
16	Remarks	—
17	Example of figures	—

8 Straightness measuring devices

8.1 General

The mechanical artefacts such as test mandrels, straightedge and square can be used as the reference for straightness measurement. Straightness can also be measured by the application of a small angle measurement. Other special measurement methods such as the application of optical instruments are also included in this clause. For uncertainty contributors (see also Table D.3). Table 9 shows the summary of straightness measuring devices with typical measuring range.

Table 9 — Typical measuring range of straightness measurement devices

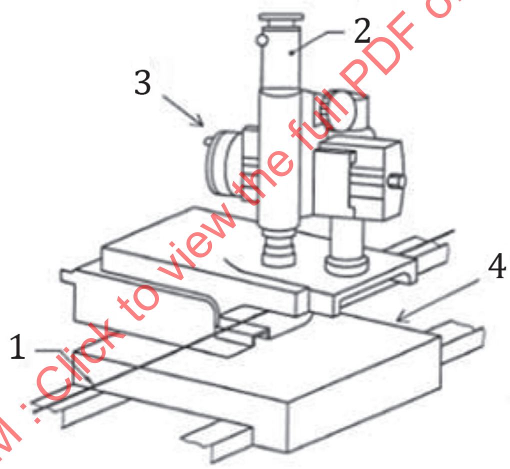


8.2 Taut wire with optical reading device

1	Name of instrument	Taut wire with optical reading device
2	Description	The horizontal deviation of the wire centre is measured by a microscope or other optical device to evaluate the straightness of the machine motion on which the microscope is fixed.
3	Typical size in mm	Diameter should be less than 0,1 mm to 0,7 mm
4	Typical material	Steel or nylon strings
5	Recommended reading system	Microscope with reticle and micrometer adjustment to indicate its position accurately in respect to the taut wire. Instead of using microscope, CCD, laser scanning micrometer or other image processing devices can be applied to detect the wire image. With the electric image detecting devices, wire position can directly readout by the system. Laser scanning micrometer; (See 7.3.2.6)
6	Operating environment	Workshop conditions As air draught influences the stability of the wire, still air condition (low temperature gradient, etc.) required
7	Related standards	—
8	Reference to ISO 230 series	ISO 230-1:2012, 8.2.2.2

Table 9 *(continued)*

9	Uncertainty of measurement	Major contributors: straightness of wire, tension force; see Table D.3	
		EXAMPLE: —	
10	Remarks	The microscope can be adjusted on the machine by means of a precision level (which can be integral with the microscope support). The two ends of the wire are lined up by means of the cross-hairs of the measuring microscope. Readings are taken in the horizontal plane as the table is traversed. Care should be taken when handling the wire, which should be of sufficient tension and free from kinks. The wire diameter should be as small as possible, in any case not more than 0,1 mm. Vertical configuration is possible for measurement of vertical column straightness measurement.	
11	Example of figures	See Figure 27	



Key

1 taut wire

2 microscope

3 micrometer head

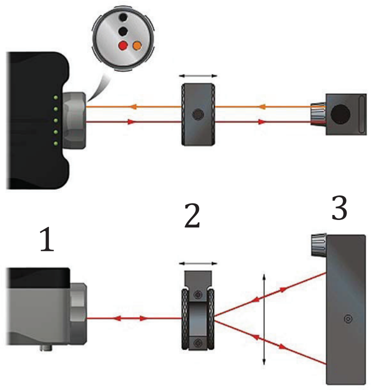
4 machine slide

NOTE See also ISO 230-1:2012, 8.2.2.2, Figure 39.

Figure 27 — Taut wire with microscope

8.3 Laser interferometer with straightness optics

1	Name of instrument	Laser interferometer with optical accessory
2	Description	The outgoing beam from the laser passes through the straightness interferometer which splits it into two beams which diverge at a small angle and are directed to the straightness reflector. The beams are then reflected from the straightness reflector and return along a new path to the straightness interferometer as shown in the figure. At the straightness interferometer, the two beams are converged and a single beam is returned to the entry port in the laser head. There are two types of optics, one with plane mirrors and others with 90° mirror.
3	Example size in mm	42 mm × 160 mm × 42 mm reflector and 40 mm × 50 mm × 30 mm interferometer
4	Example measuring range	±2,5 mm for measuring length 0,1 m to 4 m
5	Example MPE or linearity	1 % of full scale
6	Example resolution	0,01 µm
7	Example repeatability	—
8	Frequency response	—
9	Operating environment	Workshop conditions
10	Long-term stability of measurement	—
11	Equivalent thermal expansion coefficient in µm/(m °C)	—
12	Related standards	—
13	Reference to ISO 230 series	ISO 230-1:2012, 8.2.2.5
14	Uncertainty of measurement	Major contributors: see Table D.3
		EXAMPLE: U = 2 µm/m in temperature controlled room, U = 6 µm/m in normal workshop [U(k = 2)]
15	Remarks	A kind of optical instrument
16	Example of figures	See Figure 28



Key

1 laser head

2 Wollaston prism

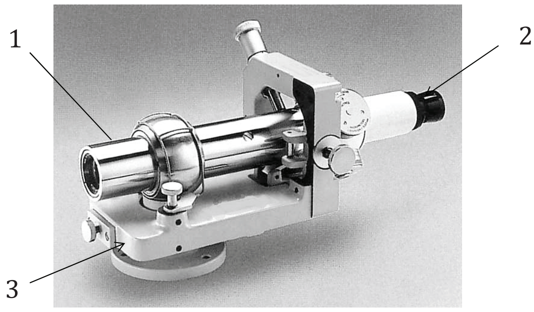
3 two plane mirror

Figure 28 — Laser interferometer with straightness optical accessory

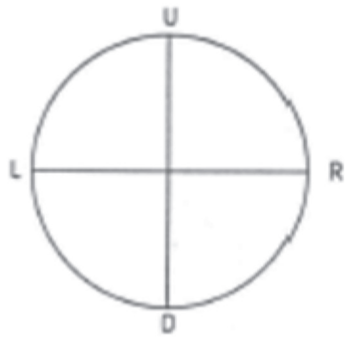
8.4 Alignment telescope

1	Name of instrument	Alignment telescope
2	Description	The alignment telescope with accessories is designed to test straightness, parallelism and squareness. Through an arrangement of lenses contained in tubular housing, a view of horizontal and vertical cross-wires can be projected onto a target. The vertical and horizontal displacement of the cross-wires to the target is measured directly in millimetres using the micrometer dials. The graduated focusing dial varies the position of the focusing lens, enabling targets to be focused from zero to infinity. The focus of the cross-wires is achieved at the eyepiece. The telescope is most commonly mounted on a horizontal base containing a spherical trunnion to allow lateral and vertical adjustments of the line of sight. Straightness can be measured by moving the target along the line of sight. Accessories to accommodate precision levels and optical squares extend the capacity of the instrument to measure parallelism and squareness.
3	Example size	500 mm × 200 mm × 100 mm
4	Example measuring range	1 m to 10 m depending on uncertainty of measurement
5	Example MPE or linearity	3 µm/1 m, 10 µm/5 m
6	Example resolution	1 µm
7	Repeatability	—
8	Frequency response	—
9	Measuring force or load	Non-contact
10	Operating environment	Workshop conditions

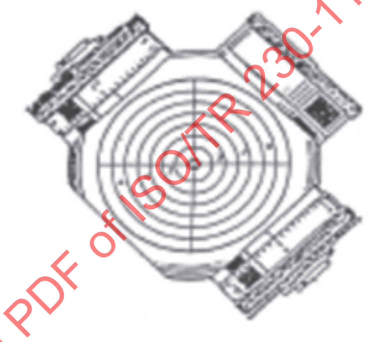
11	Long-term stability of reading	—
12	Equivalent thermal expansion coefficient in µm/(m °C)	—
13	Related standards	—
14	Reference to ISO 230 series	ISO 230-1:2012, 8.2.2.3
15	Uncertainty of measurement	Major contributors: see Table D.3
		EXAMPLE: U = 3 µm/1 m [U(k = 2)] measurement under controlled circumstance
16	Remarks	The centre of the target should be situated as near to the functional point as possible. The distance between the optical axis of the telescope and the centre of the target should be read directly on the reticule or by means of the optical micrometer. Ensure that the micrometer dial readings are interpreted correctly, i.e. +ve is not confused with −ve. A suggested rule of convention is the "LURD" principle [see Figure 29 b)] (i.e. left, up, right, down). A kind of optical instrument
17	Example of figures	See Figure 29



a) Alignment telescope



b) LURD principle



c) View of cross wire, target and micrometer dials

Key

1 telescope
2 eye piece
3 adjusting table
U up
L left
D down
R right

NOTE See also ISO 230-1:2012, 8.2.2.3.

