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Technical drawings — Geometrical tolerancing — Tolerancing of form, orientation, location and run-out — Verification principles and methods — Guidelines

Dessins techniques — Tolérancement géométrique — Tolérancement de forme, orientation, position et battement — Principes et méthodes de vérification — Principes directeurs

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ISO/TR 5460 was prepared by Technical Committee ISO/TC 10, *Technical drawings*.

The reasons which led to the decision to publish this document in the form of a Technical Report type 2 are explained in the Introduction.

UDC 744.4 : 621.753.1 **Ref. No. : ISO/TR 5460-1985 (E)**

Descriptors : drawings, technical drawings, tolerances : measurement, dimensional tolerances, form tolerances, tolerances of position, angular tolerances, verification, generalities.

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0 Introduction

In 1972, ISO/TC 10, *Technical drawings*, initiated work on preparing an International Standard on verification principles and methods for geometrical tolerancing. In the early stages of the work it became clear that several alternative verification methods for measuring principles were necessary so as to take account of the different types of workpieces and measuring equipment used. Since there is little experience in the various countries as to how to apply verification principles and methods on geometrical tolerances, it was decided that the results of the work would not be published as an International Standard for the time being.

It was felt, however, that the results of the work should be published in the form of a Technical Report as this could be used as a guide towards understanding how to apply the tolerancing system for form, orientation, location and run-out with respect to varying measurement conditions.

For uniformity all figures in this Technical Report are in first angle projection.

It should be understood that the third angle projection could equally well have been used without prejudice to the principles established.

For the definitive presentation (proportions and dimensions) of symbols for geometrical tolerancing, see ISO 7083.

1 Scope and field of application

1.1 This Technical Report establishes guidelines for verifying geometrical tolerancing as described in ISO 1101. The purpose is to outline the fundamentals of various verification principles which may be used in order to comply with the definitions of ISO 1101. The verification methods described in this Technical Report do not provide for a unique interpretation of the requirements of ISO 1101 and do differ amongst themselves. This Technical Report may, however, be used as a reference document for coordination and agreements in the field of geometrical tolerancing verification. The symbology and methods mentioned are not illustrated in detail and are not intended for application on end-product drawings. (See also 6.4.)

1.2 Not all verification principles are given in this Technical Report for the different types of geometrical tolerances. Within the verification principle one or more verification methods are used. (See clause 6.)

1.3 The numbering of verification principles and methods shall not be regarded as a classification of priority within the prescribed type of geometrical tolerance.

2 References

ISO 1101, *Technical drawings — Geometrical tolerancing — Tolerancing of form, orientation, location and run-out — Generalities, definitions, symbols, indications on drawings.*

ISO 2692, *Technical drawings — Geometrical tolerancing — Maximum material principle.*[1]

ISO 4291, *Methods for the assessment of departure from roundness — Measurement of variations in radius.*

ISO 4292, *Methods for the assessment of departure from roundness — Measurement by two- and three-point methods.*

ISO 5459, *Technical drawings — Geometrical tolerancing — Datums and datum systems for geometrical tolerances.*

ISO 7083, *Technical drawings — Symbols for geometrical tolerancing — Proportions and dimensions.*

1) At present at the stage of draft. (Revision of ISO 1101/2-1974.)

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3 Definitions

3.1 verification principle : Fundamental geometrical basis for the verification of the considered geometrical characteristic.

NOTE — The inspection methods may not always fully check the requirements indicated on the drawing. Whether or not such methods are sufficient and acceptable depends on the actual deviations from the ideal form and on the manufacturing and inspection circumstances.

3.2 verification method : Practical application of the principle by the use of different equipment and operations.

3.3 verification equipment : Technical device necessary for a specific method.

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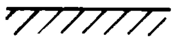
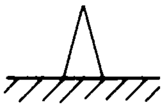
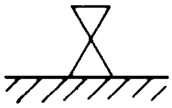
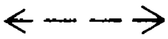
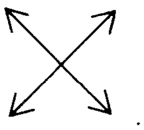
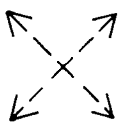
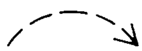
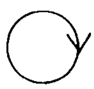
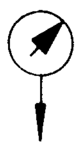
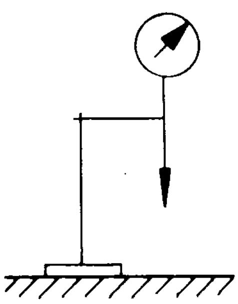
4 Symbols

The symbols shown in table 1 are applied throughout this Technical Report.

Table 1

Symbol		Interpretation
1		Surface plate (Measuring plane)
2		Fixed support
3		Adjustable support
4		Continuous linear traverse
5		Intermittent linear traverse
6		Continuous traverse in several directions
7		Intermittent traverse in several directions
8		Turning
9		Intermittent turning
10		Rotation
11		Indicator or recorder
12		Measuring stand with indicator or recorder Symbols for measuring stands can be drawn in different ways in accordance with the verification equipment used.

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5 Establishment of datums

5.1 Datum indication

The datum indicated on a drawing is a theoretically exact geometric reference from which required characteristics of related features are dimensioned.

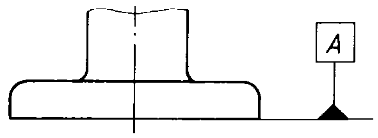
The datum feature is a real feature of a part which is marked on the drawing as a datum.

The choice of datum and toleranced feature shall be made in accordance with the functional requirements. If the verification can be simplified by changing the datum and the toleranced feature, without affecting the functional requirements, such a change could be permitted.

When it is difficult to establish a datum from a datum feature, it may be necessary to use a simulated datum feature.

The datum feature shall be sufficiently accurate in accordance with the functional requirements. It is necessary to take these requirements into consideration in the verification procedure.

The datum feature shall be arranged in such way that the maximum distance between it and the simulated datum feature has the least possible value. Practically, the datum feature shall give a stable contact either by the datum feature itself [see figure 1 a)] or by alignment of the datum feature to a simulated datum feature [see figure 1 b)].



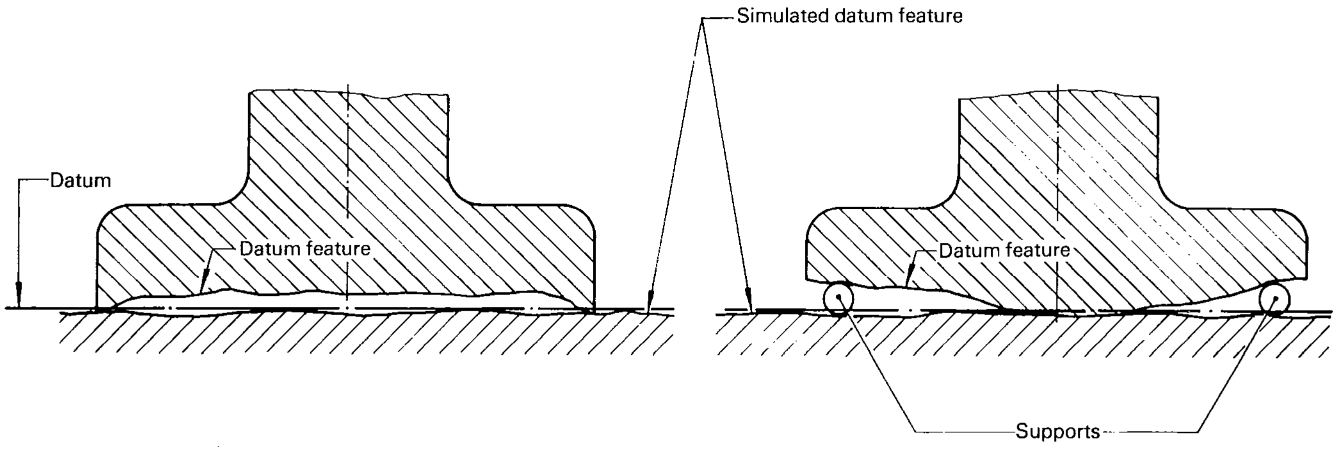


Figure 1 a)

Figure 1 b)

Figure 1 — Contact between datum feature and simulated datum feature

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5.2 A point as the datum

A point as the datum is quite unusual but can be used, for example in connection with position tolerances. However, it is difficult to find out the real datum by establishment of a simulated datum feature. In most cases, the datum is established by a simulated verification equipment (see figure 2).

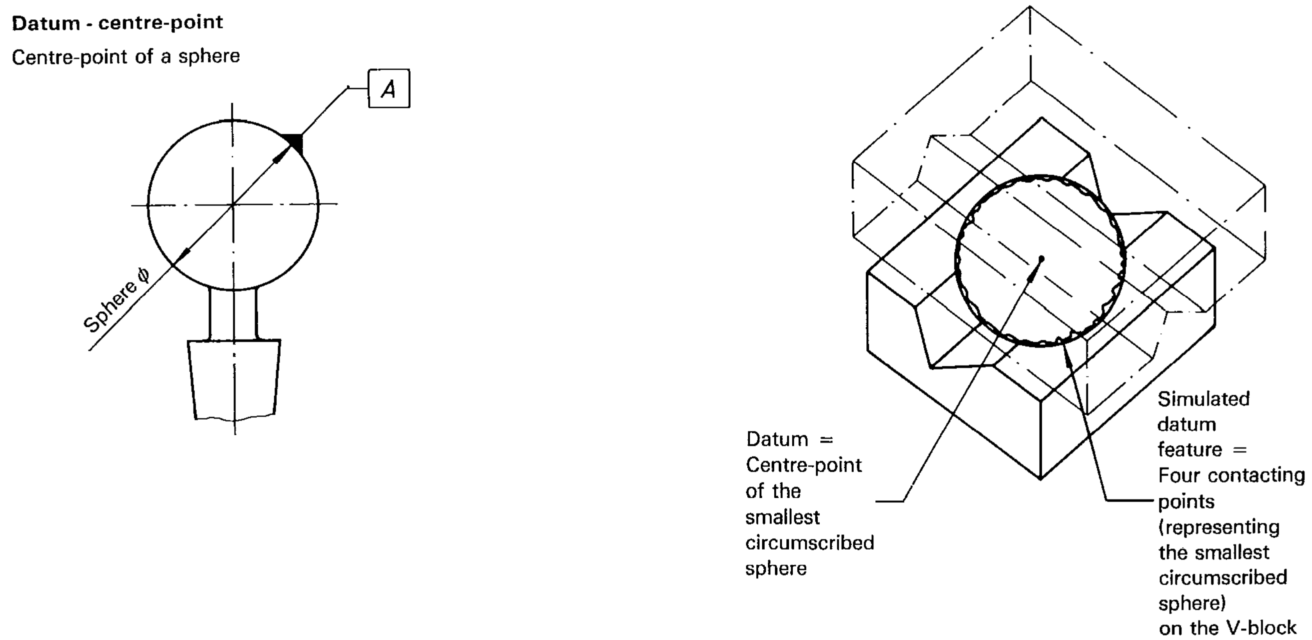

Figure 2 — Establishment of a point as the datum

5.3 A line as the datum

A line as the datum can be an edge, generating line or an axis. The edge and the generating line can be established in accordance with figure 1.

5.3.1 A generating line as the datum

If the datum is a generating line for an internal surface (for example, a hole), the establishment of the simulated datum can be made in a practical way by using a cylindrical mandrel in accordance with figure 3.

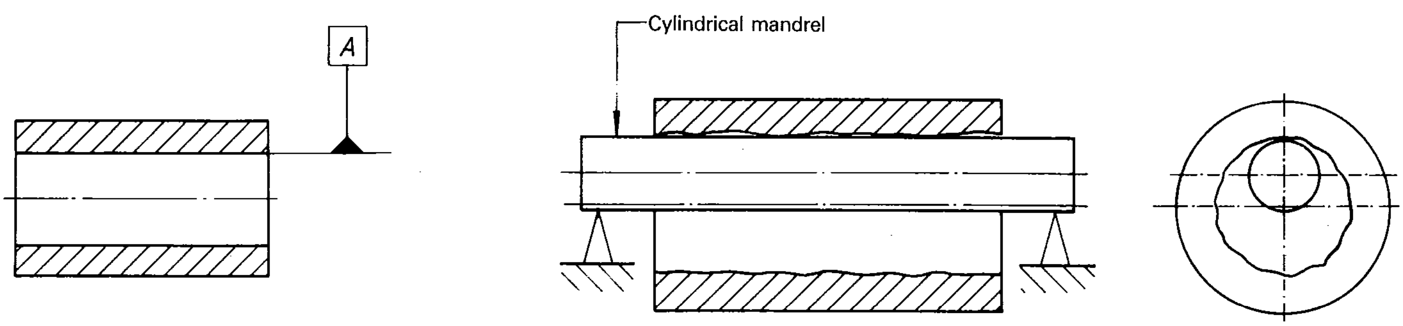

Figure 3 — Practical way of establishing a generating line as the datum

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In some cases, the alignment of datum features is time-consuming and can be replaced by mathematical or graphical evaluation (see figure 4).

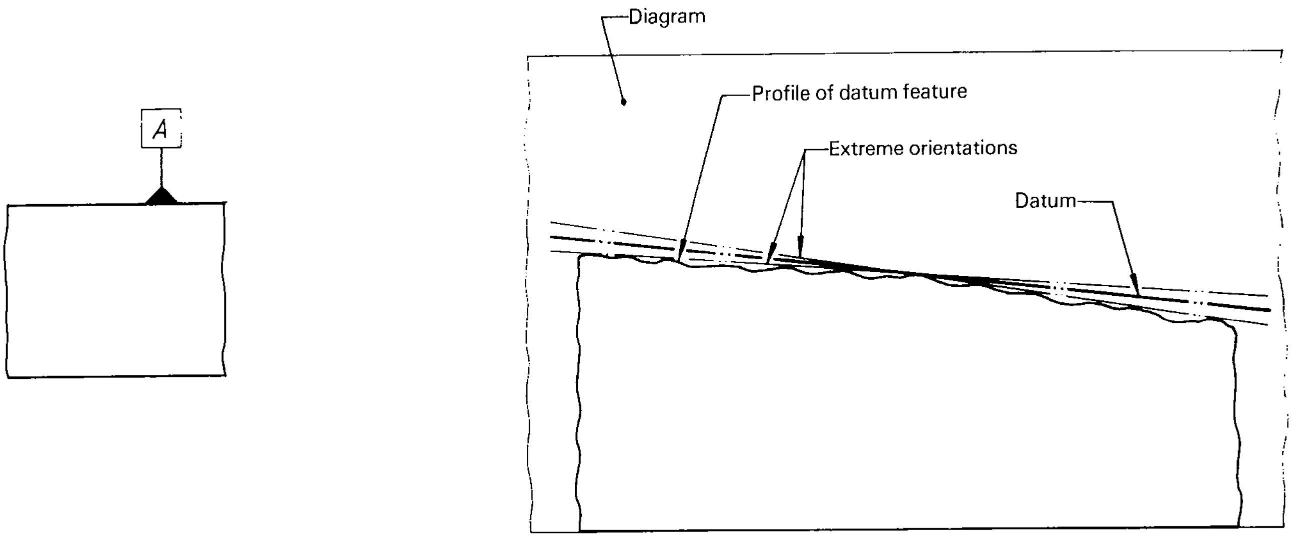

Figure 4 — Profile diagram for graphical evaluation of datum

NOTE — When graphical evaluation is used, the datum and the toleranced feature can be indicated in the same diagram.

5.3.2 An axis as the datum

An axis as the datum is always an unreal feature and shall be established by a simulated datum feature or by mathematical calculation.

An axis as the datum may well be used for both internal and external features.

The datum for an internal feature is usually established by an inscribed feature of a geometrically correct form.

For cylindrical holes, the datum can be established by a cylindrical mandrel of the largest inscribed size or by an expandable mandrel.

If the mandrel cannot achieve a stable position in the hole, the location shall be adjusted in such a way that the possible movement of it in any direction is equalized (see figure 5).

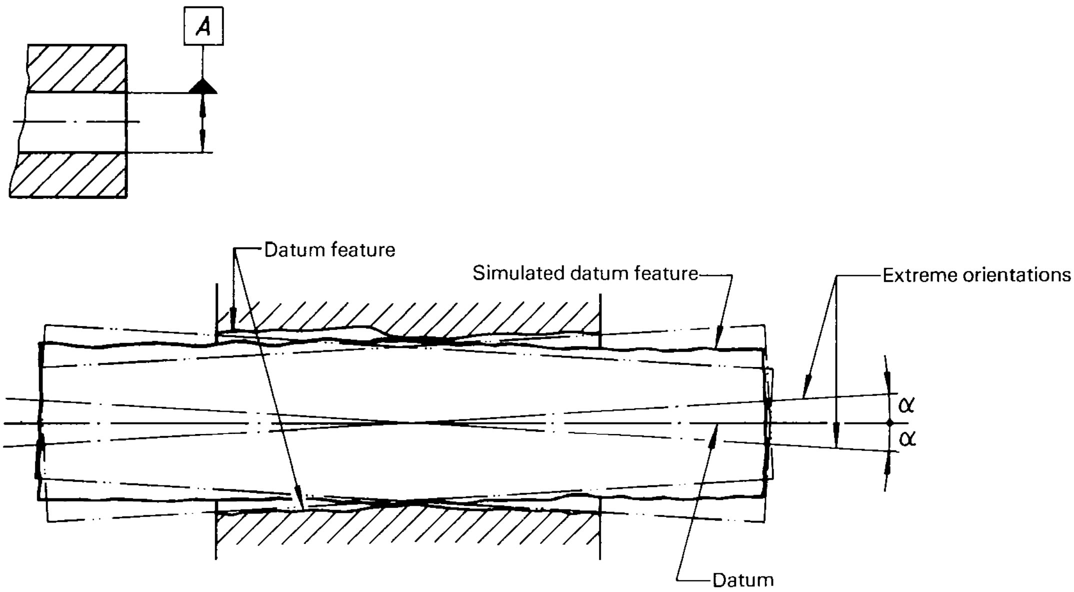

Figure 5 — Alignment of simulated datum feature in a hole

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A simplified way to establish an axis for internal features can be used by aligning it between two coaxial conical features (see figure 6).