Figure 29 — Alignment telescope

8.5 Two planes laser scanning device

1	Name of instrument	Two planes continuous sweeping laser with two single axis targets
2	Description	Continuously sweeping laser planes are produced by bending a laser beam precisely 90° using an optical pentaprism. Laser planes are used as references to measure the straightness of machine axes. The horizontal deviation and vertical deviation from the laser planes are measured by an optical target sensor for each axis to evaluate the vertical straightness and the horizontal straightness of the machine motion on which the targets are fixed. The scanner laser is mounted on an adjustment base with pitch roll and yaw adjustment for fine alignment of planes parallel to the machine movement. Two accurate levels allow to determine the parallelism to the horizontal plane or to gravity. Same system can be applied to straightness measurement and squareness measurement.
3	Example of laser emitter size	Overall dimensions: 280 mm × 220 mm × 220 mm; weight: 4,5 kg
4	Example of target sensors dimensions and weight	60 mm × 110 mm × 50 mm; 400 g
5	Example of measuring range	30 m
6	Example of beam straightness	0,001 mm/m ± 0,002 5 mm/m for air noise
7	Example of laser plane flatness	0,25" or 0,001 mm/m + maximum translation error of 0,001 3 mm in a 90° sweep
8	Example in laser plane squareness	Top laser plane to side laser plane squareness: 0,005 mm/m
9	Example of targets resolution and MPE	Cell range 5 mm; resolution: 0,000 25 mm; MPE: 0,001 5 mm Cell range 24 mm; resolution: 0,000 5 mm; MPE: 0,003 5 mm
10	Recommended reading system	Multiple axes display based on display with wireless connection to the sensors or wireless interface to PC in order to collect and memorize data for further analysis and reporting
11	Operating environment	Workshop conditions The performance of a laser system is affected by turbulence in the atmosphere, it is extremely important to use both the fans to mix the air and electronic noise filtering when maximum system MPE is required.
12	Related standards	—
13	Reference to ISO 230 series	ISO 230-1:2012, 12.2.5.3
14	Uncertainty of measurement	Major contributors: see Table D.5 EXAMPLE: Typical value for uncertainty U = 5 µm on 3 m travel [U(k = 2)]
15	Remarks	The horizontal and vertical straightness can be collected at the same time A kind of optical instrument.
16	Example of figures	See Figure 30

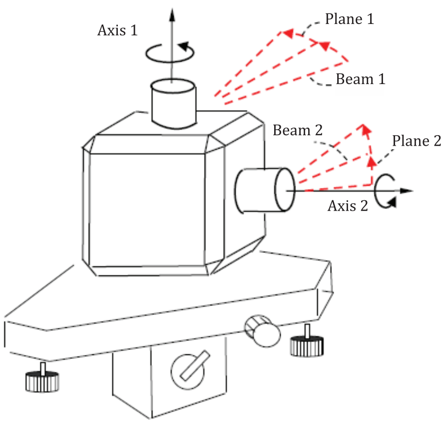
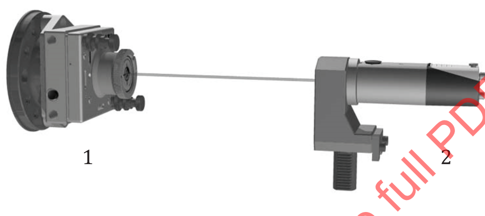


Figure 30 — Two planes continuous sweeping laser with two single axis targets

8.6 Alignment laser

1	Name of instrument	Alignment laser
2	Description	The alignment laser with accessories is designed to test straightness, parallelism and squareness. The laser beam is used as reference and the deviation in distance between the laser beam and the measurement object is measured in two or more positions, with the use of the two dimensional position detector. The vertical and horizontal displacement of the spot on the target is measured directly in millimetres using the two dimensional sensor. Straightness can be measured by moving the target along the line of sight.
3	Example size	Receiver: 60 mm × 50 mm × 40 mm; 120 g Transmitter: 60 mm × 60 mm × 140 mm; 1 100 g
4	Example measuring range	up to 50 m depending on uncertainty of measurement
5	Example MPE or linearity	1 % of full scale or 6 µm
6	Example resolution	1 µm
7	Repeatability	3 µm
8	Frequency response	3 Hz
9	Measuring force or load	Non-contact
10	Operating environment	0 °C to 50 °C, workshop environment.
11	Long-term stability of reading	—
12	Equivalent thermal expansion coefficient in µm/(m °C)	—

13	Related standards	—
14	Reference to ISO 230 series	ISO 230-1:2012, 8.2.2.3
15	Uncertainty of measurement	Major contributors: see Table D.3
		EXAMPLE: –
16	Remarks	There are several types. Some can operate with wireless operation. Application to flatness, parallelism and squareness measurements are also possible. The centre of the detector should be situated as near to the functional point as possible. A kind of optical instrument
17	Example of figures	See Figure 31



Key

1 transmitter

2 receiver

Figure 31 — Alignment laser

9 Squareness measuring devices

9.1 General

Squareness measurement is performed with mechanical artefacts such as square and cylindrical square. This section indicates angle measuring devices with application of other instruments such as optical instruments. For uncertainty contributors (see also Table D.4). Table 10 shows the summary of squareness measuring devices with typical measuring range.

Table 10 — Typical measuring range of squareness measuring devices

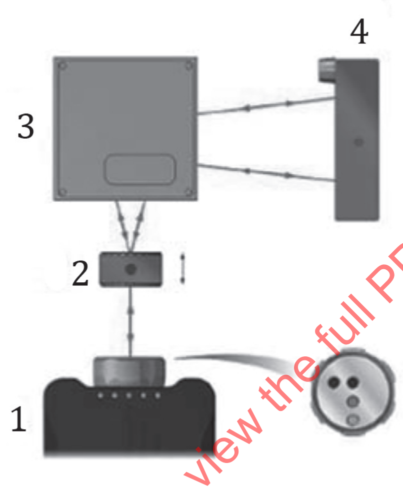
Squareness measurement	Typical applicable working range (length): < 10 mm	10 mm – 100 mm	100 mm – 1 m	1 m – 10 m	> 10 m
Reference squares		←	—	→	
Reference cube		←	→		
Laser with squareness optics			←	→	
Optical square with angle reading device			←	—	→
Index table with straightedge			←→		
Three planes laser scanning device			←	—	→
Ball bar application			←	→	
2D ball array		←	→		
Two dimensional digital scale	←	—	→		