In this case, the eventual eccentricity of the chamfer to the hole itself may constitute a serious source of error when establishing the datum.

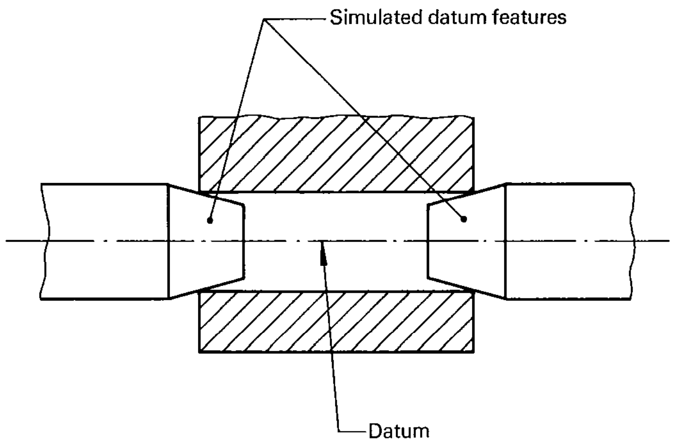

Figure 6 — Simplified alignment of an axis as the datum (internal features)

The datum for an external feature should be established by a circumscribing feature of a geometrically correct form.

For cylindrical shafts, the datum can be established by a cylindrically encircling gauge of the smallest circumscribed size or by a collet chuck.

If the position of the gauge is not stable, it shall be adjusted in such a way that the possible movement of it in any direction is equalized. (Same principle as in figure 5.)

The datum for cylindrical shafts may be established in a simplified way using, for example, V-blocks, V-yokes, L-blocks or L-yokes (see figure 7).

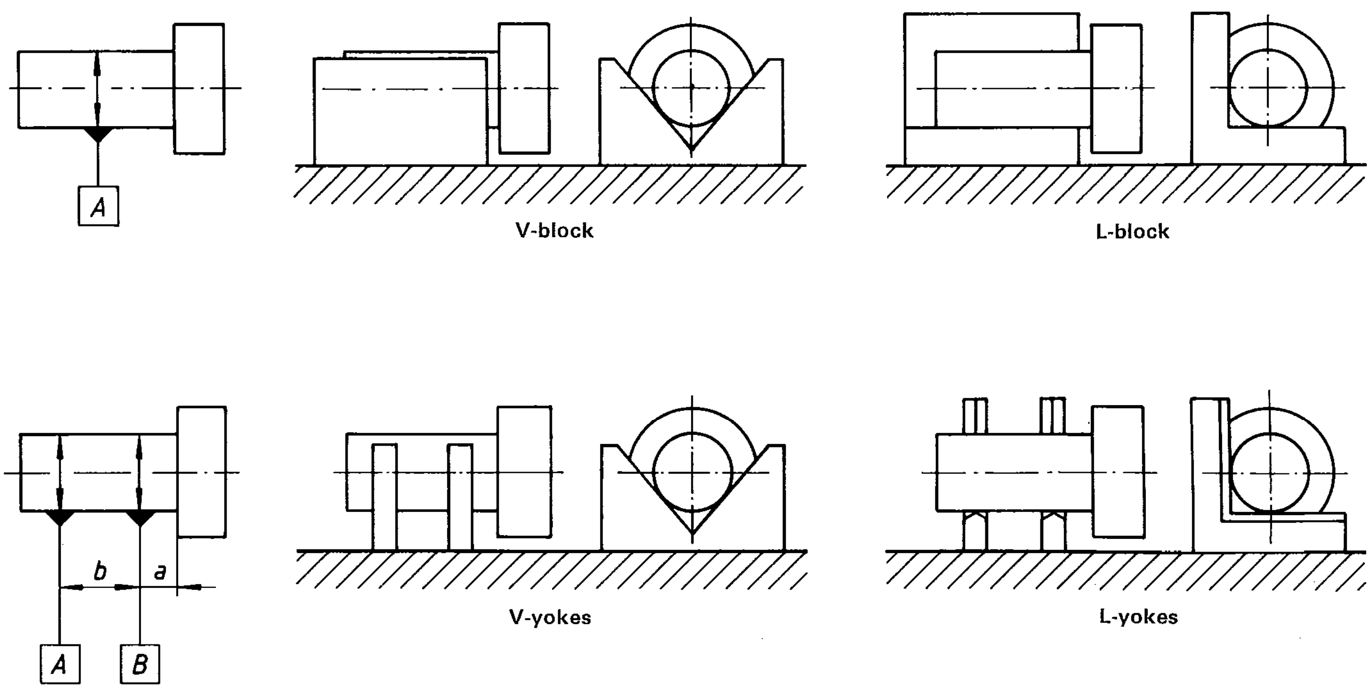

Figure 7 — Simplified alignment of an axis as the datum (external features)

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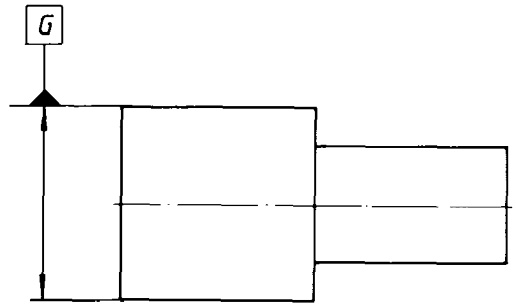
Depending on the form deviations of the datum feature, the angle in the V-block and the V-yokes can affect the position of the datum, which also affects the measured value.

An axis as the datum can also be established by graphical evaluation, for example in accordance with figure 8.



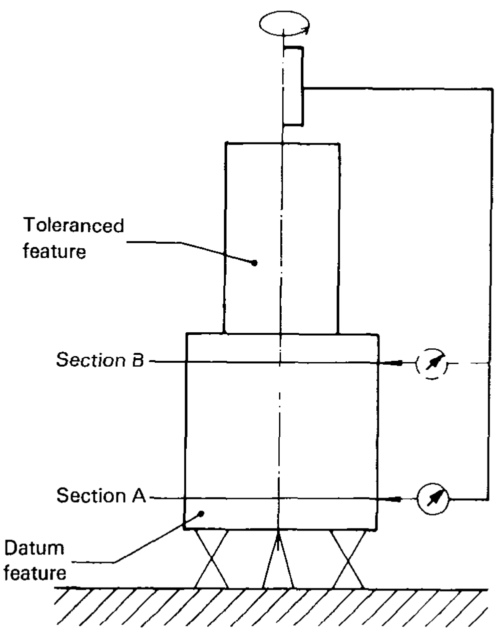


Figure 8a) — Measurement of simulated datum feature from a fixed axis

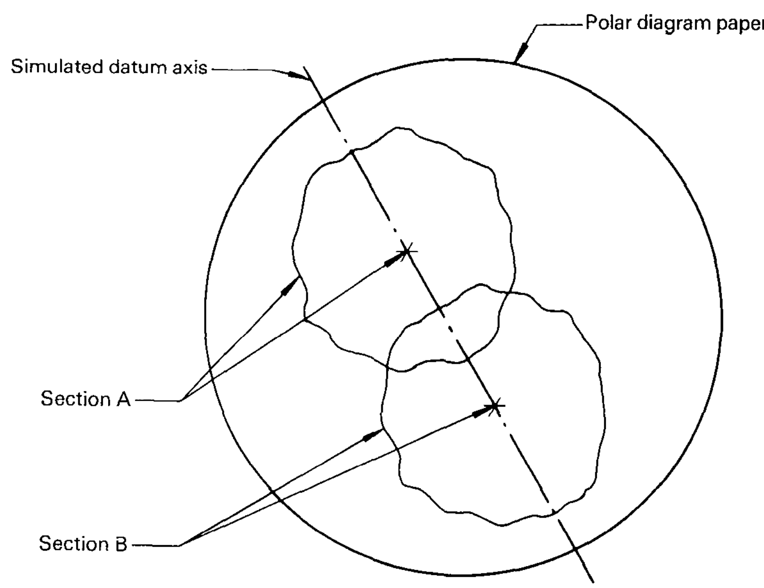


Figure 8b) — Graphical evaluation of the datum axis

5.3.3 A common axis as the datum

In some cases, the datum is a common axis of two separate datums which can be established by internal or external features (inscribed, circumscribing or expandable).

The deviations of form and location of the datum features will affect the position of the common axis which can also affect the toleranced features.

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The guidance of the datum features should be used in such a way that the simulated datum features are coaxial (see figure 9).

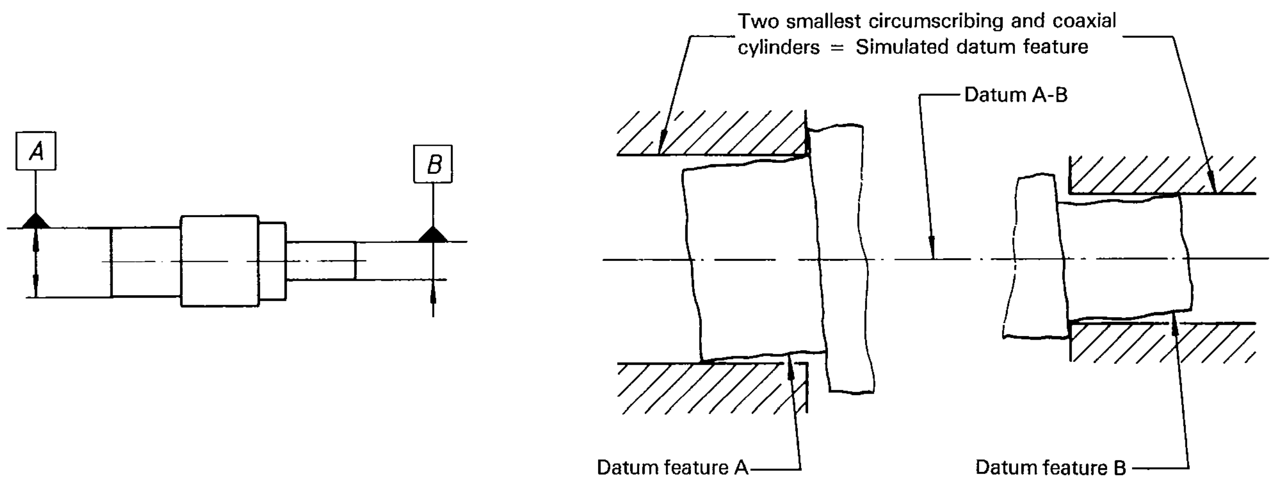

Figure 9 — Guidance of two datum features when the datum is a common axis

As it is difficult to establish a common datum in accordance with the method mentioned above, a simplified method using V-blocks, V-yokes, L-blocks and L-yokes may be used (see also figure 7).

In some cases, the datum can be established by a coaxial pair of conical centres.

It should be noted that the deviations between the centres and the datum shall be added to the measured value of the toleranced feature (see figure 10).

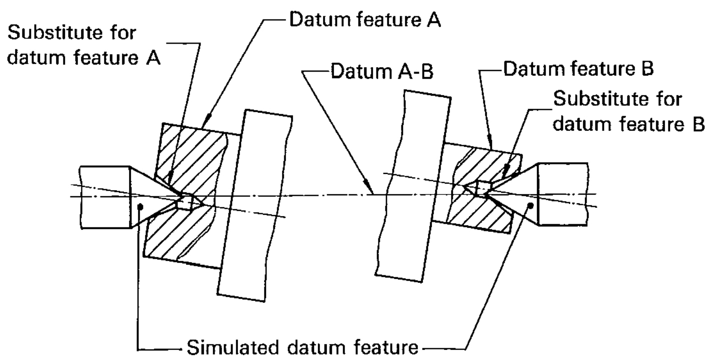

Figure 10 — Conical centres used as substitutes for cylindrical datum features

5.4 A surface as the datum

A surface as the datum can be a plane or have other forms. When the datum is a plane, it can be established in accordance with figure 1.

In practice, the datum will be established in a simplified way by three supports (points) situated as far as possible from each other on the datum feature.

When certain points or surfaces on the drawing are specified as datum targets, these shall be used for the alignment of the simulated datum features.

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5.5 Multiple datums

If the datum consists of two or more datum features, their sequence may be important (see figure 11).

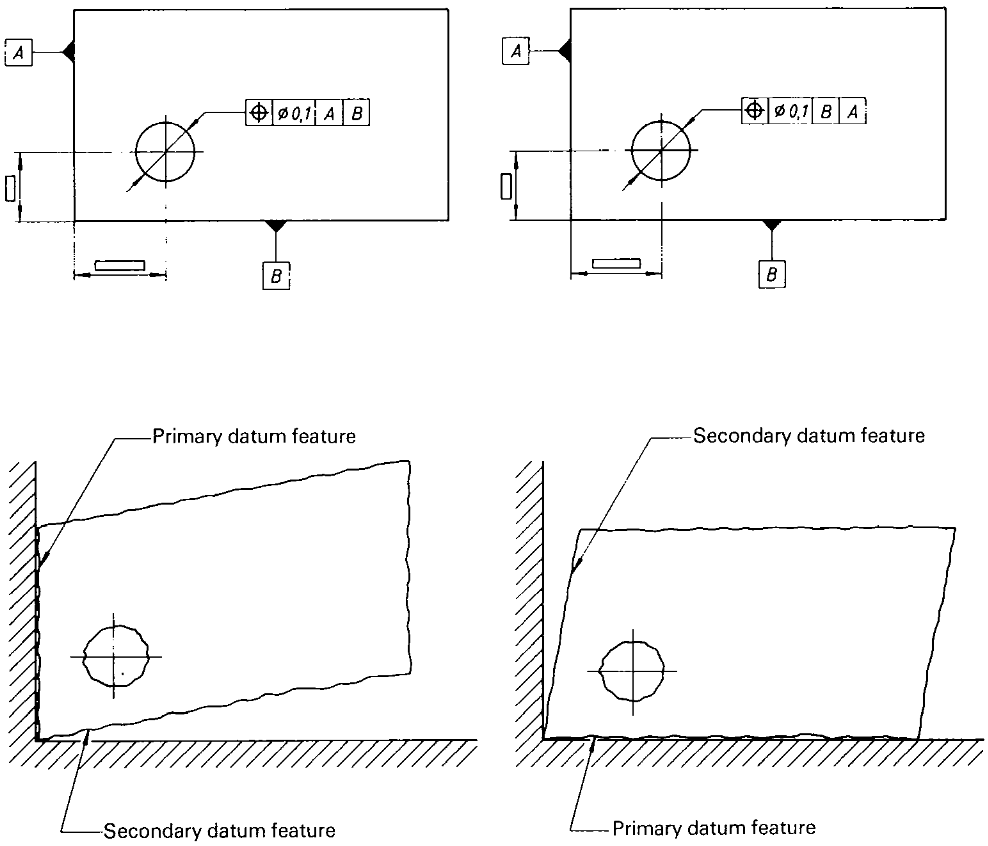

Figure 11 — Influence on the toleranced feature depending on the sequence of the datum features used on the toleranced feature

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If the datum consists of three datum features, it should be noted that the primary datum feature (A) can be aligned in accordance with figure 12a). The secondary datum feature shall be aligned on two points [see figure 12b)] and the tertiary datum feature on one point [see figure 12c)].

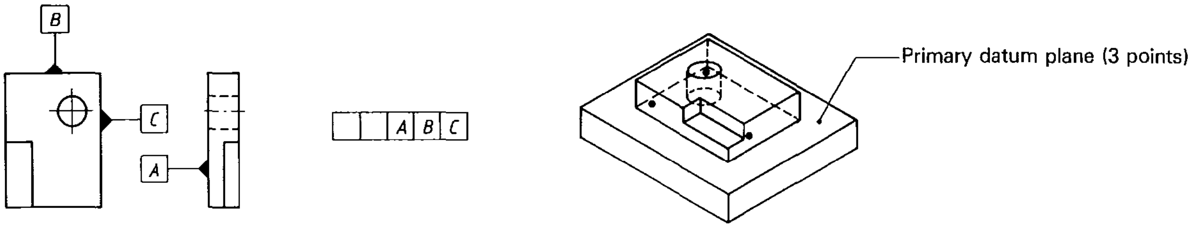

Figure 12a)

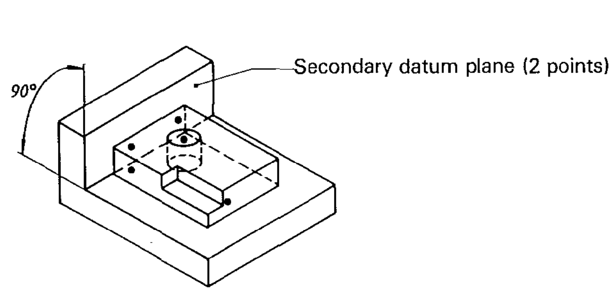

Figure 12b)

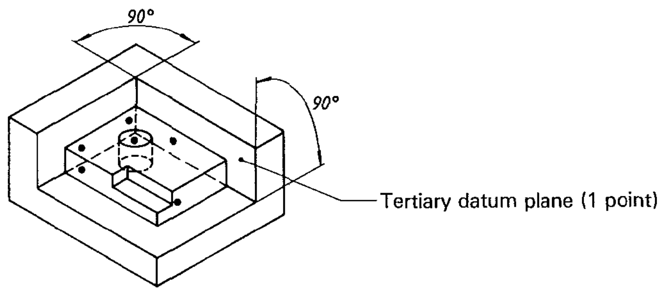

Figure 12c)

Figure 12 — Establishment of three plane datum system

6 Verification principles and methods

6.1 The verification principles and methods are arranged in such a way that for each tolerance characteristic the corresponding verification principles are used as principal headings.

For each verification principle, a number of verification methods are shown in association with particular application examples arranged in order of tolerance zones. For each method, an example of verification equipment is outlined. Comments are added when required.

The resulting tabular arrangement has the following characteristics :

Headings

- Symbol
- Tolerance zone and application example
- Verification method
- Comments

The column "**Symbol**" gives the different geometric characteristics in conformity with ISO 1101.

The column "**Tolerance zone and application example**" shows, firstly, the tolerance zone, in accordance with ISO 1101, and, secondly, an application example which is the same as that shown in ISO 1101. When this example has been considered insufficient in order to illustrate the methods fully, further examples have been added.

The column "**Verification method**" gives

- the number of the method;
- the figure illustrating the verification method;
- the essential characteristics of the verification methods;
- the readings to be taken;
- the required repetitions;
- the treatment of the readings obtained;
- the acceptance criteria associated with the measured value.

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The column "**Comments**" gives supplementary information, for example :

- a particular application;
- any restrictions in application;
- any particular sources of errors;
- any particular requirements as to equipment;
- an example of verification equipment.

6.2 It should be noted that the influence of the following basic verification factors are not included :

- verification equipment accuracy;
- verification performance accuracy;
- design (character) of verification equipment.

These factors may sometimes have a greater influence on the measuring result than the difference between the verification methods described.

6.3 In this Technical Report, the verification principles are exemplified by commonly used verification methods. Most of these methods can be carried out with various verification equipment. The most commonly used equipment is shown, and it can generally be found in workshops. It should be noted that the examples of verification methods do not give complete information about the inspection of the object.

6.4 The numbering adopted in this Technical Report was chosen for easy reference purposes. The clauses for the different geometrical characteristics have been given a number :

- the first digit (starting with 7 for straightness) denotes the geometrical tolerance to be checked;
- the second digit (starting with 1) denotes the verification principle;
- the third digit (starting with 1) denotes the verification method relating to the defined principle.

Verification equipment relevant to the methods is not numbered.

Examples :

Verification method for straightness 1.4 (clause 7) means verification principle for straightness No. 1, method No. 4.

Verification method for parallelism 2.1 (clause 13) means verification principle for parallelism No. 2, method No. 1.

This referencing method is not to be quoted on end-product drawings, because it could be misinterpreted as a modifier of the tolerancing requirements. However, the referencing method may be used on derived or associated documents, as used by manufacturing and inspection departments, etc., as an indication of the method used, for example :

a) straightness, method 7.1.4;

b) parallelism, method 13.2.1.

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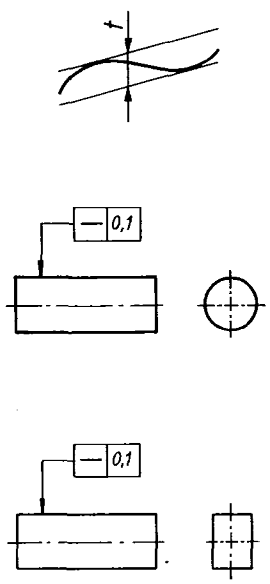
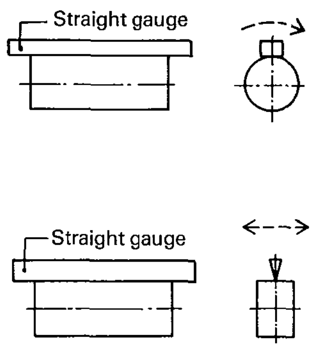
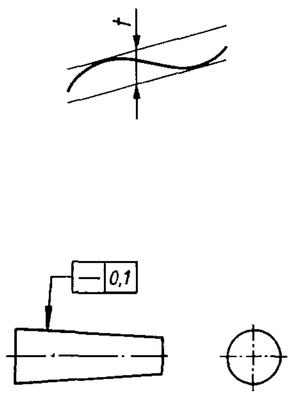
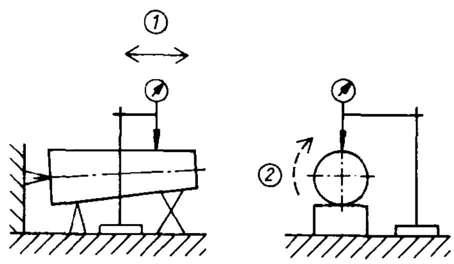
7 Verification of straightness

7.1 Principle 1 — Verifying straightness deviations by comparing with a straight element

Symbol	Tolerance zone and application example	Verification method	Comments
—		**Method 7.1.1**  Place the gauge on the object in such a position that the maximum distance between the gauge and the object is a minimum. The straightness deviation is the maximum distance between the generating line of the object and that of the gauge. Measure the required number of generating lines.	Taut wire could be used for large objects (> 1 m).
		**Method 7.1.2**  Place the object with the upper generating line parallel to the surface plate. Record the measurements along the entire generating line. (1) The straightness deviation is the maximum difference in indicator readings of the measured generating line. Measure the required number of generating lines. (2)	

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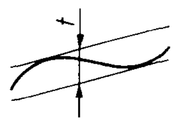
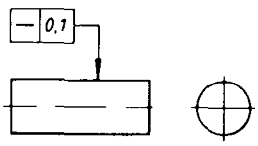
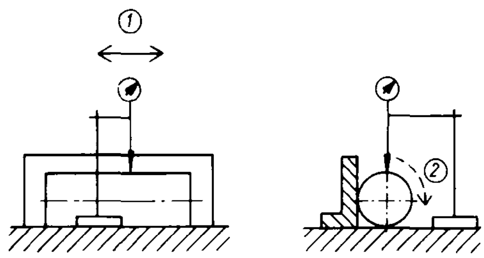
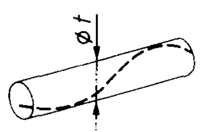
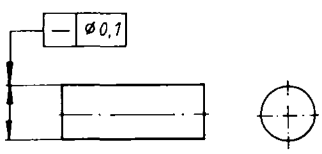
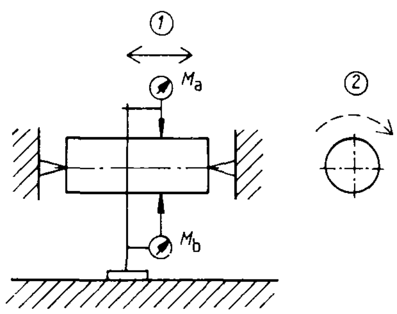
7.1 Principle 1 — Verifying straightness deviations by comparing with a straight element *(continued)*

Symbol	Tolerance zone and application example	Verification method	Comments
—	 	**Method 7.1.3**  Place the object on a surface plate and against a square plate. Take indicator readings along the entire generating lines and transfer them to a diagram. The straightness deviation is evaluated from the diagram. (1) Measure the required number of generating lines. (2)	
	 	**Method 7.1.4**  Clamp the object between two coaxial centres parallel to the surface plate. Record the measurements along the two generating lines. (1) Record half the difference between the two indicator readings at each point in a diagram, that is : $\frac{M_a - M_b}{2}$ The straightness deviation is evaluated from the diagram. Measure the required number of axial sections. (2) The straightness deviation is considered to be the maximum recorded value of any axial section.	

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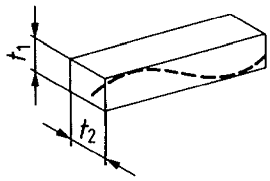
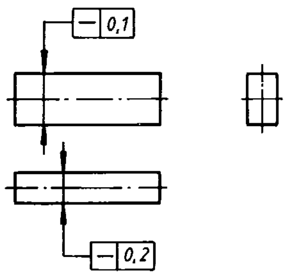
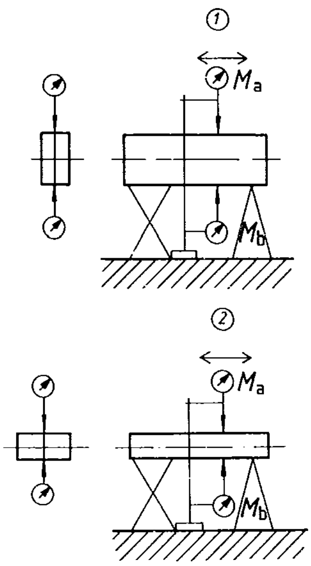
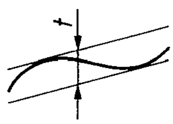
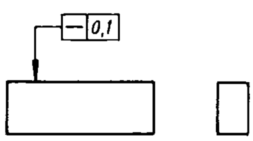
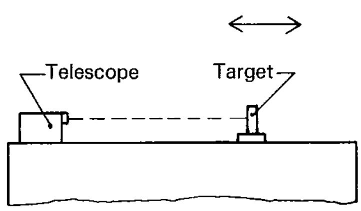
7.1 Principle 1 — Verifiying straightness deviations by comparing with a straight element *(continued)*

Symbol	Tolerance zone and application example	Verification method	Comments
	 	**Method 7.1.5**  Align the object parallel to the surface plate. Record the measurements along the two generating lines. (1) and (2) Record half the difference between the two indicator readings at each point in the diagram, that is : $\frac{M_a - M_b}{2}$ Carry out the measurement in the two specified directions. (1) and (2) The straightness deviation is evaluated from the diagrams.	
	 	**Method 7.1.6**  Align the telescope parallel to the surface. Measure the deviations with a target which is moved along the surface. Transfer the deviations to a diagram and evaluate the straightness from these. Measure the required number of generating lines.	This method is mainly used for large objects. A straightness measuring laser could also be used.

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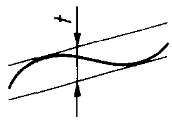
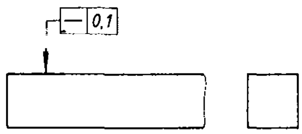
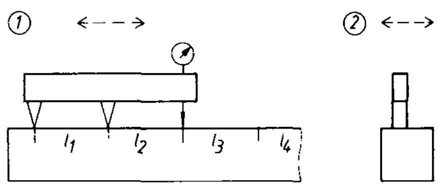
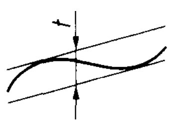
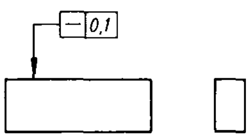
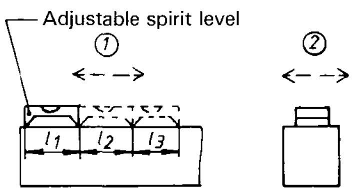
7.1 Principle 1 — Verifying straightness deviations by comparing with a straight element *(concluded)*

Symbol	Tolerance zone and application example	Verification method	Comments
—	 	**Method 7.1.7**  $l = l_1 = l_2 = l_n$ Set the indicator to zero on a surface plate. Move the instrument in specified steps, *l*, along the generating line under consideration. Record the indicator reading at each step. (1) The straightness deviation is evaluated from a cumulative diagram. Measure the required number of generating lines. (2)	This method is mainly used for large objects. Errors in setting the zero will cumulate by the repetition of measuring steps.

7.2 Principle 2 — Verifying straightness deviations by measuring angle deviations

Symbol	Tolerance zone and application example	Verification method	Comments
—	 	**Method 7.2.1**  $l = l_1 = l_2 = l_3 = l_n$ Place the adjustable spirit level at one end of the generating line and set it to zero. Move the spirit level in specified steps along the generating line under consideration. Record the values at each step. (1) The straightness deviation is evaluated from a cumulative diagram, where the incremental straightness deviation = $l \times$ indication value. Measure the required number of generating lines. (2)	This method is mainly used for large objects. If the spirit level is not adjustable, the object shall be horizontally aligned. A pendulum instrument with feet may also be used.

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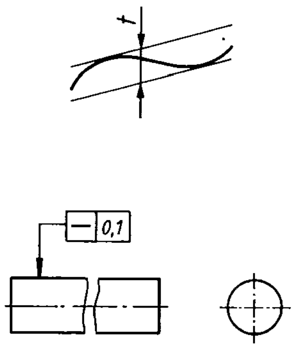
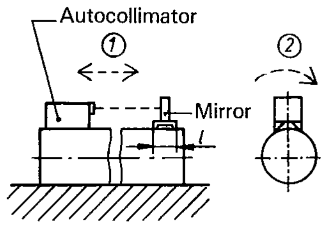
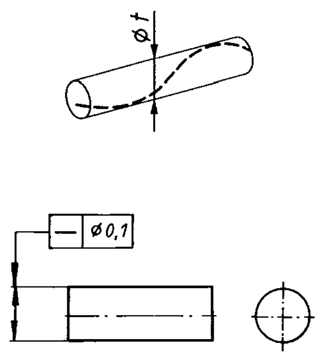
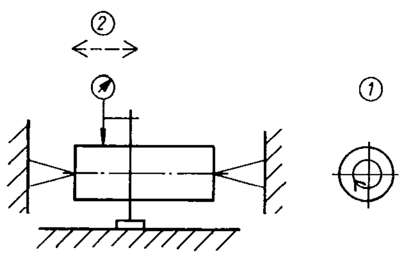
7.2 Principle 2 — Verifying straightness deviations by measuring angle deviations *(concluded)*

Symbol	Tolerance zone and application example	Verification method	Comments
—		**Method 7.2.2**  Align the measuring equipment with the object. Move the autocollimator mirror with feet at a specified distance, *l*, in specified steps along the generating line under consideration and record the values. (1) The straightness deviation is calculated from a cumulative diagram. Measure the required number of generating lines. (2)	This method is mainly used for large objects. Continuous movement may also be used when recording the result. An angle measuring laser device may also be used.

7.3 Principle 3 — Verifying straightness deviations by finding centres of consecutive cross-sections

Symbol	Tolerance zone and application example	Verification method	Comments
—		**Method 7.3.1**  Clamp the object between two coaxial centres parallel to the surface plate. Rotate the object around a fixed axis. Record half the difference of the indicator readings during one complete revolution in a polar diagram. (1) Measure the required number of axial sections. (2) The straightness deviation of the object axis is considered to be the maximum deviation between the evaluated centres.	

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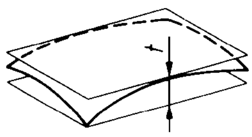
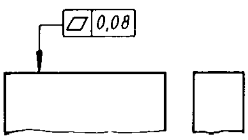
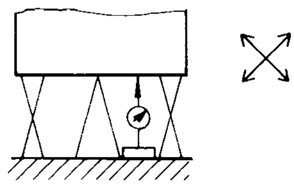
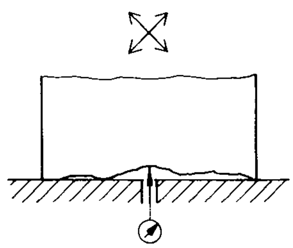
8 Verification of flatness

8.1 Principle 1 — Verifying flatness deviations by comparing with a flat element

Symbol	Tolerance zone and application example	Verification method	Comments
⏥	 	**Method 8.1.1**  Align the object as a superimposed surface on the surface plate. Measure the distance between the object and the surface plate at the required number of points. The flatness deviation is the maximum difference between the measured distances.	The object is generally aligned by bringing three widely separated points on the surface to the same distance from the surface plate. In this case, the measured values shall be entered on the diagram and evaluated or corrected mathematically.
		Method 8.1.2  Place the object stably on the surface plate. Measure the distance between the object and the surface plate at the required number of points. The flatness deviation is the maximum difference between the measured distances.	The size of the surface plate should be at least twice the object size. For convex surfaces, the object should be adjusted to the surface plate in such a way that the deviation is minimized.