9.2 Laser interferometer with squareness and straightness optics

1	Name of instrument	Laser interferometer with optical accessory
2	Description	Squareness measurements are carried out by making straightness measurements along each of the two nominally orthogonal axes of interest, using a common reference. A common reference is required so that the two sets of straightness measurements can be compared and the out of squareness of the two axes calculated. The common reference is normally the optical alignment of the straightness reflector, which is neither moved (relative to the table), nor adjusted, between the two straightness measurements. An optical square is used for at least one of the straightness measurements to allow the laser beam to be aligned along each axis without touching the straightness reflector. The optical principles of squareness measurements are the same as those for straightness measurements, but with the additional use of the optical square.
3	Example size in mm	160 mm × 160 mm × 60 mm, (optical unit)
4	Example measuring range	±3/(measuring length in m)
5	Example MPE or linearity	1 % of full scale
6	Example resolution	0,01 µm/m
7	Example repeatability	—
8	Frequency response	—
9	Operating environment	Workshop environment.
10	Long-term stability of measurement	—

Table 10 *(continued)*

11	Equivalent thermal expansion coefficient	—
12	Related standards	—
13	Reference to ISO 230 series	ISO 230-1:2012, 10.3.2.4
14	Uncertainty of measurement	Major contributors: see Table D.3
		EXAMPLE: —
15	Remarks	A kind of optical instrument
16	Example of figures	See Figure 32



Key

1 laser head

2 Wollaston prism

3 optical square

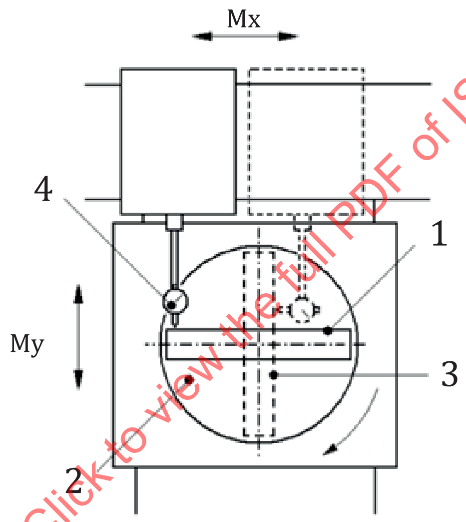
4 two-plane mirror

Figure 32 — Laser interferometer with squareness and straightness optical accessory

9.3 Index table with straightedge

1	Name of instrument	Index table with straightedge
2	Description	—
3	Example size and weight:	200 mm × 200 mm × 60 mm; 3 kg
4	Example measuring range	360°
5	Example MPE or linearity	0,4″
6	Example resolution	2° (180 division)
7	Example repeatability	0,2″
8	Frequency response	—
9	Measuring force or load	—
10	Operating environment	Workshop conditions

11	Long-term stability of reading	—
12	Equivalent thermal expansion coefficient in µm/(m °C)	—
13	Related standards	—
14	Reference to ISO 230 series	ISO 230-1:2012, Figure 65
15	Uncertainty of measurement	Major contributors: see Table D.3
		EXAMPLE: —
16	Example of figures	See Figure 33



Key

1 straightedge at 0°
2 index table
3 straightedge at 90°
4 linear displacement sensor
M_x X-direction motion
M_y Y-direction motion

Figure 33 — Index table with straightedge

9.4 Three planes laser scanning device

1	Name of instrument	Three planes continuous sweeping laser with two single axis targets
2	Description	Continuously sweeping laser planes are produced by bending a laser beam precisely 90° using an optical pentaprism. Laser planes are orthogonal to each other and, thus, can be used as reference to measure the squareness between surfaces or machine axes. The laser plane is made parallel to a surface or line of motion by adjusting the pitch, roll or yaw of the laser base until the target displays the same reading at each reference point. The targets are then used to measure the deviation from the reference points up to 30 m away from the laser. Two accurate levels allow to determinate the parallelism to the horizontal plane or to gravity. Same system can be applied to straightness measurement and flatness measurement.
3	Example of laser emitter size and weight	Overall dimensions: 280 mm × 220 mm × 220 mm; weight: 4,5 kg
4	Example of target sensors dimensions and weight	60 mm × 110 mm × 50 mm; weight: 400 g
5	Example of measuring range	30 m each direction
6	Example of beam straightness	0,001 mm/m ± 0,002 5 mm/m for air noise
7	Example of laser plane flatness	0,25″ or 0,001 mm/m + maximum translation error of 0,001 3 mm in a 90° sweep
8	Example in laser plane squareness	Top laser plane to side laser plane squareness: 0,005 mm/m
9	Example of targets resolution and MPE	Cell range 5 mm; resolution: 0,000 25 mm; MPE: 0,001 5 mm Cell range 24 mm; resolution: 0,000 5 mm; MPE: 0,003 5 mm
10	Recommended reading system	Multiple axes display based on display with wireless connection to the sensors or wireless interface to PC in order to collect and store data for further analysis and reporting.
11	Operating environment	Workshop conditions The performance of a laser system is affected by turbulence in the atmosphere, it is extremely important to use both the fans to mix the air and electronic noise filtering when maximum system MPE is required.
12	Related standards	—
13	Reference to ISO 230 series	ISO 230-1:2012, 12.2.5.3
14	Uncertainty of measurement	Major contributors: see Table D.5 EXAMPLE: Typical value for uncertainty U = 5 µm on 3 m travel [$U(k = 2)$].
15	Remarks	The three plane squareness can be collected without repositioning the instrument and change the references points. A kind of optical instrument
16	Example of figures	See Figure 34

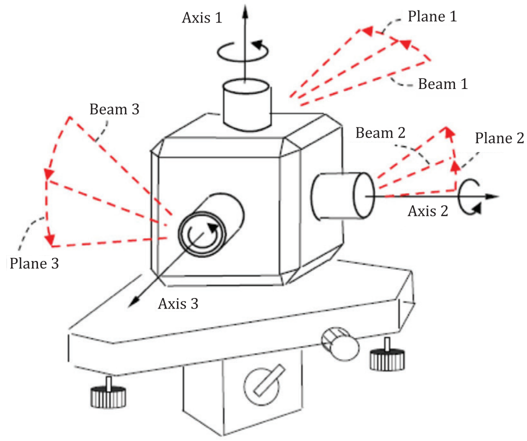


Figure 34 — Three planes continuous sweeping laser with two single axis targets

10 Flatness measuring devices

10.1 General

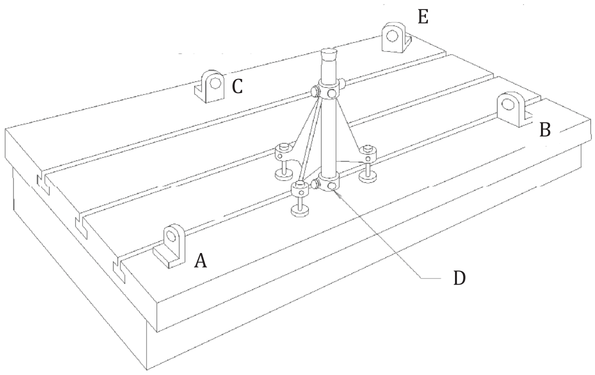
Flatness can be measured with reference artefacts such as straightedge, surface plate. Angle measurement instrument such as levels, autocollimators can be applied for measurement of flatness of functional surfaces of machine tool components (see ISO 230-1). Other applicable measuring instruments are also indicated. Table 11 shows the summary of flatness measuring devices with typical measuring range.

Table 11 — Typical measuring range of flatness measuring devices

Flatness measurement	**Typical applicable working range (length)**				
	10 mm	100 mm	1 m	10 m	
Surface plate		◄────	────►		
Sweep optical square			◄──	────►	
Laser with angular optics			◄────	────	─►
Single planes laser scanning device			◄──	────	──►

10.2 Sweep optical square

1	Name of instrument	Sweep optical square
2	Description	The sweep optical square is used in conjunction with the alignment telescope and three datum targets to establish a reference plane which enables a surface to be checked for flatness (see Figure 35). The telescope is mounted in a frame which carries a rotating optical unit housing a pentagonal prism. The frame contains adjustable supports to bring the plane swept by the instrument to the centre of the datum targets. The targets are focused as described in 8.4, and a micrometer dial on the rotating optical unit measures the vertical displacement of the targets with respect to the cross-wires.
3	Example size	600 mm × 300 mm × 300 mm
4	Example measuring range	Up to 10 m
5	Example MPE or linearity	5 µm/2 m
6	Example resolution	0,002 mm
7	Example repeatability	Depends on the circumstances
8	Frequency response	—
9	Measuring force or load	Non-contact
10	Operating environment	Workshop environment
11	Long-term stability of reading	—
12	Equivalent thermal expansion coefficient in µm/(m °C)	—
13	Related standards	—
14	Reference to ISO 230 series	ISO 230-1:2012, 12.2.5.1
15	Uncertainty of measurement	Major contributors: see Table D.3
		EXAMPLE: U = 2 µm/1 m square [$U(k = 2)$]
16	Remarks	The following precautions should be taken in use. a) Avoid using where there are changes in temperature which could cause undue refraction. b) Ensure that the base of the magnetic target mount is clean. c) Ensure that the micrometer dial readings are interpreted correctly, i.e. positive is not confused with negative. A suggested rule of convention is the LURD principle [see Figure 29 b)]. d) Ensure that focus settings are sharp. e) Whenever possible, ensure that the instruments are mounted rigidly. A kind of optical instrument
17	Example of figures	See Figure 35



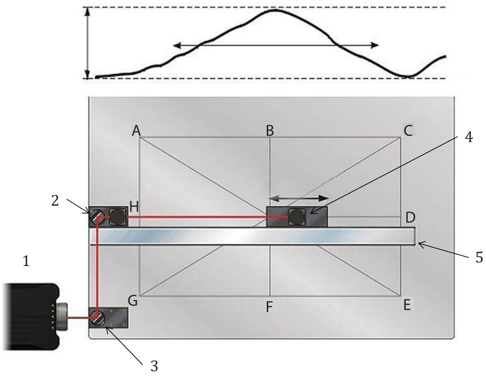
Key

A first reference target
B second reference target
C third reference target
D sweep optical square
E movable target mirror

Figure 35 — Sweep optical square

10.3 Laser interferometer with angular optics

1	Name of instrument	Laser interferometer with flatness optical accessory
2	Description	The angular interferometer is attached to the turning mirror and the angular reflector is attached on top of the selected flatness base. The angular interferometer is placed in the path between the laser head and the angular reflector. The laser beam is split into two by the beam-splitter inside the angular interferometer. One part of the beam (the measurement beam A_1) passes straight through the interferometer and is reflected by one of the twin reflectors of the angular reflector back through the interferometer and into the laser head. The other beam (measurement beam A_2) passes through the periscope part of the angular interferometer to the second reflector from where it returns through the interferometer and into the laser head. An angular measurement is produced by comparing the path difference between the beams A_1 and A_2, (i.e. the measurement is independent of the distance between the laser and the interferometer). The flatness reading displayed by the software is the incremental height between the front and back feet of the flatness baseplate on which the angular reflector is fitted. This incremental height is calculated from the angular measurement and a knowledge of the distance between the centres of the front and back feet of the flatness baseplate. This distance, termed the foot-spacing is entered into the calibration software before measurement starts. For each measurement line, the angular interferometer (mounted on the flatness turning mirror) stays stationary, while the reflector (mounted on a flatness base) moves along the line in incremental steps defined by the foot-spacing. (see 12.2.5.4)
3	Example size in mm	70 mm × 40 mm × 40 mm; 70 mm × 40 mm × 40 mm (optical unit only)
4	Example measuring range	0 m to 15 m, ± 1,5 mm
5	Example MPE or linearity	1,2 % of full scale
6	Example resolution	0,01 µm
7	Example repeatability	2″
8	Frequency response	—
9	Operating environment	Workshop environment.
10	Long-term stability of measurement	—
11	Equivalent thermal expansion coefficient	—
12	Related standards	None
13	Reference to ISO 230 series	See 12.2.5.4
14	Uncertainty of measurement	Major contributors: see Table D.3
		EXAMPLE: —
15	Remarks	A kind of optical instrument
16	Example of figures	See Figure 36



Key

1	laser head
2	angular interferometer
3	turning mirror
4	angular reflector
5	guide plate
A-C, C-E, E-G, G-A, B-F, D-H, A-H, C-G	lines of measurement

Figure 36 — Laser interferometer with flatness optical accessory

10.4 Single plane laser scanning device

1	Name of instrument	Single plane continuous sweeping laser with one or three single axis targets.
2	Description	Continuously sweeping laser plane is produced by bending a laser beam precisely 90° using an optical pentaprism. Laser plane is flat and can be used as reference to measure the flatness of a machine surface both horizontally and vertically. The laser plane is made parallel to a surface by adjusting the pitch, roll or yaw of the laser base until the targets displays the same reading at each reference point. The targets are then used to measure the deviation from the reference points up to 30 m away from the laser. Two accurate levels allow to determinate the parallelism to the horizontal plane. Same system can be applied to straightness and squareness measurements
3	Example of laser emitter size and weight	Overall dimensions: 280 mm × 220 mm × 220 mm; weight: 4,5 kg
4	Example of target sensors dimensions and weight	60 mm × 110 mm × 50 mm; weight: 400 g
5	Example of measuring range	30 m radius
6	Example of beam straightness	0,001 mm/m ± 0,002 5 mm/m for air noise
7	Example of laser plane flatness	0,25″ or 0,001 mm/m + maximum translation error of 0,001 3 mm in a 90° sweep
8	Example of targets resolution and MPE	Cell range 5 mm; resolution: 0,000 25 mm; MPE: 0,001 5 mm Cell range 24 mm; resolution: 0,000 5 mm; MPE: 0,003 5 mm

9	Recommended reading system	Multiple axes display based on display with wireless connection to the sensors or wireless interface to PC in order to collect and memorize data for further analysis and reporting.
10	Operating environment	Workshop conditions The performance of a laser system is affected by turbulence in the atmosphere, it is extremely important to use both the fans to mix the air and electronic noise filtering when maximum system MPE is required.
11	Related standards	—
12	Reference to ISO 230 series	ISO 230-1:2012, 12.2.5.3
13	Uncertainty of measurement	Major contributors: see Table D.5 EXAMPLE: Typical value for uncertainty U = 5 µm on 3 m travel [$U(k = 2)$].
14	Remarks	A kind of optical instrument
15	Example of figures	See Figure 37

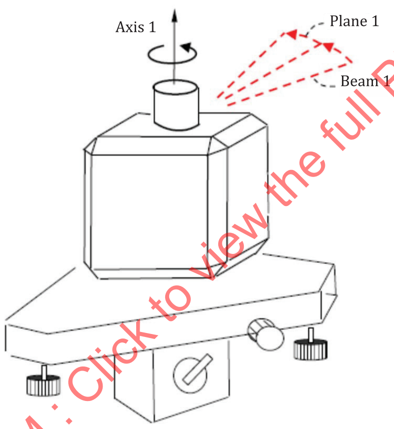


Figure 37 — Single plane continuous sweeping laser with one or three single axis targets

11 Angle measuring instruments

11.1 General

Angle measuring instruments are classified as follows:

— partial circle (angle) measuring instruments (levels, autocollimator, laser angle measurement device);

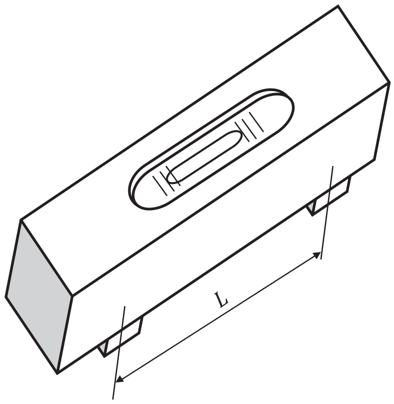
— full circle (360°) angle measuring instruments (Polygon, Precision index, Rotary encoder).