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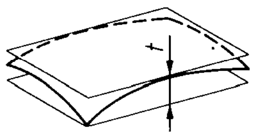
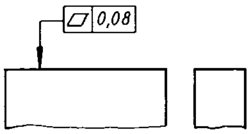
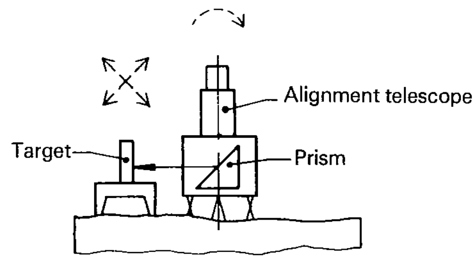
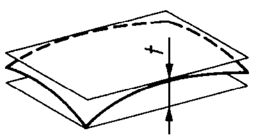
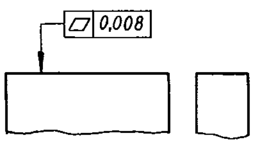
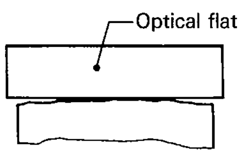
8.1 Principle 1 — Verifying flatness deviations by comparing with a flat element *(concluded)*

Symbol	Tolerance zone and application example	Verification method	Comments
⏥	  	**Method 8.1.3**  Place the alignment telescope on the object. Align the rotating axis perpendicular to the superimposed surface of the object. The flatness deviation is the maximum difference from the calculated superimposed surface.	This method is suitable for large surfaces. The alignment of the rotating axis can be corrected mathematically.
	  	**Method 8.1.4**  Place the optical flat on the object and observe it in monochromatic light. The flatness deviation is the number of interference lines counted, multiplied by $\lambda/2$ of the light used. $\left(\frac{\lambda}{2} \approx 0{,}3\ \mu\text{m}\right)$	This method demands a highly reflective surface. This method is practical only for small objects with flatness deviations up to 20 µm, depending on the size of the optical flat. The optical flat should be adjusted to the object in such a way that the deviation is minimized.

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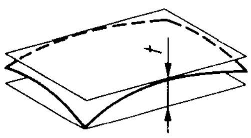
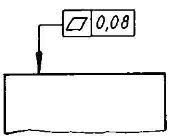
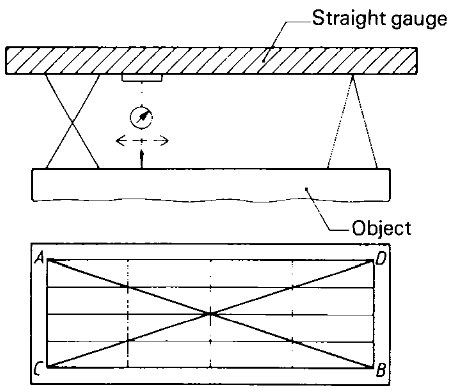
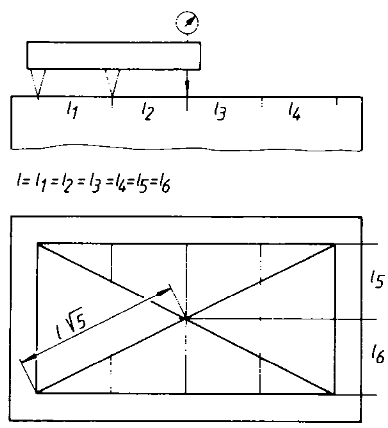
8.2 Principle 2 — Verifying flatness deviations by comparing with a straight element in several directions

Symbol	Tolerance zone and application example	Verification method	Comments
⏥	 	**Method 8.2.1**  Place a straight gauge diagonally on one adjustable support and one fixed support, with both ends at the same distance from the object. Measure the distance between the object and straight gauge at specified positions along the diagonal (A-B) in relation to the measured value at the centre. Repeat the measurement along the other diagonal (C-D), and record the values in a diagram after correction for the median point distance. These two diagonals form a reference plane from which all other points are determined. The flatness deviation is evaluated from the diagram.	This measurement is self-controlling to a certain extent, as many points are determined several times using the straight gauge in a different direction. Generally used to measure surface plates.
		Method 8.2.2  Set the indicator to zero on a surface plate. Move the instrument in steps, l, in three directions. The flatness deviation is evaluated from a cumulative diagram.	This method is mainly used for large surfaces. Errors in setting the zero will cumulate by the repetition of measuring steps. If another pattern is used, the formula will be changed.

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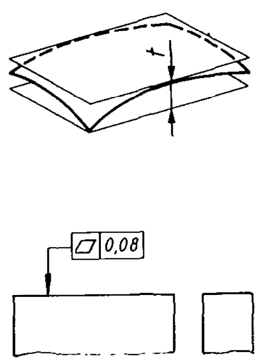
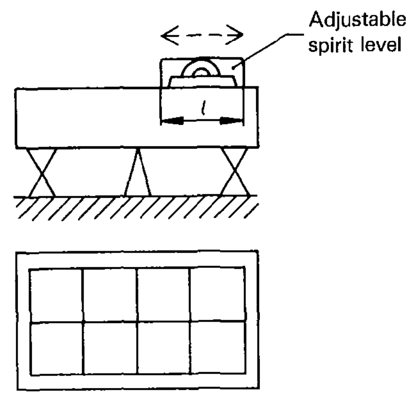
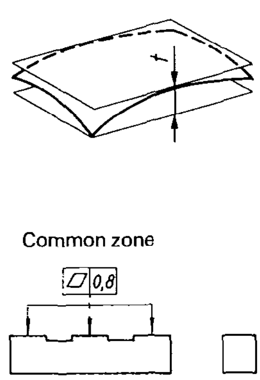
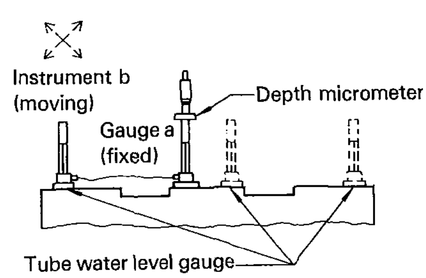
8.3 Principle 3 – Verifying flatness deviations by measuring deviations from the horizontal in several directions

Symbol	Tolerance zone and application example	Verification method	Comments
⏥		**Method 8.3.1**  Place an adjustable spirit level of a specified length on the object. Take measurements step by step in several sections in one direction. Record the deviations from the horizontal in a cumulative diagram. Repeat the measurements, as previously described, but at right angles to those already taken and also record them in the diagram. The flatness deviation is evaluated from the cumulative diagram where the incremental deviation = $l \times$ indication of the level.	This method is mainly used for large surfaces. The horizontal alignment is achieved either by means of an adjustable support or an adjustable spirit level. The measurements are self-controlling as many points are determined twice. A pendulum instrument may also be used.
		**Method 8.3.2**  The water level gauge a and instrument b are initially located as shown in the figure. Set gauge a to zero. Then move instrument b along any flat element and record the readings on gauge a. The flatness deviation is evaluated from a diagram.	This method is mainly used for large surfaces. Practical for horizontal surfaces only.

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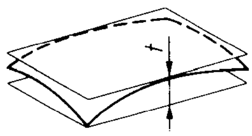
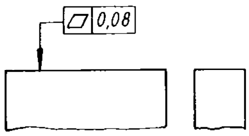
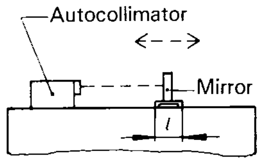
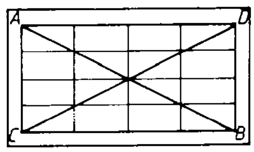
8.4 Principle 4 — Verifying flatness deviations by measuring angle deviations in several directions

Symbol	Tolerance zone and application example	Verification method	Comments
⏥	  	**Method 8.4.1**   Place a mirror with feet at a specified distance, *l*, at a corner of the object. Adjust the autocollimator parallel to the object surface. Measure the angle deviation in specified positions along the diagonal direction (A-B) and record the values in a diagram. Repeat the measurement in the direction of the other diagonal (C-D). These two diagonals form a reference plane from which all other points are determined, using an appropriate feet distance. The flatness deviation is evaluated from the cumulative diagram where the incremental deviation = *l* × the reading of the autocollimator.	This measurement is self-controlling to a certain extent, as many points are determined several times. Continuous movement may also be used when recording the result. An angle measuring laser device may also be used.

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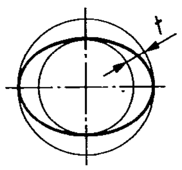
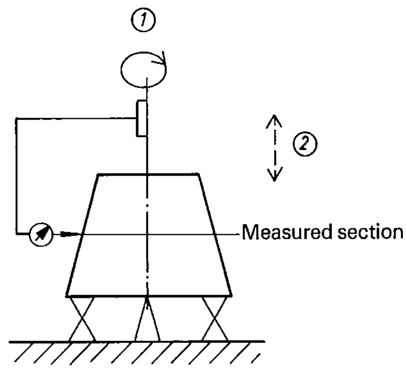
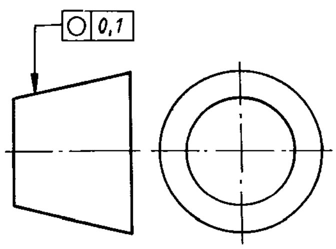
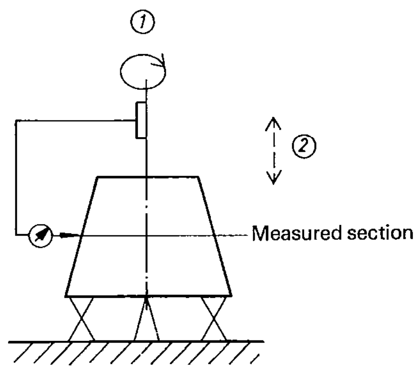
9 Verification of circularity

9.1 Principle 1 — Verifying circularity deviations by measuring variation in radius from a fixed common centre

Symbol	Tolerance zone and application example	Verification method	Comments
○		**Method 9.1.1 — Minimum zone centre**  Align the object with the measuring equipment. Their axes shall be coaxial. Record the radial differences during one complete revolution. (1) Evaluate the minimum zone centre from a polar diagram and/or by computers. Measure the required number of sections. (2) The circularity deviation is the minimum radial difference obtained between two concentric circles.	Applicable for both external and internal surfaces. Equipment for measurement of radius variation from fixed centre : rotating stylus or rotating table, with recorder or computer, to be used.
		**Method 9.1.2 — Least square centre**  Align the object with the measuring equipment. Their axes shall be coaxial. Record the radial differences during one complete revolution. (1) Evaluate the least square centre from a polar diagram and/or by computers. Measure the required number of sections. (2) The circularity deviation is the radial difference obtained between inscribed and circumscribing circles with their centres coinciding with the centre of the mean circle.	Applicable for both external and internal surfaces. This method is recommended for diagram and/or computer evaluation. Equipment for measurement of radius variation from fixed centre : rotating stylus or rotating table, with recorder or computer, to be used.

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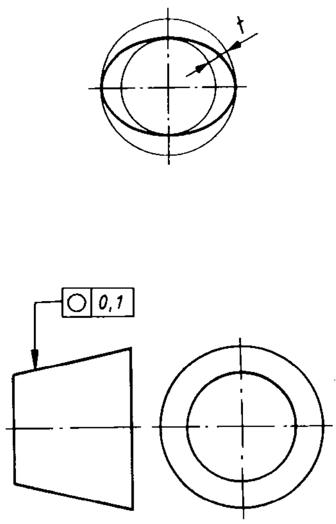
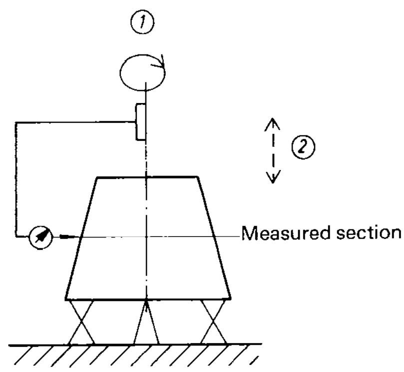
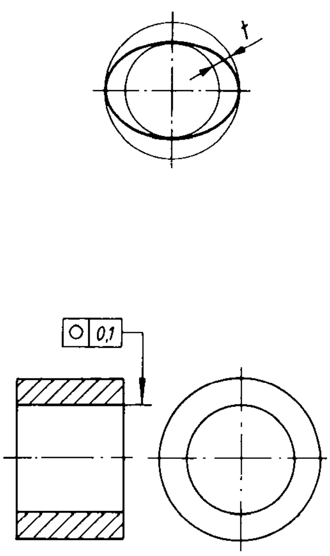
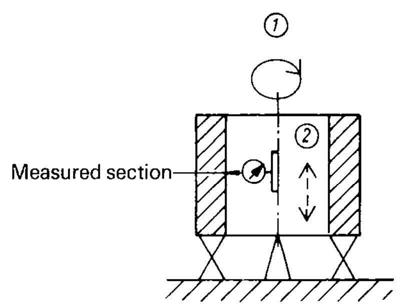
9.1 Principle 1 — Verifying circularity deviations by measuring variation in radius from a fixed common centre *(concluded)*

Symbol	Tolerance zone and application example	Verification method	Comments
○		**Method 9.1.3 — Minimum circumscribing circle**  Align the object with the measuring equipment. Their axes shall be coaxial. Record the radial differences during one complete revolution. (1) The evaluation is made by minimum circumscribing circle. Measure the required number of sections. (2) The circularity deviation is the radial difference between inscribed circle and the smallest circumscribing circle having the same centre.	Applicable for external surfaces. This method is recommended with diagram and/or computer evaluation. Equipment for measurement of radius variation from fixed centre : rotating stylus or rotating table, with recorder or computer, to be used.
		**Method 9.1.4 — Maximum inscribed circle**  Align the object with the measuring equipment. Their axes shall be coaxial. Record the radial differences during one complete revolution. (1) The evaluation is made by maximum inscribed circle. Measure the required number of sections. (2) The circularity deviation is the radial difference between the largest inscribed circle and the circumscribing circle having the same centre.	Applicable for internal surfaces. This method is recommended with diagram and/or computer evaluation. Equipment for measurement of radius variation from fixed centre : rotating stylus or rotating table, with recorder or computer, to be used.

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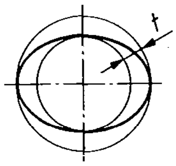
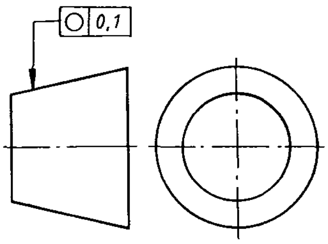
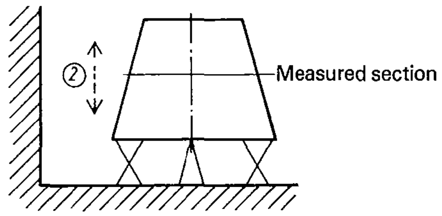
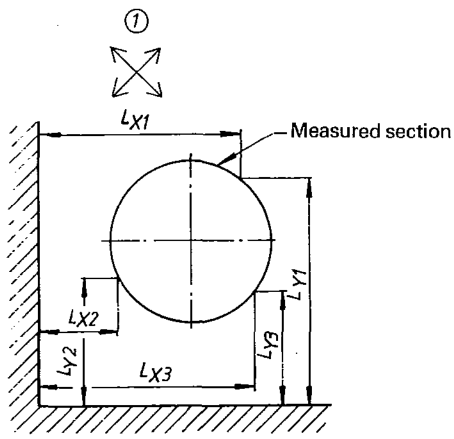
9.2 Principle 2 — Verifying circularity deviations by measuring coordinates

Symbol	Tolerance zone and application example	Verification method	Comments
○	 	**Method 9.2.1**   Align the object with the coordinate measuring equipment. Measure distance L in two coordinates at any point on the circular section. Measure the required number of points on the circumference. (1) The circularity evaluation may be carried out by calculation from the least square centre. Measure the required number of sections. (2)	Applicable for both external and internal surfaces. Coordinate measuring machine or measuring microscope, with computer, to be used.

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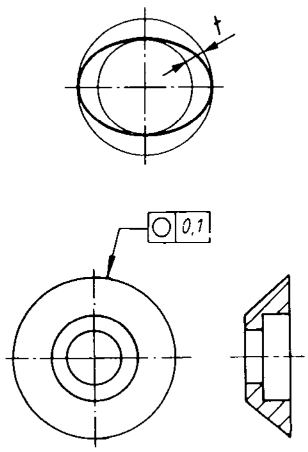
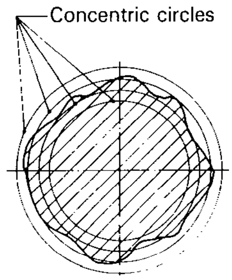
9.3 Principle 3 — Verifying circularity deviations by profile projection

Symbol	Tolerance zone and application example	Verification method	Comments
○		**Method 9.3.1**  Compare the profile of the object to concentric circles. The circularity is evaluated from concentric circles.	This method is limited to features within the capacity of the projector. Profile projector apparatus or light section equipment (luminous belt scanning equipment) to be used.