For uncertainty contributors, see Table D.4.

11.2 Level

11.2.1 Precision level

1	Name of instrument	Precision level
2	Description	A level can be fitted with a micrometer screw or with graduation lines on the tube, with or without adjustable screw. In the first case, the changes in slope are read on the deviation of the micrometer; in the second case they are read directly on the graduation lines of the tube. The constant of a level or apparent sensitivity, *n*, is the change in tilt, expressed in millimetres per millimetre (or in seconds of arc), which produces a displacement of the bubble by one division.
3	Example size and weight	250 mm × 50 mm × 50 mm; 1 kg
4	Example measuring range	±1°
5	MPE or linearity	MPE of the level should not exceed 0,020 mm/1 000 mm (range) and the bubble should move through at least one division for a change of angle not greater than 0,05 mm/1 000 mm.
6	Example resolution	0,02 mm/m
7	Repeatability	0,01 mm/1 000 mm
8	Frequency response	Less than 2 s
9	Measuring force or load	—
10	Operating environment	0 °C to 40 °C
11	Long-term stability of reading	0,01°/°C
12	Equivalent thermal expansion coefficient in µm/(m °C)	—
13	Related standards	JIS B 7510
14	Reference to ISO 230 series	ISO 230-1:2012, 8.4.2.1, 12.1.3.1, 12.2.3.2, 12.2.4, 12.3.2.2.2, 12.3.2.3.2,12.3.2.8 and 12.3.2.9
15	Uncertainty of measurement	Major contributors: see Table D.4
		EXAMPLE: —
16	Remarks	The flatness of the base should comply with the following tolerances: — 0,004 mm for *L* < 250 mm; — 0,006 mm for 250 mm < *L* < 500 mm. In the case of a level having a continuous unrelieved flat base, it is important that the base be not convex. Tests with a level should be carried out in as short a time as possible, and measurements should be repeated in the reverse direction in order to take account of temperature variations which can occur between the initial and final readings. As their glass tubes are liable to deform with age, spirit levels should be recalibrated at regular periods. The date of each calibration should be given on the levels calibration sheet.
17	Example of figures	See Figure 38



Key

L foot length

Figure 38 — Precision level

11.2.2 Electronic level

1	Name of instrument	Electronic level
2	Description	Hanging pendulum with damping device inclines according to gravity. Its inclination angle is detected by linear displacement sensor or angle encoder.
3	Example size	100 mm × 150 mm × 45 mm
4	Example measuring range	±19,99 mm/m or 1,999 mm/m
5	Example MPE or linearity	20 % of reading
6	Example of reduced (corrected) MPE at specific points	—
7	Example resolution	0,01 mm/m or 0,001 mm/m
8	Example repeatability	0,001 mm/m
9	Frequency response	Less than 3 s
10	Measuring force or load	—
11	Operating environment	0 °C approximately 40 °C
12	Long-term stability of reading	0,01°/°C
13	Equivalent thermal expansion coefficient and in µm/(m°C)	11
14	Related standards	—
15	Reference to ISO 230 series	See ISO 230-1:2012, 8.1

16	Uncertainty of measurement	Major contributors: see Table D.4
		EXAMPLE: —
17	Remark	Electronic levels, in comparison with precision levels, are more sensitive, respond faster and can be interfaced to automatic plotting devices, are much affected by human body temperature. It is important that the magnification be periodically calibrated using a sine bar to tilt it through a known angle. Some electronic levels are adversely affected by magnetic force, e.g. magnetic chucks or magnetic dial indicator bases. Ensure that the surface at 90° to the direction of measurement is level within the instrument manufacturer's specification. When checking for absolute level, two readings with the level should be taken, the second being made after the level has been rotated through 180°. The two readings should be algebraically added together and divided by two, to provide the mean reading. When making a topographical survey, it is important to know the foot distance, *L*, between the middle of the support points, and to take readings by moving the level and its support in increments of *L* between each reading, ensuring that the trailing foot occupies the same point that the leading foot occupied during the previous reading.
18	Example of figures	See Figure 39

a) 1D Electronic level **b) 2D Electronic level**

Figure 39 — Electric level

11.2.3 Inclinometer

1	Name of instrument	Inclinometer
2	Description	Hanging pendulum with damping device inclines according to gravity. Its inclination angle is measured by grating, or an angle encoder up to 45°.
3	Example size and weight	100 mm × 75 mm × 30 mm; 0,5 kg

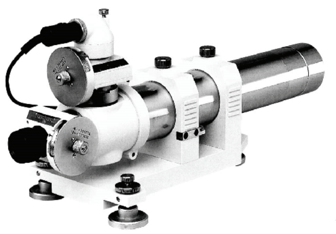
4	Example measuring range	±45°
5	Example MPE or linearity	2′
6	Example resolution	0,02 mm/m
7	Repeatability	—
8	Frequency response	Less than 2 s
9	Measuring force or load	—
10	Operating environment	0 °C to 40 °C
11	Long-term stability of reading	0,01°/°C
12	Equivalent thermal expansion coefficient in µm/(m °C)	11
13	Related standards	—
14	Reference to ISO 230 series	See ISO 230-1:2012, 8.1
15	Uncertainty of measurement	Major contributors: see Table D.4
		EXAMPLE: —
16	Remarks	—
17	Example of figures	—

11.3 Autocollimators

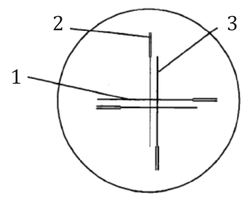
11.3.1 Autocollimator

1	Name of instrument	Autocollimator
2	Description	Target wires take the place of the light source and these are illuminated by a lamp and condenser at the side, the light being reflected along the optical axis by a transparent reflector. Parallel beam hit the mirror the inclination of which is to be measured. The reflected parallel beam is then focused on the eyepiece graticule to produce the image of the target graticule. A rotation of the target mirror (mounted on the moving component) around a horizontal axis, orthogonal to the optical axis, entails a vertical displacement of the image of the reticule in the focal plane. The measurement of this displacement, which is made with the ocular micrometer, allows determining the angular deviation of the mirror. NOTE Photo-electric autocollimator and laser autocollimator have the same principle. The reading device is different from the manual autocollimator.
3	Example size and weight:	60 mm diameter × 420 mm length: 5 kg
4	Example measuring range	9 m
5	Example MPE or linearity	The micrometer drum is graduated in half-seconds, and with a good reflecting surface it is possible to obtain repeat readings to within 1/4 arc second.
6	Example resolution	0,1″
7	Example repeatability	—
8	Frequency response	—
9	Measuring force or load	None
10	Operating environment	Workshop conditions
11	Long-term stability of reading	—