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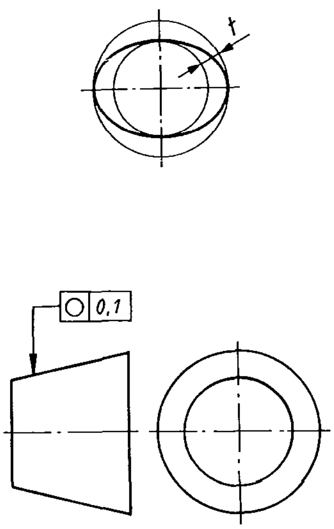
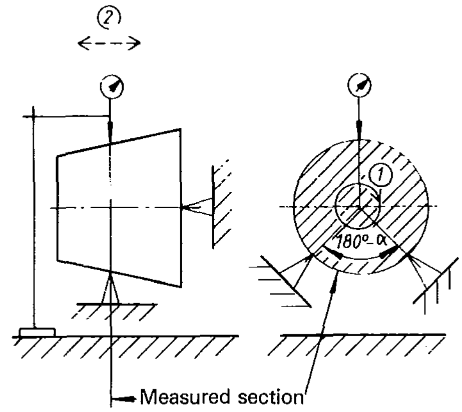
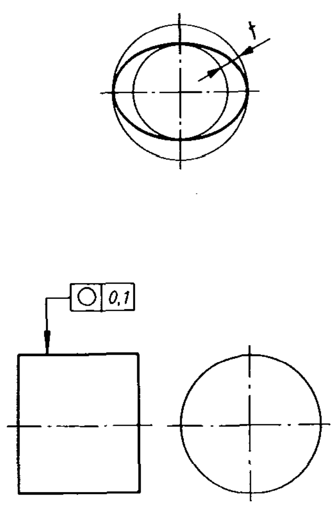
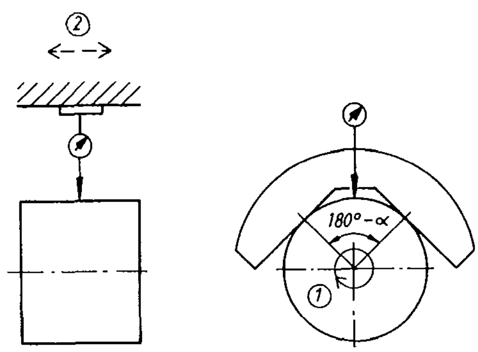
9.4 Principle 4 — Verifying circularity deviations by two- or three-point measurement

Symbol	Tolerance zone and application example	Verification method	Comments
○	 	**Method 9.4.1 — Summit (three-point measurement)**  Align the object with the measuring equipment. The object axis shall be perpendicular to the measuring direction and fixed axially. The indicator reading during one complete revolution is used for the calculation. (1) Repeat the measurements at the required number of sections. (2) The circularity deviation should be evaluated from the indicator readings, taking into consideration the α-value and the number of lobes.	The measurement is carried out to check odd lobed-form errors. The even lobed-form errors can be checked by two-point measurement. The most common angles are : α = 90° and 120° or 72° and 108° This method can be used for rotation of either the object or equipment. Applicable for both external and internal surfaces.
	 	**Method 9.4.2 — Rider (three-point measurement)**  Align the object with the measuring equipment. The object axis shall be perpendicular to the measuring direction and fixed axially. The indicator reading during one complete revolution is used for the calculation. (1) Repeat the measurements at the required number of sections. (2) The circularity deviation should be evaluated from the indicator readings, taking into consideration the α-value and the number of lobes.	The measurement is carried out to check odd lobed-form errors. The even lobed-form errors can be checked by two-point measurement. The most common angles are : α = 90° and 120° or 72° and 108° This method can be used for rotation of either the object or equipment. Applicable for both external and internal surfaces.

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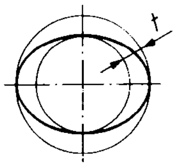
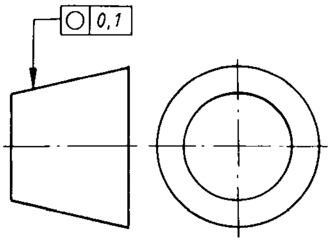
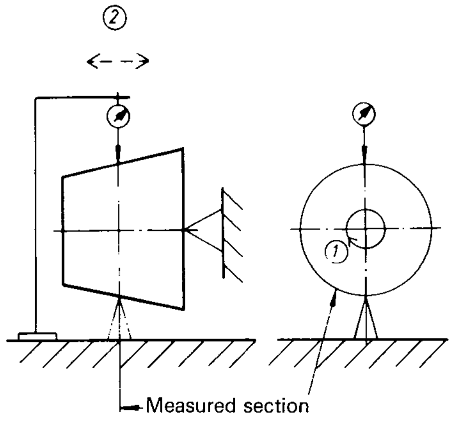
9.4 Principle 4 — Verifying circularity deviations by two- or three-point measurement *(concluded)*

Symbol	Tolerance zone and application example	Verification method	Comments
○	 	**Method 9.4.3 — (two-point measurement)**  Align the object with the measuring equipment. The object axis shall be parallel to the surface plate and in the same position as the turning centre. Measure the diameter difference during one complete revolution. (1) Repeat the measurements at the required number of sections. (2) The circularity deviation is considered to be half of the difference obtained.	This method determines only the even lobed circularity deviation. The odd lobed deviation requires a three-point measurement. Applicable for both external and internal surfaces. This principle may be used for rotation of either the object or equipment.

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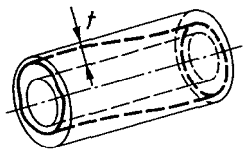
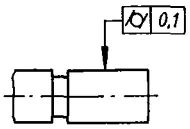
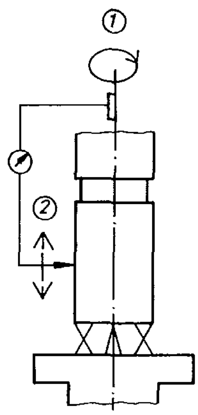
10 Verification of cylindricity

10.1 Principle 1 — Verifying cylindricity deviations by measuring variation in radius from a fixed common axis

Symbol	Tolerance zone and application example	Verification method	Comments
⌭	 	**Method 10.1.1**  Align the object with the measuring equipment. Their axes shall be coaxial. Record the radial difference during one complete revolution. (1) Measure the required number of sections, without resetting the indicator. (2) Evaluate the minimum zone cylinder from polar diagrams and/or by computer. The cylindricity deviation is evaluated from polar diagrams and/or by computer as the radial difference of the minimum zone cylinders.	This method is time-consuming without sophisticated equipment. Equipment for measurement of variation in radius from a fixed common axis, with a recorder for polar diagrams and/or computer, to be used.

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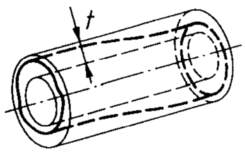
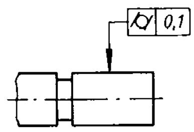
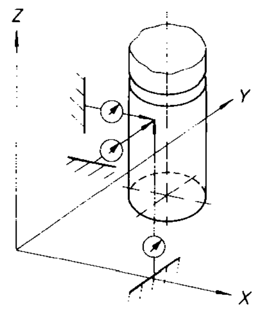
10.2 Principle 2 — Verifying cylindricity by measuring three coordinates

Symbol	Tolerance zone and application example	Verification method	Comments
⌭	  	**Method 10.2.1**  Align the object with the coordinate measuring equipment. Measure the required number of points on the cylindrical surface in three coordinates. The cylindricity deviation is evaluated from diagrams and/or by computer as the radial difference of the minimum zone cylinders.	This method is time-consuming without sophisticated equipment. Three-coordinate measuring machine, with a recorder and a computer, to be used.

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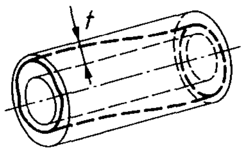
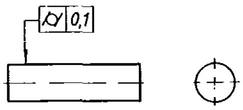
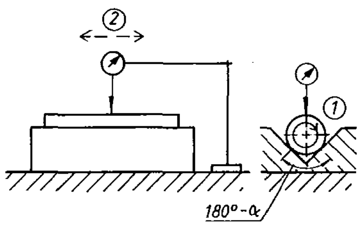
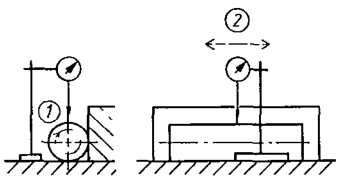
10.3 Principle 3 — Verifying cylindricity deviations by measuring several cross-sections in V- and L-supports

Symbol	Tolerance zone and application example	Verification method	Comments
⌭	 	**Method 10.3.1**  Place the object in a V- block. Measure the object at a radial section during one complete revolution. (1) Repeat the measurements at the required number of sections, without resetting the indicator. (2) The cylindricity deviation should be evaluated from the indicator readings, taking into consideration the α-value and the number of lobes.	The V-block shall be longer than the object. Applicable for external surfaces only. This method determines only the odd lobed cylindricity deviations.
		Method 10.3.2  Place the object on a surface plate and against a square plate. Measure the object at a radial section during one complete revolution. (1) Repeat the measurements at the required number of sections, without resetting the indicator. (2) The cylindricity deviation is half of the full indicator movement.	Applicable for external surfaces only. This method determines only the even lobed cylindricity deviations. The odd lobed deviation requires a three-point measurement.

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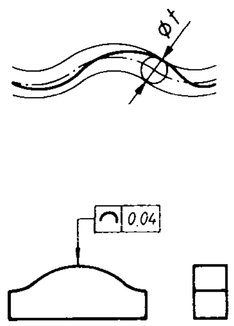
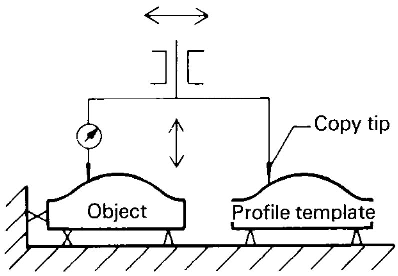
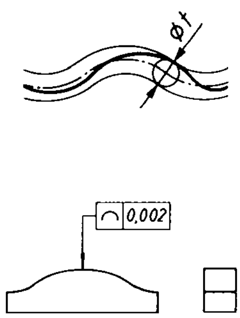
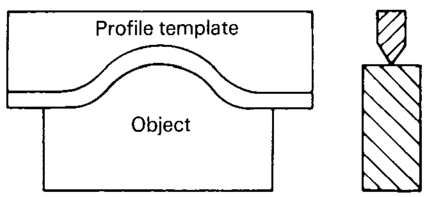
11 Verification of profile of any line

11.1 Principle 1 — Verifying profile deviations of any line by comparing with an element of correct profile

Symbol	Tolerance zone and application example	Verification method	Comments
⌒		**Method 11.1.1**  Align the object correctly with the copying system and the profile template. The indicator records the deviations of the object from the correct profile template. The extreme variations are compared with the calculated limits of deviations in the measured direction. The profile deviation is the maximum value of the indicator readings, but corrected to normal to the theoretical profile as the measuring direction is not normal to the surface.	The indicator tip and the copy tip shall have an identical shape.
		**Method 11.1.2**  Place the profile template on the object and align it in the specified direction. Inspect the object and the profile template against a specified light. If no light column is observed, the form of the object does not deviate by more than 0,003 mm from the form of the profile template (numerical values are not obtainable).	For larger deviations, a profile template may be separated from the object by a predetermined distance at both ends and the resulting space gauged with a step pin gauge.

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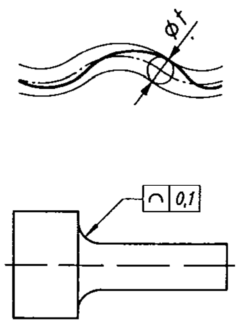
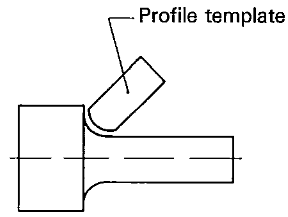
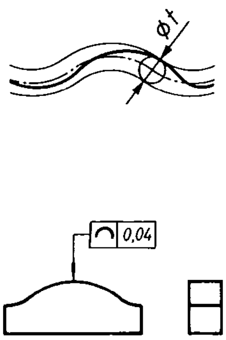
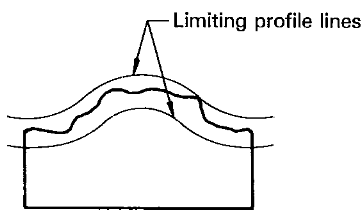
11.1 Principle 1 — Verifying profile deviations of any line by comparing with an element of correct profile (*concluded*)

Symbol	Tolerance zone and application example	Verification method	Comments
⌒		**Method 11.1.3**  Place the profile template on the object and align it in the specified direction. Compare the profile of the object with the profile template.	The accuracy can be improved by using two templates with limit form. By using one template the amount of the actual deviation is uncertain.
		**Method 11.1.4**  Project the profile onto a screen. Compare the projected profile with the limiting profile lines. The actual profile shall be contained within the two limiting profile lines.	This method is limited to features within the capacity of the projector. Profile projector to be used.

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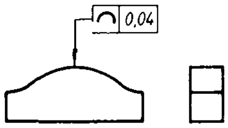
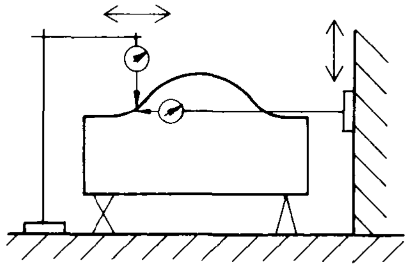
11.2 Principle 2 — Verifying profile deviations of any line by measuring coordinates

Symbol	Tolerance zone and application example	Verification method	Comments
⌒	 	**Method 11.2.1**  Align the object in the correct orientation relative to the surface plate. Measure the two coordinates at the required number of points along the profile. Record the measured values and compare them with the limiting profiles.	The shape of the stylus should be taken into account. Coordinate measuring machine to be used.

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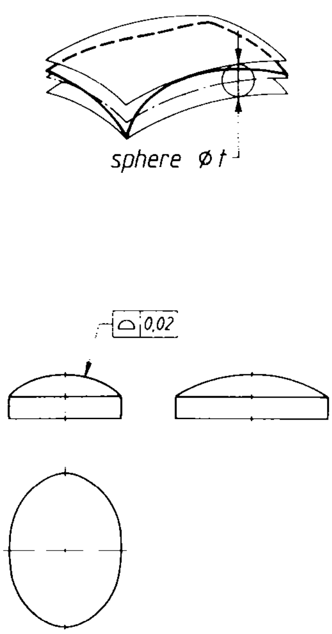
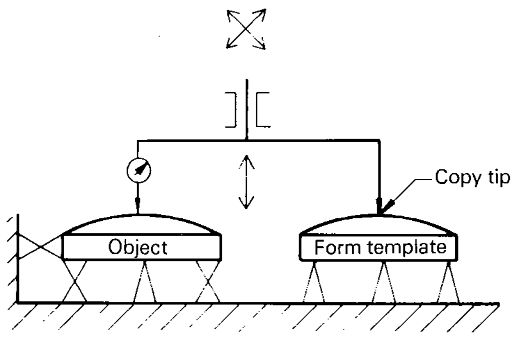
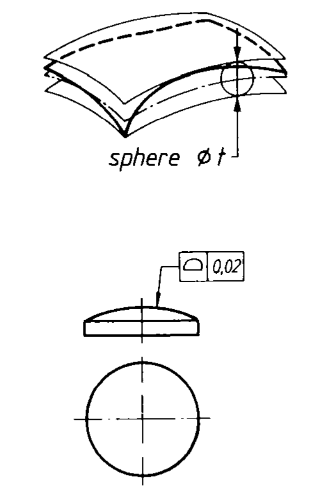
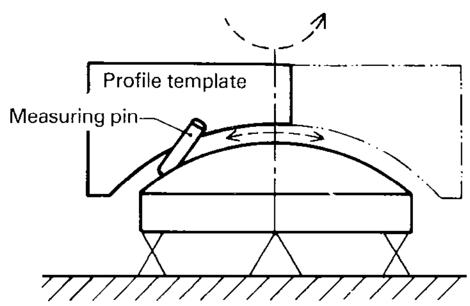
12 Verification of profile of any surface

12.1 Principle 1 — Verifying profile deviations of any surface by comparing with an element of correct form

Symbol	Tolerance zone and application example	Verification method	Comments
⌓		**Method 12.1.1**  Align the object with the copy system and the form template. The indicator records the deviations of the object. The surface profile deviation is the maximum value of the indicator readings, corrected to normal to the theoretical surface profile.	The indicating tip and the copy tip shall have an identical shape.
		**Method 12.1.2**  Position the object relative to the rotational axis. Align the profile template at a required distance from the object. Measure the required number of positions. The form deviation is determined by comparing the maximum and minimum readings.	This method is applicable to surfaces of revolution only. Device for the rotation of the object or the template to be used.