12	Equivalent thermal expansion coefficient in µm/(m °C)	—
13	Related standards	JIS B 7538
14	Reference to ISO 230 series	ISO 230-1:2012, 8.4.2.2, 9.2.1.1, and 12.1.3.2
15	Uncertainty of measurement	Major contributors: see Table D.4
		EXAMPLE: —
16	Remarks	During measurements, the autocollimator telescope should be made integral with the component bearing on the line to be checked, and should be mounted on a steady rigid support. Mirror is mounted on the line to be measured. Any deflection of the machine should be noted. It is important to avoid vibrations or rapid changes of temperature. A kind of optical instrument
17	Example of figures	See Figure 40



a) Autocollimator



b) Field of view of autocollimator

Key

1 eyepiece graticule cross lines

2 twin setting lines

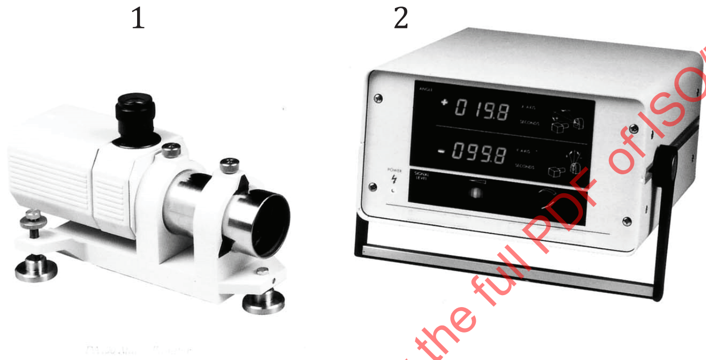
3 reflected image of target graticule

Figure 40 — Autocollimator

11.3.2 Photo-electric autocollimators

1	Name of instrument	Photo-electric autocollimator
2	Description	Photo-electric autocollimator; Electric devices which can detect the image position of the wires is involved in the auto collimator (see Figure 40 b). Because of its high sensitivity and wide range of capabilities, simultaneous X and y-axis angle changes can also be read out with one setting.
3	Example size and weight:	60 mm diameter × 500 mm length: 5 kg
4	Typical measuring range	±20″
5	Typical MPE or linearity	0,1 % to 0,05 % of full scale range
6	Resolution	0,1 to 0,01″
7	Repeatability	Depends on environmental conditions
8	Frequency response	30 Hz (at 0,1″); 1 000 Hz (at 1″)

9	Measuring force or load	—
10	Operating environment	Workshop conditions
11	Long-term stability of reading	0,2″/m for 1 °C gradient
12	Equivalent thermal expansion coefficient in µm/(m °C)	—
13	Related standards	JIS B 7538
14	Reference to ISO 230 series	ISO 230-1:2012, 8.4.2.2, 9.2.1.1, and 12.1.3.2
15	Uncertainty of measurement	Major contributors: see Table D.4
		EXAMPLE: —
16	Remarks	A kind of optical instrument
17	Example of figures	See Figure 41



Key

1 photo-electric collimator head

2 reading device

Figure 41 — Photo-electric autocollimator

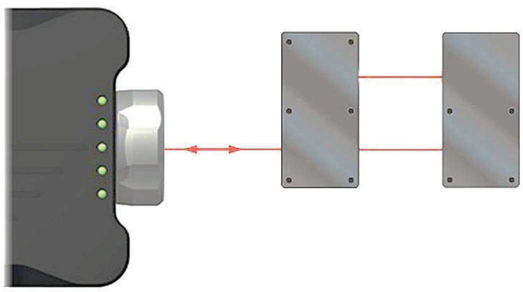
11.3.3 Laser autocollimators

1	Name of instrument	Laser autocollimators
2	Description	See 11.3.2

11.4 Laser interferometer with angular optics

1	Name of instrument	Laser interferometer with angle measuring device
2	Description	For angular measurement to take place, there needs to be a rotation of one optical component (the angular reflector) with respect to the other (the angular interferometer). This causes a change in the path difference between the two measurement beams, as described below. This change in path difference is determined by the fringe-counting circuitry in the laser and is converted to an angular measurement, or angular error, by the software. The angular interferometer is placed in the beam path between the laser head and the angular reflector. The side of the angular interferometer with two optical faces face away from the laser head, towards the reflector. For pitch measurements along a horizontal axis, both optical components are mounted vertically; for yaw measurements, they are both mounted horizontally. The laser beam is split into two by the beam-splitter contained within the angular interferometer. One part of the beam passes straight through the interferometer and is reflected from one half of the angular reflector back to the laser head. The other beam passes through the periscope of the angular interferometer to the other half of the angular reflector, which returns it through the interferometer to the laser head. Angular measurements are achieved by comparing the path difference between the beams, (i.e. measurement is independent both of the distance between the laser and the angular interferometer and of the distance between the angular interferometer and the angular reflector).
3	Typical size and weight	70 mm × 70 mm × 40 mm; 200 g, both reflector and interferometer optics
4	Example measuring range	0 m to 15 m; ±175 mm/m
5	Example MPE or linearity	1,2 % of full scale
6	Example resolution	0,01″
7	Example repeatability	—
8	Frequency response	—
9	Measuring force or load	—
10	Operating environment	Workshop conditions
11	Long-term stability of reading	—
12	Equivalent thermal expansion coefficient in µm/(m °C)	—
13	Related standards	—
14	Reference to ISO 230 series	ISO 230-1:2012, 8.4.2.3, 12.1.3.3 and 12.2.5.4

15	Uncertainty of measurement	Major contributors: see Table D.4
		EXAMPLE: —
16	Remarks	Correction of environmental influences is of small importance. Variable conditions are still of concern. Tilt angle other than the measuring target can affect measurement uncertainty. A kind of optical instrument
17	Example of figures	See Figure 42



Key

1 laser head

2 interferometer

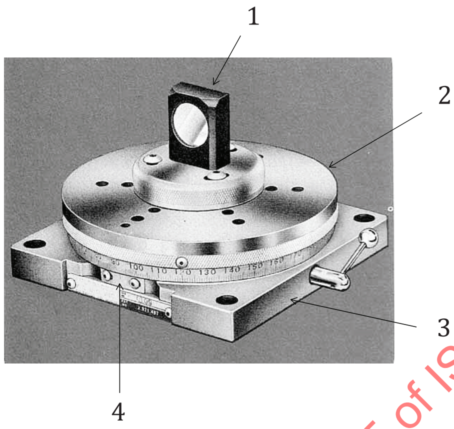
3 angle optics

Figure 42 — Laser interferometer with angle measuring device

11.5 Reference indexing table with optical angle reading device

1	Name of instrument	Reference indexing table (Mechanical polygon)
2	Description	—
3	Example size and weight	130 mm × 130 mm × 30 mm; 0,6 kg
4	Measuring range	360°
5	MPE or linearity (recommended)	0,5″ to 2″
6	Example of reduced (corrected) MPE at specific points	—
7	Example resolution or step	360/12; 360/8; 360/4
8	Example repeatability	0,1″
9	Frequency response	—
10	Materials	Steel
11	Operating environment	Workshop conditions
12	Long-term stability of reading	—
13	Equivalent thermal expansion coefficient in µm/(m °C)	Equal to steel
13	Related standards	—
14	Reference to ISO 230 series	ISO 230-1:2012, 9.2.1.1 and 10.3.2.3

15	Uncertainty of measurement	Major contributors: see Table D.4
		EXAMPLE: —
16	Remark	Setting tilt angle effect, see Bibliographic reference[26]
17	Example of figures	See Figure 43



Key

1 target mirror

2 index table

3 body

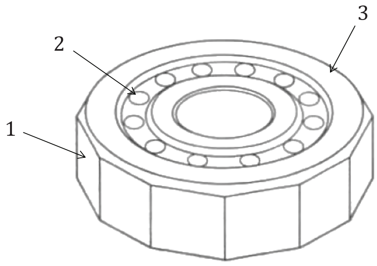
4 angle reading point

Figure 43 — Reference indexing table (mechanical polygon)

11.6 Optical polygon with optical reading device

1	Name of instrument	Optical polygon
2	Description	—
3	Example size and weight:	130 mm × 130 mm × 30 mm; 0,2 kg Reflection surface area: 30 mm × 20 mm
4	Measuring range	360°
5	MPE or linearity (recommended)	2″ (depending on autocollimator)
6	Example of reduced (corrected) MPE at specific points (µm)	0,2“
7	Example resolution or step	360/12; 360/8; 360/4
8	Example repeatability	Depends on autocollimator
9	Frequency response	—
10	Materials	Crown, quartz glass
11	Operating environment	20 °C ± 5 °C
12	Long-term stability of reading	—
13	Equivalent thermal expansion coefficient in µm/(m °C)	Equal to glass materials
14	Related standards	JIS B7432
15	Reference to ISO 230 series	ISO 230-1:2012, 9.2.1.1 and ISO 230-2