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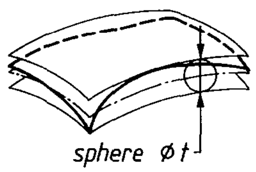
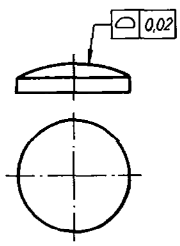
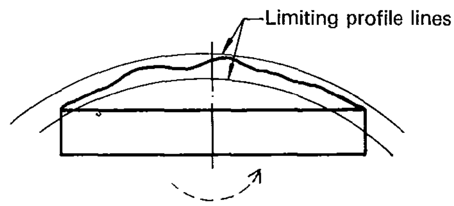
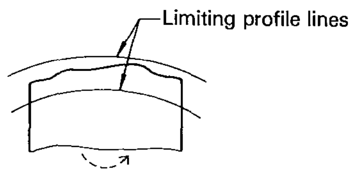
12.1 Principle 1 — Verifying profile deviations of any surface by comparing with an element of correct form *(concluded)*

Symbol	Tolerance zone and application example	Verification method	Comments
⌓	 	**Method 12.1.3**  Project the profile onto the screen of a profile projector with light-cut. Take the projected profiles at the required number of positions and compare them with the limiting profile lines.	This method is usually applied to external surfaces and is limited to features within the capacity of the projector.
		Method 12.1.4  Project the required number of profiles onto the screen using a profile projector (shadowgraph). Compare the projected profiles with the limiting profile lines.	This method is limited to convex surfaces.

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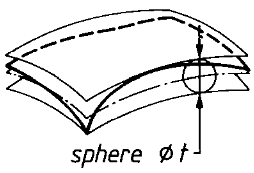
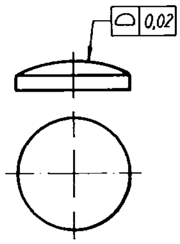
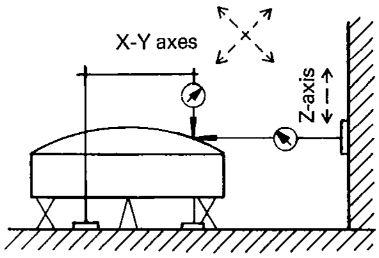
12.2 Principle 2 — Verifying profile deviations of any surface by measuring coordinates

Symbol	Tolerance zone and application example	Verification method	Comments
⌓	 	**Method 12.2.1**  Align the object with the measuring surface plate. Measure three coordinates at the required number of points on the surface. Record the measured values and compare them with the coordinates of the limiting surface profiles.	The form and the size of the stylus should be taken into account. Coordinate measuring machine to be used.

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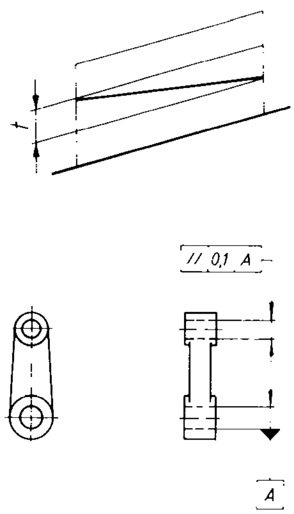
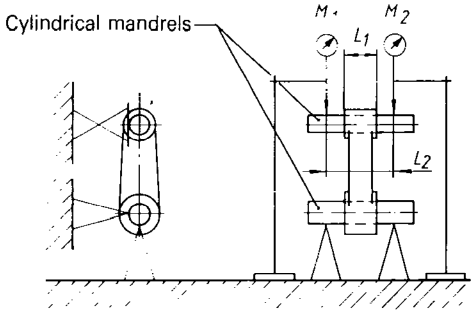
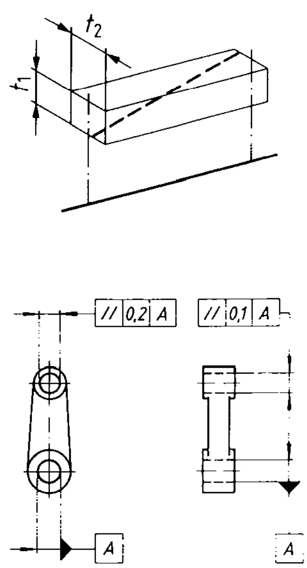
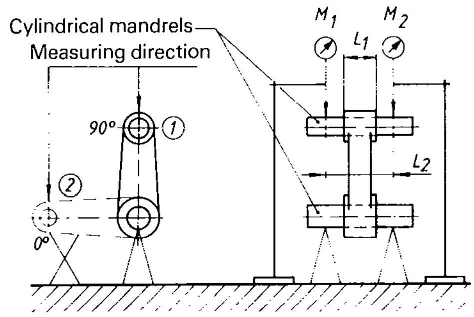
13 Verification of parallelism

13.1 Principle 1 — Verifying parallelism deviations by measuring distance

Symbol	Tolerance zone and application example	Verification method	Comments
//		**Method 13.1.1**  Simulate the datum axis and feature axis with axes of inscribed cylinders extended outside the holes. Make arrangements to achieve the correct measuring direction (adjustable support). Keep the axial measuring positions under control. The parallelism deviation, *Pd*, is calculated from the formula $Pd = \frac{\lvert M_1 - M_2 \rvert \times L_1}{L_2}$	The cylindrical mandrels may be either expanded or selected to fit in the holes without clearance. If the upper mandrel can be orientated in more than one direction, the orientation should be such that the measured deviation from parallelism becomes a minimum.
		**Method 13.1.2**  Simulate the datum axis and feature axis with axes of inscribed cylinders extended outside the holes. Position the object in such a way that the measurement may be carried out in the two directions indicated on the drawing. Carry out the measurements on the mandrel in positions (1) and (2). The parallelism deviation, *Pd*, is calculated from the formula $Pd = \frac{\lvert M_1 - M_2 \rvert \times L_1}{L_2}$	The cylindrical mandrels may be either expanded or selected to fit in the holes without clearance. If the upper mandrel can be orientated in more than one direction, the orientation should be such that the measured deviation from parallelism becomes a minimum.

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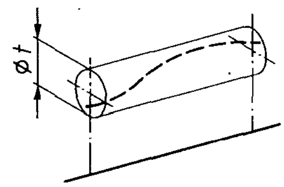
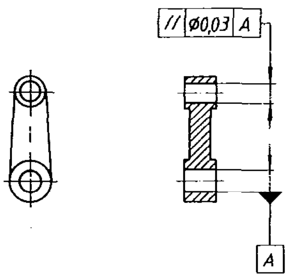
13.1 Principle 1 — Verifying parallelism deviations by measuring distance *(continued)*

<table>
<tr><th>Symbol</th><th>Tolerance zone and application example</th><th>Verification method</th><th>Comments</th></tr>
<tr><td rowspan="2">//</td><td>




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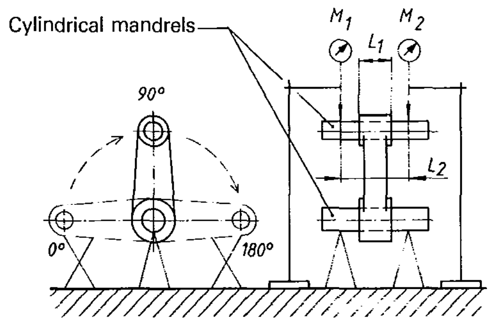
Method 13.1.3



Simulate the datum axis and feature axis with axes of inscribed cylinders extended outside the holes.

Keep the axial measuring positions under control.

Carry out the measurements on the mandrel positions, M_1 and M_2.

Repeat the measurements in the required number of angular positions between 0° and 180°.

The parallelism deviation, Pd, is calculated from the formula

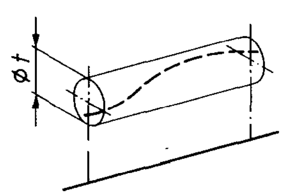
$$Pd = \frac{|M_1 - M_2| \times L_1}{L_2}$$

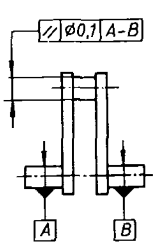
</td><td>

The cylindrical mandrels may be either expanded or selected to fit in the holes without clearance.

If the upper mandrel can be orientated in more than one direction, the orientation should be such that the measured deviation from parallelism becomes a minimum.

Measurement can be restricted to two perpendicular directions. The square root of the sum of the squares of the two deviations obtained shall be less than the specified tolerance value.

</td></tr>
<tr><td>




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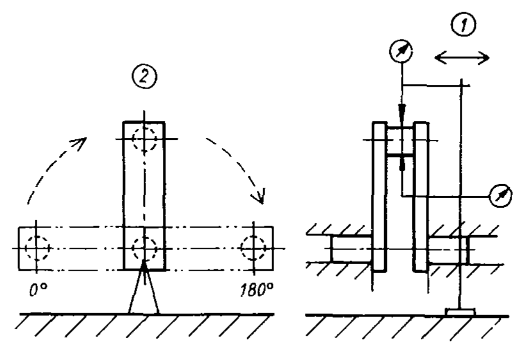
Method 13.1.4



Position the datum axis parallel to the surface plate and simulate it with the axis of coaxial circumscribing cylinders.

Carry out measurements in the required number of angular positions between 0° and 180°. (2)

Record half the difference of the two indicator readings in the same section. (1)

The parallelism deviation is the maximum deviation of the recorded values.

</td><td>

Measurement can be restricted to two perpendicular directions. The square root of the sum of the squares of the two deviations obtained shall be less than the specified tolerance value.

Precision chucking device to be used.

</td></tr>
</table>

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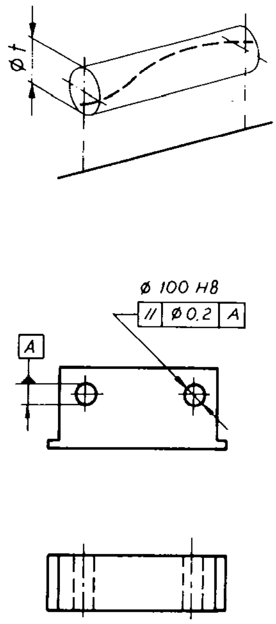
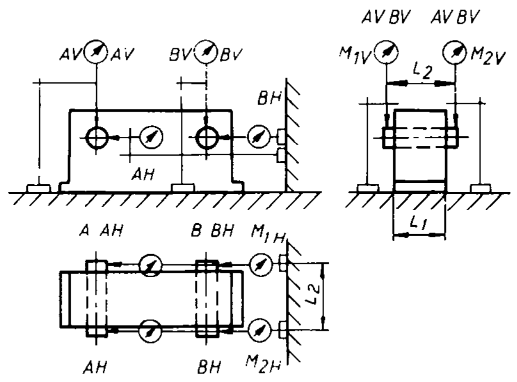
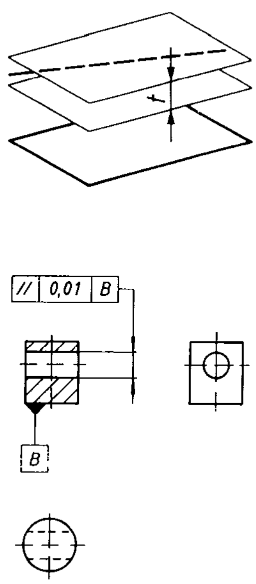
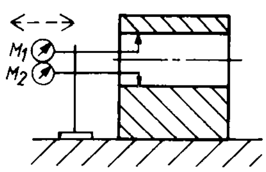
13.1 Principle 1 — Verifying parallelism deviations by measuring distance *(continued)*

Symbol	Tolerance zone and application example	Verification method	Comments
//		**Method 13.1.5**  Simulate the datum axis and feature axis with the axes of inscribed cylinders. Carry out the measurements in horizontal and vertical directions as illustrated in the diagram. Keep the axial measuring positions under control. The parallelism deviation, Pd, is calculated from the following formula $Pd = \frac{L_1 \times \sqrt{(\Delta_{BV} - \Delta_{AV})^2 + (\Delta_{BH} - \Delta_{AH})^2}}{L_2}$ where $M_{1V} - M_{2V}$ for datum A = Δ_{AV} $M_{1H} - M_{2H}$ for datum A = Δ_{AH} $M_{1V} - M_{2V}$ for cylinder B = Δ_{BV} $M_{1H} - M_{2H}$ for cylinder B = Δ_{BH}	The cylindrical mandrels may be either expanded or selected to fit in the holes without clearance. If the right-hand mandrel can be orientated in more than one direction, the orientation should be such that the measured deviation from parallelism becomes a minimum.
		**Method 13.1.6**  Simulate the datum with the base plane covering the entire datum surface. Simulate the feature axis with the median line of top and bottom generating lines. Measure the generating lines in the required number of axial positions. Record half the difference between the two indicator readings in a diagram, that is $\frac{M_1 - M_2}{2}$, at each point. The maximum deviation of these values is the parallelism deviation.	

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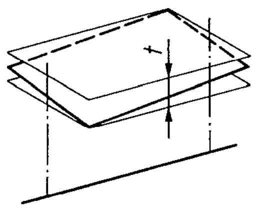
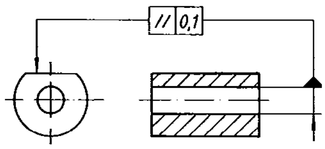
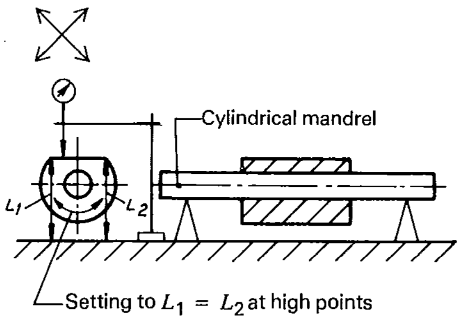
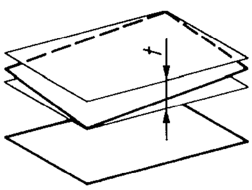
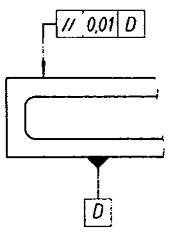
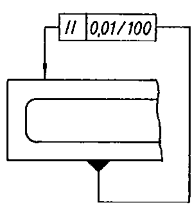
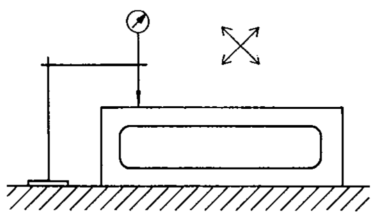
13.1 Principle 1 — Verifying parallelism deviations by measuring distance (*concluded*)

Symbol	Tolerance zone and application example	Verification method	Comments
//	  	**Method 13.1.7**  Simulate the datum axis with the axis of the inscribed cylinder. Align the toleranced surface parallel to the surface plate prior to measurement. Carry out measurements on the surface. The parallelism deviation is the full indicator movement.	The cylindrical mandrel may be either expanded or selected to fit in the hole without clearance. The alignment of the object may also be corrected mathematically.
	   	**Method 13.1.8**  Place the object on a surface plate covering the entire datum surface. Carry out measurements all over the surface. Carry out measurements over the required number of 100 mm lengths in any direction over the entire surface. In both examples, the parallelism deviation over the considered length is the full indicator movement.	

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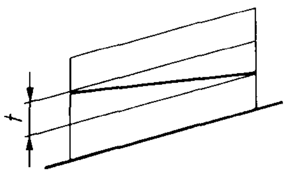
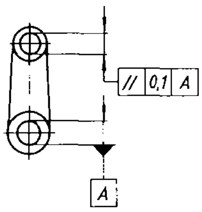
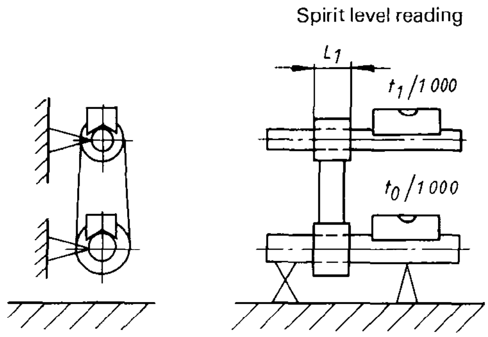
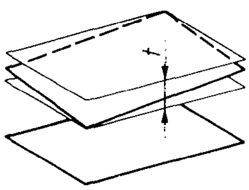
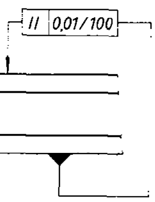
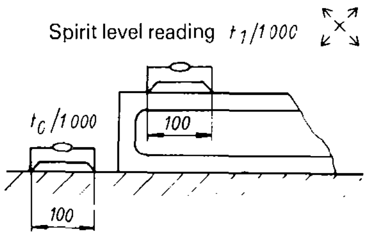
13.2 Principle 2 — Verifying parallelism deviations by measuring angles

Symbol	Tolerance zone and application example	Verification method	Comments
//	 	**Method 13.2.1**  Simulate the datum axis and feature axis with cylindrical mandrels. Record spirit level indications on both mandrels. The parallelism deviation, *Pd*, is calculated from the formula $Pd = \frac{\lvert t_1 - t_0 \rvert \times L_1}{1\ 000}$	An adjustable spirit level and fixed supports may also be used.
	 	**Method 13.2.2**  Place the object on a surface plate. Record the spirit level indications. The parallelism deviation, *Pd*, is calculated from the formula $Pd = \frac{\lvert t_1 - t_0 \rvert \times 100}{1\ 000}$	

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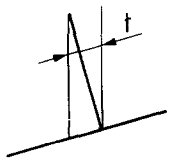
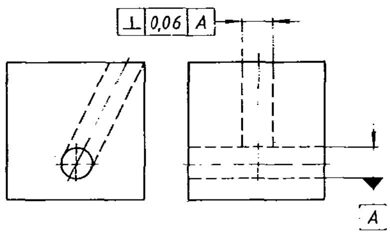
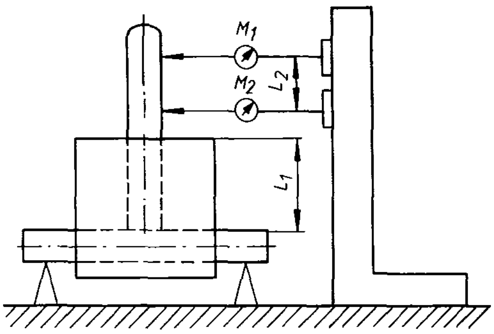
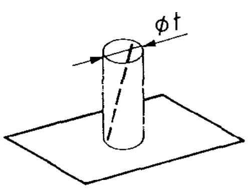
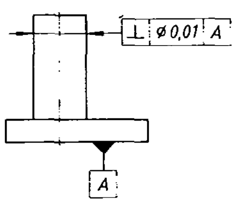
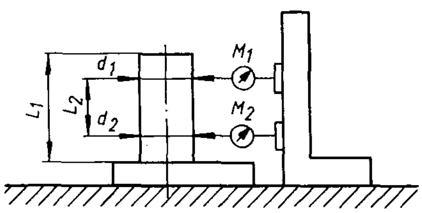
14 Verification of perpendicularity

14.1 Principle 1 — Verifying perpendicularity deviations by measuring distance

Symbol	Tolerance zone and application example	Verification method	Comments
⊥	 	**Method 14.1.1**  Simulate the datum axis with an inscribed cylinder parallel to the surface plate. Simulate the toleranced axis with another inscribed cylinder extending outside the hole. Then align the object in the correct position relative to the measuring equipment. Measure the distance from the square (M_1 and M_2) at two heights, L_2 apart. The perpendicularity deviation, Pd, is calculated from the formula $$Pd = \frac{\lvert M_1 - M_2 \rvert \times L_1}{L_2}$$	The cylindrical mandrel may be either expanded or selected to fit in the hole without clearance.
	 	**Method 14.1.2**  Place the object on a surface plate. Measure the distance (M_1 and M_2) between the cylinder which simulates the toleranced feature and the square at two heights, L_2 apart. Measure the difference between the diameters d_1 and d_2. Perpendicularity deviation in this direction G is $$Pd_G = \left[(M_1 - M_2) - \left(\frac{d_2 - d_1}{2} \right) \right] \times \frac{L_1}{L_2}$$ Repeat the measurements in direction H perpendicular to direction G and compute the measurements. The perpendicularity deviation, Pd, of the toleranced feature is $$Pd = \sqrt{(Pd_G)^2 + (Pd_H)^2}$$	If the deviation from straightness of the axis cannot be ignored, measurements in more than two sections are necessary. When the toleranced feature is the axis of a hole, it is simulated by a cylindrical mandrel which may be expanded or selected to fit in the hole without clearance and which extends outside the hole. If the tolerance requirement is indicated in one direction only, Pd_G is the perpendicularity deviation (see method 14.1.4).

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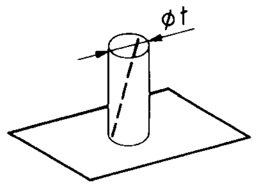
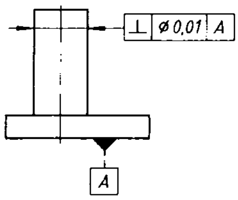
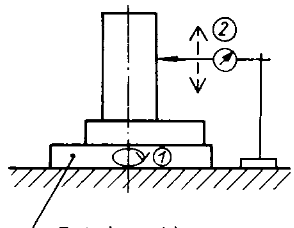
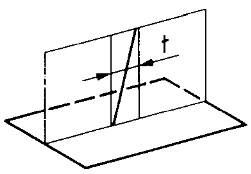
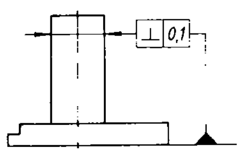
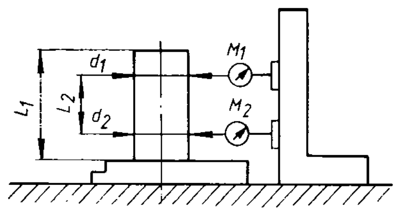
14.1 Principle 1 — Verifying perpendicularity deviations by measuring distance *(continued)*

Symbol	Tolerance zone and application example	Verification method	Comments
⊥	 	**Method 14.1.3**  Place the object on a rotating table and centre it at an extreme end of the cylinder relative to the rotational axis. Measure the radial variation during rotation of the table. (1) Measure the required number of sections. (2) The perpendicularity deviation is half the full indicator movement.	Usually the lowest section of the toleranced feature is centred.
	 	**Method 14.1.4**  Place the object on a surface plate. Measure the distance (M_1 and M_2) between the cylinder and the square at two heights, L_2 apart. Measure the difference between diameters d_1 and d_2. The perpendicularity deviation is $Pd = \left[(M_1 - M_2) - \left(\frac{d_2 - d_1}{2}\right)\right] \times \frac{L_1}{L_2}$	When the toleranced feature is the axis of a hole, it is simulated by a cylindrical mandrel which may be expanded or selected to fit in the hole without clearance and which extends outside the hole.

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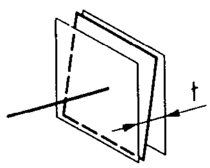
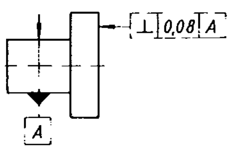
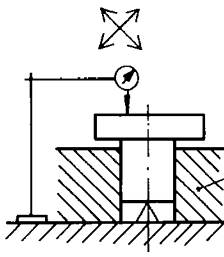
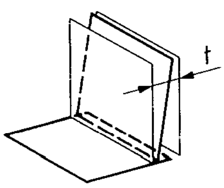
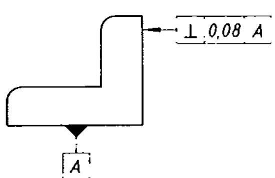
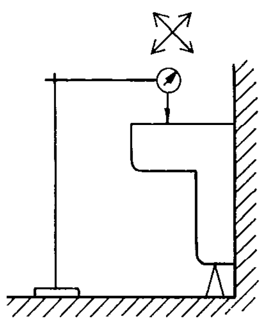
14.1 Principle 1 — Verifying perpendicularity deviations by measuring distance *(continued)*

Symbol	Tolerance zone and application example	Verification method	Comments
⊥	 	**Method 14.1.5**  Place the object in a guide feature selected to fit it. Adjust the datum axis perpendicular to the surface plate. Measure the distance between the toleranced feature and the surface plate. The perpendicularity deviation is the full indicator movement.	
	A surface to a datum plane  	**Method 14.1.6**  Clamp the object to an angle plate which is on a surface plate. The toleranced surface shall be adjusted to the surface plate prior to measurement. The perpendicularity deviation is the full indicator movement.	

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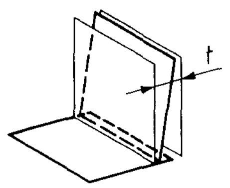
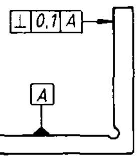
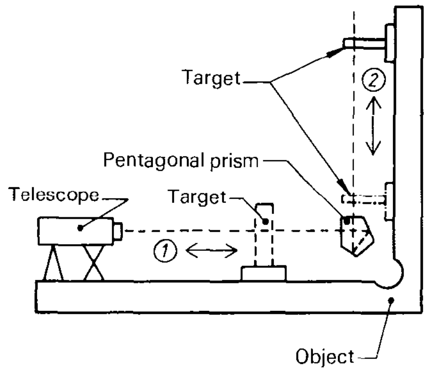
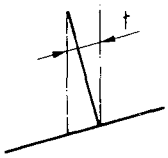
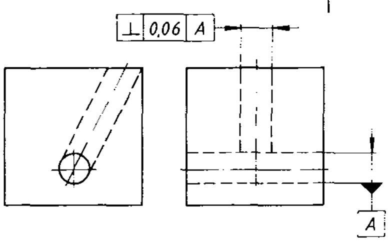
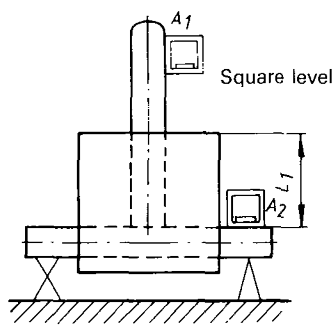
14.1 Principle 1 — Verifying perpendicularity deviations by measuring distance (*concluded*)

Symbol	Tolerance zone and application example	Verification method	Comments
⊥	 	**Method 14.1.7**  Adjust the telescope parallel to the datum of the object. (1) Move the target along the toleranced feature in the vertical direction and record the values. (2) The perpendicularity deviation is calculated mathematically from the recorded values.	This method is generally used for large objects.

14.2 Principle 2 — Verifying perpendicularity deviations by measuring angles

Symbol	Tolerance zone and application example	Verification method	Comments
⊥	 	**Method 14.2.1**  Simulate the datum axis with an inscribed cylinder aligned horizontally. Simulate the toleranced axis with another inscribed cylinder extending outside the hole. The perpendicularity deviation between the surface of the simulating datum axis and the mandrel is measured as a difference of the inclinations A_1 and A_2 of the features against the perpendicular sides of a square. The perpendicularity deviation, Pd, is $Pd = (A_1 - A_2) \times L_1$	The cylindrical mandrel may be either expanded or selected to fit in the hole without clearance.

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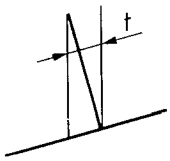
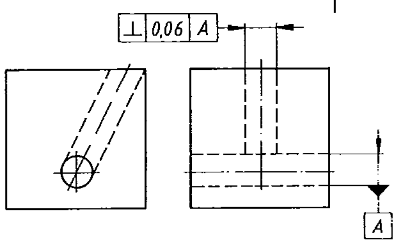
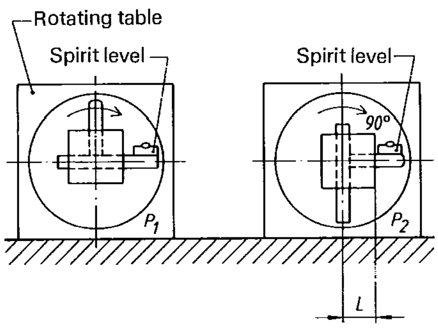
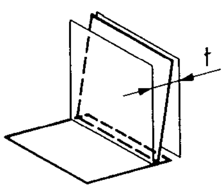
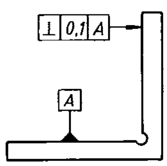
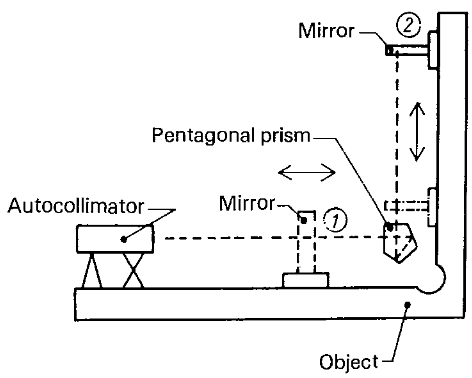
14.2 Principle 2 — Verifying perpendicularity deviations by measuring angles *(concluded)*

Symbol	Tolerance zone and application example	Verification method	Comments
⊥	  	**Method 14.2.2**  Simulate the toleranced feature (axis of the hole) with the axis of an inscribed cylinder extending outside the hole. Clamp the object on a rotating table the horizontal axis of which is perpendicular to the axis of both the toleranced and the datum feature. Record the angular positions (P_1 and P_2) of the rotating table when the mandrel and the simulated datum axis are in the same inclination relative to the surface plate. The perpendicularity deviation, Pd, is $Pd = \tan\lvert P_1 - P_2\rvert \times L$	The object is clamped so that the rotating axis is perpendicular to the tolerance plane. The object used in method 14.1.5 may be verified by the same verification method. The object is clamped so that the rotating axis is perpendicular to the datum line. The object used in method 14.1.6 may be verified by the same verification method. The object is clamped so that the rotating axis is parallel with the intersectional line of the toleranced feature and the datum plane. Inclination indicating instrument, etc., and autocollimator with mirror and V-block to be used.
	  	**Method 14.2.3**  Adjust the autocollimator parallel to the datum feature. (1) Move the mirror along the toleranced feature and record the values. (2) The perpendicularity deviation is calculated from the recorded values.	This method is generally used for large objects.

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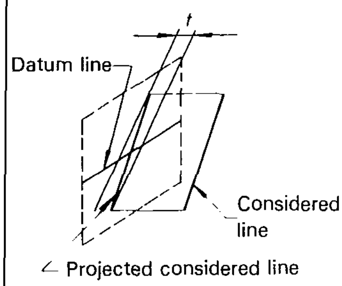
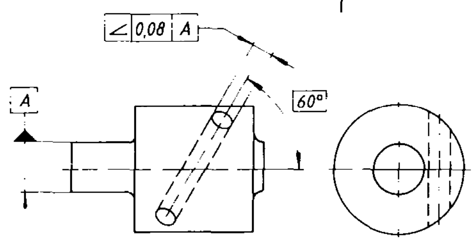
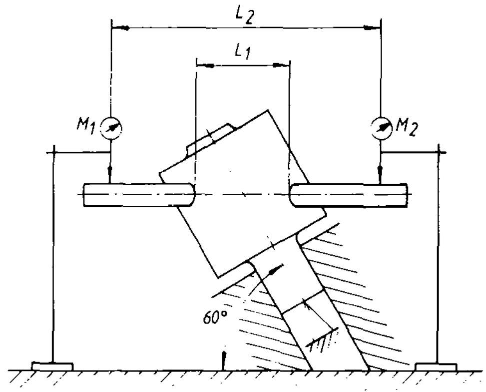
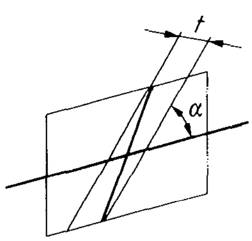
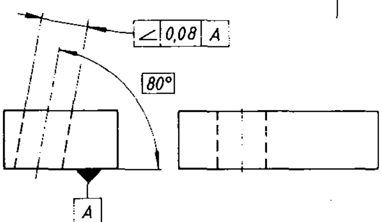
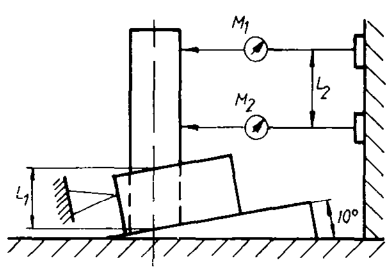
15 Verification of angularity

15.1 Principle 1 — Verifying angularity deviations by measuring distance

Symbol	Tolerance zone and application example	Verification method	Comments
∠	 	**Method 15.1.1**  Place and align the object in an enclosing guide element with the specified angle. Turn the object so that the difference $M_1 - M_2$ is an algebraic minimum. The angularity deviation, Ad, is : $Ad = \frac{\|M_1 - M_2\| \times L_1}{L_2}$	The cylindrical mandrel may be either expanded or selected to fit in the hole without clearance.
	 	**Method 15.1.2**  Place the object on an angle plate with the angle 10° (90° − 80°). Fit a mandrel in the toleranced hole. Turn the object on the angle plate so that the difference $M_1 - M_2$ is an algebraic minimum. Measure the distance of the mandrel from a square on two heights, L_2 apart. The angularity deviation, Ad, is $Ad = \frac{\|M_1 - M_2\| \times L_1}{L_2}$	The cylindrical mandrel may be either expanded or selected to fit in the hole without clearance.