16	Uncertainty of measurement	Major contributors: see Table D.4
		EXAMPLE: —
17	Remarks	A kind of optical instrument
18	Example of figures	See Figure 44



Key

1 reference mirror surfaces

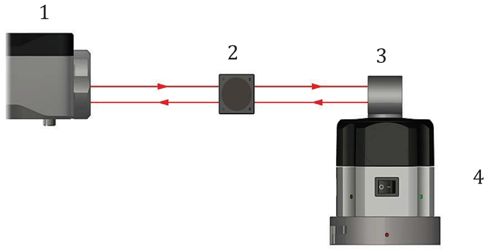
2 angle identity number

3 reference surface

Figure 44 — Optical polygon

11.7 Laser assisted index device

1	Name of instrument	Laser assisted index
2	Description	—
3	Example size	180 mm × 140 mm × 65 mm;
4	Example measuring range	360°, ± 10°
5	Example MPE or linearity	2″
6	Example resolution	0,01″
7	Example repeatability	0,2″
8	Frequency response	—
9	Measuring force or load	Normal load: 5 kg
10	Operating environment	Workshop conditions
11	Long-term stability of reading	—
12	Equivalent thermal expansion coefficient in µm/(m °C)	Equal to steel
13	Related standards	—
14	Reference to ISO 230 series	ISO 230-1:2012, 9.2.1.2
15	Uncertainty of measurement	Major contributors: see Table D.4
		EXAMPLE: —
15	Remarks	Motorized index. Controlled by PC A kind of optical instrument
16	Example of figures	See Figure 45

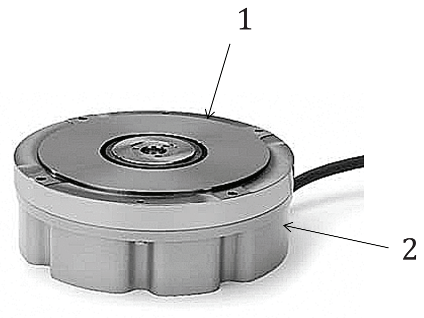


Key
1 laser head
2 angular interferometer
3 angular reflector
4 angle indexing device

Figure 45 — Laser assisted index

11.8 Reference angle encoders

1	Name of instrument	Rotary encoder
2	Description	—
3	Example size and weight:	150 mm diameter. × 50 mm height
4	Measuring range	360°
5	Example MPE or linearity	1″
6	Example of reduced (corrected) MPE at specific points in µm	—
7	Example resolution	0,1″ to 10″
8	Repeatability	0,2″
9	Example frequency response	100 kHz at interface output signal
10	Measuring force or load	—
11	Operating environment	Workshop conditions
12	Long-term stability of reading	—
13	Equivalent thermal expansion coefficient in µm/(m °C)	—
14	Related standards	—
15	Reference to ISO 230 series	ISO 230-1:2012, 9.2.1.3
16	Uncertainty of measurement	Major contributors: see Table D.4
		EXAMPLE: —
17	Remarks	Two rotary encoders with data processing system can be used for gear hobbing machine accuracy check. A kind of optical instrument
18	Example of figures	See Figure 46



Key

1 rotating unit surface

2 main body

Figure 46 — Rotary encoder

12 Special purpose instruments

12.1 General

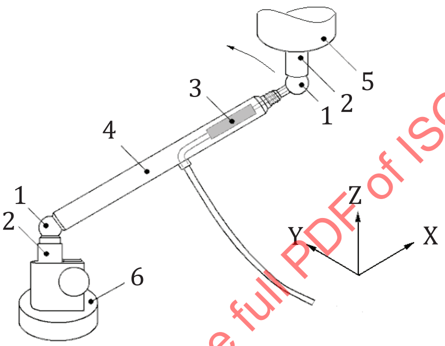
Special purpose instruments are designed for limited application. These are specially designed hardware and general sensors, special test rig or fixture and software. For uncertainty contributors, see also Table D.5.

12.2 Single dimensional position reading device

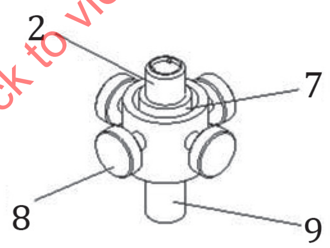
12.2.1 Telescoping ball bar

1	Name of instrument	Telescoping ball bar
2	Description	A telescoping bar, integrated with a linear displacement sensor and having a ball at each end, is attached to machine tool side and workpiece side. Relative displacements between the balls are continuously measured, recorded and plotted. The instrument can be applicable to the measurement of circular deviation, and squareness between two straight motions.
3	Example size and weight:	Nominal length 100 mm to 300 mm
4	Example measuring range	1,6 mm
5	Example MPE or linearity	1,6 µm of full scale
6	Example resolution	0,1 µm
7	Repeatability	—
8	Frequency response	300 samples/s
9	Measuring force or load	—
10	Operating environment	0 °C to 50 °C
11	Long-term stability of reading	10 000 revolutions under normal use
12	Equivalent thermal expansion coefficient	(0 ± 0,03) ppm/°C
13	Related standards	—

14	Reference to ISO 230 series	ISO 230-1:2012, 11.2.4.1.3, 11.2.5.2 and ISO 230-4
15	Uncertainty of measurement	Major contributors: see Table D.5
		EXAMPLE: —
16	Remarks	In the case of partial arc measurement, centring process can be important. Special centring device [see Figure 47 b)] can be useful. Reversal method (rotate magnetic socket to change contact position) can be useful to check the contact surface accuracy.
17	Example of figures	See Figure 47



a) Telescoping ball bar



b) Precision centring device

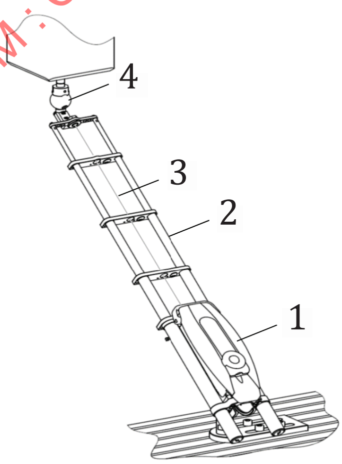
Key

1 sphere
2 magnetic socket
3 linear displacement sensor
4 telescoping bar
5 machine spindle
6 mounting support (table side)
7 magnet holder
8 centring adjust screw
9 stem to chuck

Figure 47 — Telescoping ball bar

12.2.2 Long range telescoping ball bar

1	Name of instrument	Long range telescoping ball bar
2	Description	A telescoping bar, integrated with a linear displacement sensor and having a ball at each end, attached to machine tool side and workpiece side. Relative displacement is continuously measured and recorded typically by an interferometer. Instrument is suitable for indirect measurement of linear and rotary axis based on multilateration as well as for circular testing.
3	Example size and weight:	40 mm × 80 mm × 350 mm; 2 kg
4	Example measuring range	250 mm to 1 000 mm (ball to ball)
5	Example MPE or linearity	1 µm of full scale
6	Example resolution	0,01 µm
7	Repeatability	0,5 µm
8	Frequency response	1 000 samples/s
9	Measuring force or load	<1 Nm (with reversal movement)
10	Operating environment	10 °C to 40 °C
11	Long-term stability of reading	—
12	Equivalent thermal expansion coefficient in µm/(m °C)	See laser interferometer
13	Related standards	—
14	Reference to ISO 230 series	ISO 230-1:2012, 11.7.5 and ISO 230-4
15	Uncertainty of measurement	Major contributors: see Table D.5
16	Remarks	Mechanical repeatability of magnetic cups crucial
17	Example of figures	See Figure 48



Key

1 interferometer

2 telescope

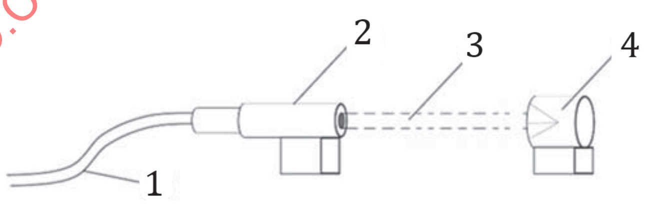
3 measuring beam

4 sphere with reflector

Figure 48 — Long range telescoping ball bar

12.2.3 Fibre interferometer

1	Name of instrument	Absolute fibre interferometer
2	Description	Interferometer with absolute measuring capability. The beam can recover absolute distance after interruption. Technology is, for example, based on frequency scanning lasers with passive optical sensor heads. Systems are typically capable of driving multiple sensors. Measurement is performed in intervals. Real time capability is not provided.
3	Example size and weight:	Instrument: 800 mm × 400 mm × 600 mm: 25 kg Sensor: diameter: 8 mm, length: 25 mm, weight: 20 g
4	Example measuring range	0,02 m to 30 m
5	Example MPE or linearity	0,5 µm/m
6	Example resolution	0,1 µm
7	Repeatability	0,2 µm/m
8	Frequency response	up to 2 000 000 samples/s
9	Measuring force or load	0
10	Operating environment	10 °C to 40 °C
11	Long-term stability of reading	—
12	Equivalent thermal expansion coefficient [µm/(m °C)]	See laser interferometer (7.2.1)
13	Related standards	—
14	Reference to ISO 230 series	—
15	Uncertainty of measurement	Major contributors: see Table D.5 (interferometer)
16	Remarks	Long fibre length is possible, especially suitable for deformation monitoring and regular geometric verification. A kind of optical instrument
16	Example of figures	See Figure 49



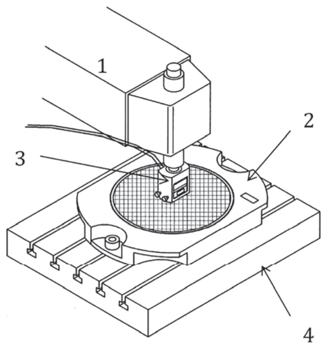
Key
1 optical fibre
2 beam launch
3 measuring beam
4 retro reflector

Figure 49 — Absolute fibre interferometer

12.3 Multi-dimensional position reading device

12.3.1 Two-dimensional digital scale

1	Name of instrument	Two-dimensional digital scale
2	Description	Reference grid encoder is placed on the machine workpiece side, and two-dimensional scale detectors are attached to the tool side. Relative motion between these is continuously recorded and plotted.
3	Example size and weight:	Maximal nominal diameters: 320 mm
4	Example measuring range	300 mm
5	Example MPE or linearity	2 µm
6	Resolution	0,004 µm to 0,1 µm
7	Repeatability	—
8	Frequency response	2 000 samples/s
9	Measuring force or load	Non-contact
10	Operating environment	0 °C to 50 °C
11	Long-term stability of reading	Depends on thermal stability
12	Equivalent thermal expansion coefficient	(8 ± 0,03) ppm/°C
13	Related standards	—
14	Reference to ISO 230 series	ISO 230-1:2012, 11.2.4.1.4
15	Uncertainty of measurement	Major contributors: see Table D.5
		EXAMPLE: —
16	Remarks	The device can be applied to straightness and squareness measurements. A kind of optical instrument
17	Example of figures	See Figure 50



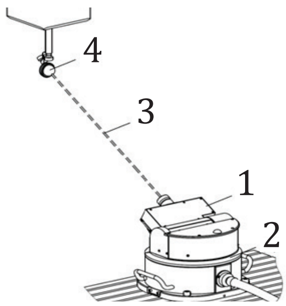
Key

1 machine spindle head
2 grid plate
3 reading head
4 machine table

Figure 50 — Two-dimensional digital scale

12.3.2 Laser tracing system

1	Name of instrument	Tracking interferometer
2	Description	This is an interferometer with servo drives that automatically direct the measurement beam to a reflector mounted on the spindle. Relative displacements are recorded by an interferometer. Instrument is suitable for indirect measurement of linear and rotary axis based on multilateration as well as for circular testing.
3	Example size and weight:	Tracking interferometer: 200 mm × 200 mm × 200 mm, 10 kg Reflector: 20 mm to 40 mm diameter, 60 g to 300 g
4	Example measuring range	0,2 m to 20 m
5	Example MPE or linearity	0,2 µm + 0,3 µm/m
6	Example resolution	0,01 µm
7	Repeatability	0,1 µm
8	Frequency response	1 000 samples/s
9	Measuring force or load	0
10	Operating environment	10 °C to 40 °C
11	Long-term stability of reading	—
12	Equivalent thermal expansion coefficient in µm/(m °C)	See laser interferometer (7.2.1)
13	Related standards	—
14	Reference to ISO 230 series	ISO 230-1:2012, 11.7.5 and ISO 230-6
15	Uncertainty of measurement	Major contributors: see Table D.5
		EXAMPLE: —
16	Remarks	Used also for coordinate measuring machines A kind of optical instrument
17	Example of figures	See Figure 51



Key

1 interferometer
2 tracking drives
3 measuring beam
4 retro reflector

Figure 51 — Tracking interferometer

12.3.3 3D-probe for spheres (contact type)

1	Name of instrument	3D-probe head for spheres, contact type
2	Description	The probe head contains three orthogonal sensors that determine simultaneously the X, Y and Z position of precision sphere.
3	Size	Length: 56 mm, diameter: 75 mm
4	Weight	375 g
5	Measuring range	1 mm in X, Y and Z
6	Sample rate	6,5 kHz (X, Y and Z)
7	Resolution	0,1 µm
8	Mounting shaft diameter	16 mm
9	Cable length (probe – interface unit)	5 m
10	Bandwidth	150 Hz (relevant for dynamic R-test application)
11	Operating environment	15 °C to 30 °C; Workshop conditions
12	Related standards	—
13	Reference to ISO 230 series	ISO 230-2, ISO 230-10:2016, 6.8, 6.9 and 6.10
14	Uncertainty of measurement	Major contributors: see Table D.5 EXAMPLE: Value for uncertainty U = 1,2 µm [$U(k = 2)$]: — Roundness error of reference ball < 0,6 µm (grade 10 or better); — Diameter variation < 2,5 µm.
15	Remarks/applications	This probe head is used in combination with: a) a single reference ball; b) a ball beam/ball plate (i.e. artefact with balls). A single reference ball is used for the R-test (rotary axes). This R-test enables the determination of allocation errors and squareness errors of rotary axes as well as dynamic error motions of the R-axis (i.e. radial, tangential and axial error motions). Measurements can be executed statically and/or dynamically. A 1D-ball array or ball beam is used for measuring linear axes of a machine tool. This enables the simultaneous determination of positioning and both straightness errors of a linear axis. 2D-ball arrays (i.e. a ball plate) can also be used in combination with this 3D-probe head.
16	Example of figures	See Figure 52

Figure 52 — 3D-probe head for spheres, contact type

12.3.4 3D-probe head, non-contact type

1	Name of instrument	3D-probe head for spheres, non-contact type
2	Description	The probe head contains three orthogonal sensors that determine simultaneously the X, Y and Z position of a precision sphere without any contact.
3	Size	Length: 130 mm, Diameter: 80 mm
4	Weight	770 g
5	Measuring range	3,5 mm in X, Y and Z
6	Sample rate	2 kHz (X, Y and Z)
7	Resolution	0,2 µm
8	Mounting shaft diameter	16 mm
9	Data transmission	USB data receiver (2,4 GHz, WPA2-security)
10	Operating environment	18 °C to 30 °C; Workshop conditions
11	Related standards	—
12	Reference to ISO 230 series	ISO 230-2, ISO 230-10:2016, 6.8, 6.9, 6.10