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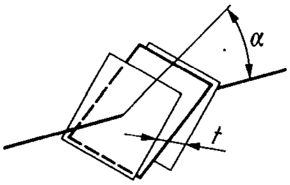
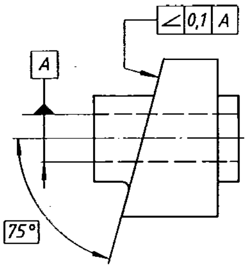
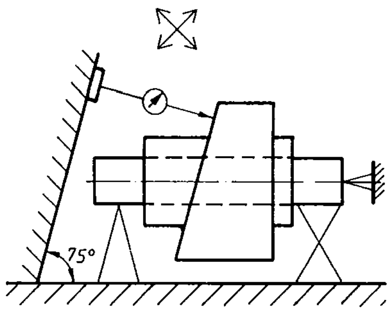
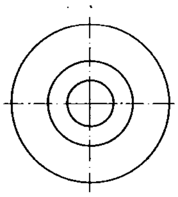
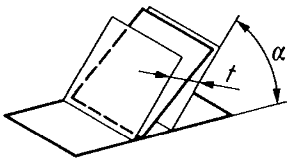
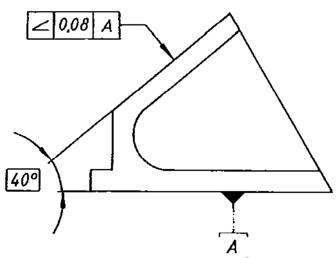
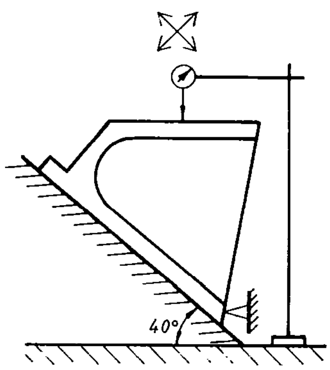
15.1 Principle 1 — Verifying angularity deviations by measuring distance *(concluded)*

Symbol	Tolerance zone and application example	Verification method	Comments
∠	 	**Method 15.1.3**   Simulate the datum axis with an inscribed cylinder and align it parallel to the horizontal surface plate and normal to the lower edge of the inclined surface plate. Remove the object until the measured deviation is a minimum. Measure the distance of the toleranced feature from an angle plate. The angularity deviation is the full indicator movement.	The cylindrical mandrel may be either expanded or selected to fit in the hole without clearance.
	 	**Method 15.1.4**  Place the object on an angle plate with an angle of 40°. Adjust the object by turning so that the full indicator movement of the toleranced feature is a minimum. The angularity deviation is the full indicator movement.	

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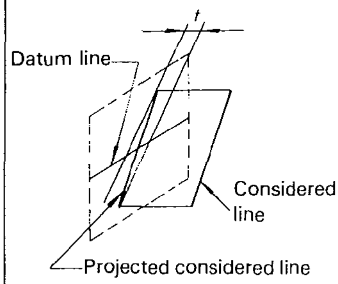
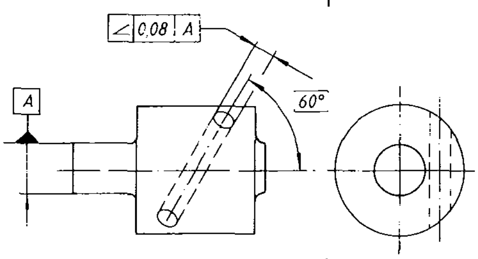
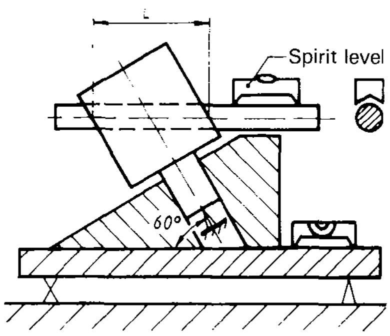
15.2 Principle 2 — Verifying angularity deviations by measuring angles

Symbol	Tolerance zone and application example	Verification method	Comments
∠	 	**Method 15.2.1**  Place the object in an enclosing guide element with the specified angle to the horizontal plane. Turn the object until the right-hand end of the mandrel is in its highest position relative to the left-hand side. Measure the inclination. The angularity deviation, Ad, is $Ad = \|\text{inclination}\| \times L$	The cylindrical mandrel may be either expandable or selected to fit in the hole without clearance.

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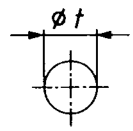
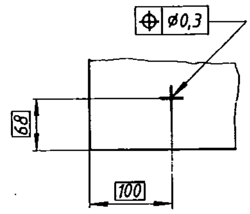
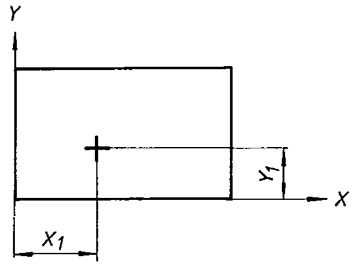
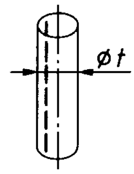
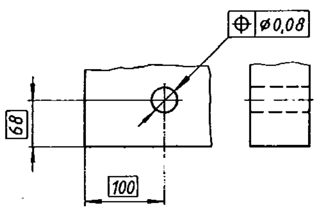
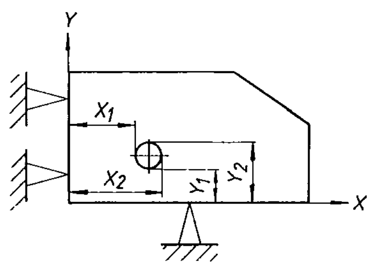
16 Verification of position

16.1 Principle 1 — Verifying position deviations by measuring coordinates or distances

<table>
<tr><th>Symbol</th><th>Tolerance zone and application example</th><th>Verification method</th><th>Comments</th></tr>
<tr><td rowspan="2">⌖</td><td>


</td><td>Method 16.1.1


Align the object with the coordinates of the measuring device.
Measure the coordinates X_1 and Y_1.
The positional deviation, Pd, is calculated from the two coordinate readings
$$Pd = \sqrt{(100 - X_1)^2 + (68 - Y_1)^2}$$
The deviation shall not exceed half the tolerance value.</td><td></td></tr>
<tr><td>


</td><td>Method 16.1.2


Align the object with the coordinates of the measuring device.
Measure coordinates X_1, X_2, Y_1 and Y_2.
The position of the hole axis in the X direction is calculated using the formula
$$X = \frac{X_2 + X_1}{2}$$
and in the Y direction using the formula
$$Y = \frac{Y_2 + Y_1}{2}$$
The positional deviation, Pd, is calculated from the derived X and Y values
$$Pd = \sqrt{(100 - X)^2 + (68 - Y)^2}$$
The deviation shall not exceed half the tolerance value.</td><td></td></tr>
</table>

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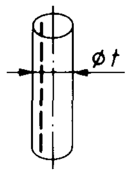
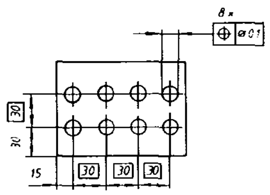
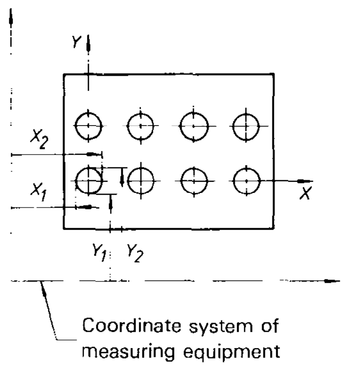
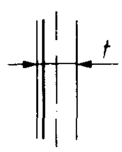
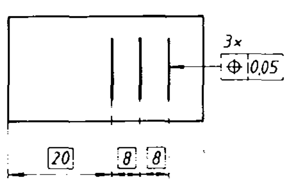
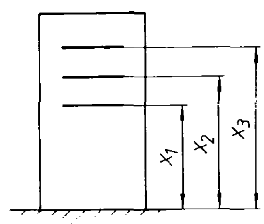
16.1 Principle 1 — Verifying position deviations by measuring coordinates or distances *(continued)*

Symbol	Tolerance zone and application example	Verification method	Comments
⌖	 	**Method 16.1.3**  When there is more than one hole, repeat the measurements and calculation as given in method 16.1.2 for each hole. Move the object in relation to the measuring coordinates in order to find the best fit. The deviation shall not exceed half the tolerance value.	Depending on the measuring equipment available, the centres of the holes can be measured directly by using measuring plugs. The best fitting position can also be obtained by a mathematical treatment.
	 	**Method 16.1.4**  Align the object with the coordinates of the measuring device. Carry out the measurements $X_1, \ldots, X_3$ along the lines. The positional deviation is equal to the difference between the maximum and minimum values respectively and the basic position of each measured line. The deviation shall not exceed half the tolerance value.	

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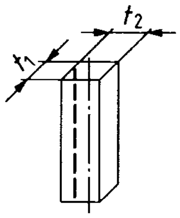
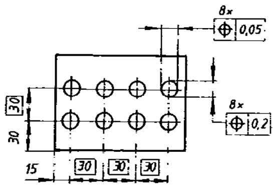
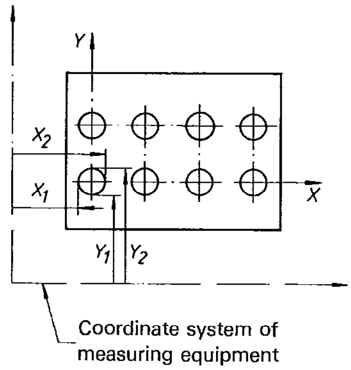
16.1 Principle 1 — Verifying position deviations by measuring coordinates or distances *(continued)*

Symbol	Tolerance zone and application example	Verification method	Comments
⌖	 	**Method 16.1.5**  Align the object with the coordinates of the measuring device. Place expandable cylindrical mandrels into the holes. Take the coordinates X_1, X_2, Y_1 and Y_2 for each hole separately. The positional deviation, Pd, in the X direction is calculated using the formula $Pd_X = \left\| \frac{X_2 + X_1}{2} - X_{\text{theoretical}} \right\|$ and in the Y direction using the formula $Pd_Y = \left\| \frac{Y_2 + Y_1}{2} - Y_{\text{theoretical}} \right\|$ Move the object in relation to the measuring coordinates in order to find the best fit. The deviation shall not excceed half the tolerance value.	Instead of expandable mandrels, cylindrical mandrels selected to fit without clearance can be used. If the form deviation of the hole does not affect the result, the measurements can be made to the edges of the hole. The best fitting position can also be obtained by mathematical treatment.

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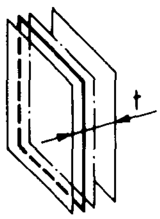
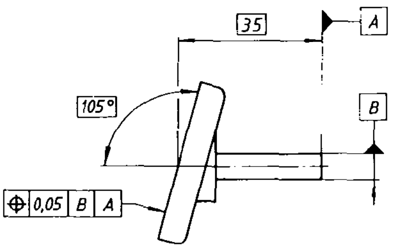
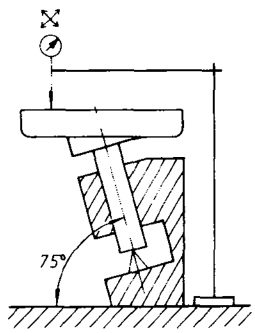
16.1 Principle 1 — Verifying position deviations by measuring coordinates or distances *(concluded)*

Symbol	Tolerance zone and application example	Verification method	Comments
⌖	 	**Method 16.1.6**  The measuring equipment includes an enclosing guide element with the specified angle. Set the indicator to zero relative to the master object. Turn the workpiece to be measured in such a way that the measured deviation on the surface is a minimum. Carry out measurements at the required number of points all over the surface. The position deviation is the maximum deviation of the indicator relative to the zeroed value. The deviation shall not exceed half the tolerance value.	

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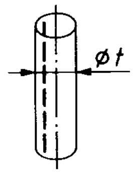
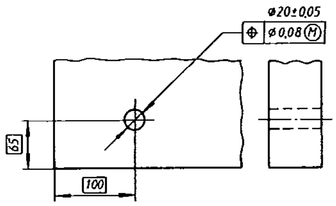
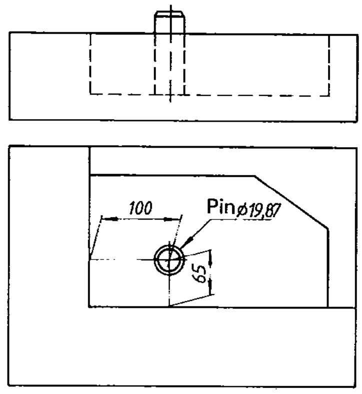
16.2 Principle 2 — Verifying position deviations by using the maximum material principle

Symbol	Tolerance zone and application example	Verification method	Comments
⌖	 	**Method 16.2.1**  Check the object in a functional gauge which accepts the pin relative to the end surfaces specified by the two theoretically exact dimensions.	

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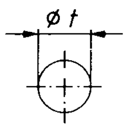
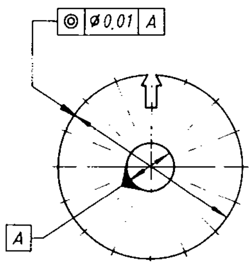
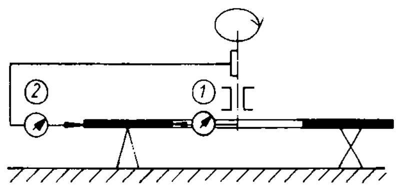
17 Verification of concentricity

17.1 Principle 1 — Verifying concentricity deviations by measuring variation in radius from a fixed common centre

Symbol	Tolerance zone and application example	Verification method	Comments
◎	 	**Method 17.1.1**  Align the considered circular feature under consideration with the measuring equipment. The plane in which the object is required to be measured shall be perpendicular to the rotating axis. Record the variation in radius from the fixed common centre during one revolution for the datum feature (1) and the toleranced feature (2). From the recording, the two centres are defined. The concentricity deviation is the distance between the two centres. The deviation shall not exceed half the tolerance value.	Equipment for measurement of radius variation from fixed centre. Rotating pointer or rotating table to be used.

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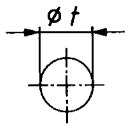
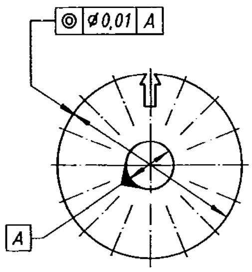
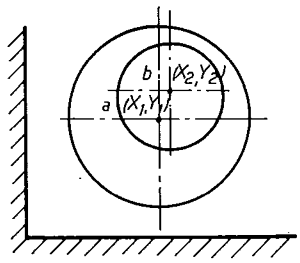
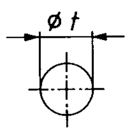
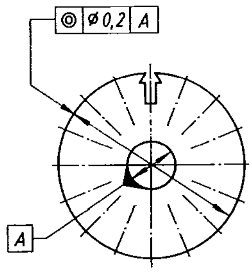
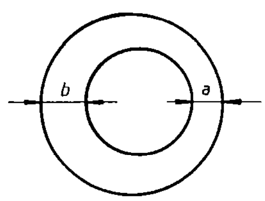
17.2 Principle 2 — Verifying concentricity deviations by measuring coordinates or distances

Symbol	Tolerance zone and application example	Verification method	Comments
◎	 	**Method 17.2.1**  Align the circular feature under consideration with the measuring equipment. The plane in which the measurement is required shall be parallel to the X-Y plane. Move the stylus so that it touches the circumference in at least three, preferably equidistant, places. Calculate the positions of centres a (X_1, Y_1) of the datum feature and b (X_2, Y_2) of the toleranced feature. The concentricity deviation is the distance between the two centres calculated using the formula Concentricity deviation $= \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2}$ The deviation shall not exceed half the tolerance value.	Applicable for external and internal circular features. The influence of form error is minimized when the measurements are repeated in other points. In that way the centre-coordinates are mean values. Coordinate measuring device with calculator or measuring microscope with calculator to be used.
	 	**Method 17.2.2**  Find, by measuring, the minimum distance a between the datum circumference and the feature circumference. Measure distance b in the opposite position (180° apart). The concentricity deviation is half the difference between distances a and b. The deviation shall not exceed half the tolerance value.	This method can be used only when the error of form can be ignored. Calliper or micrometer to be used.

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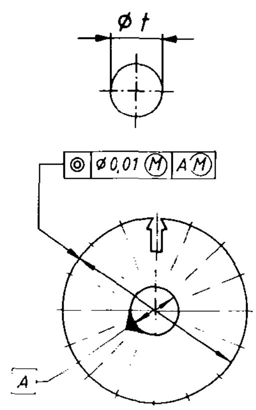
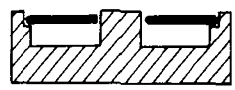
17.3 Principle 3 — Verifying concentricity deviations by using maximum material principle

Symbol	Tolerance zone and application example	Verification method	Comments
◎		**Method 17.3.1**  Check the object using a functional gauge. Indicate the datum and feature axis with coaxial external and internal cylinders.	Design of function gauge : The datum cylinder shall have the minimum dimension of the hole. The feature register shall have the maximum dimension plus the tolerance of concentricity.

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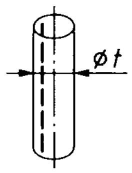
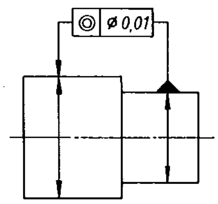
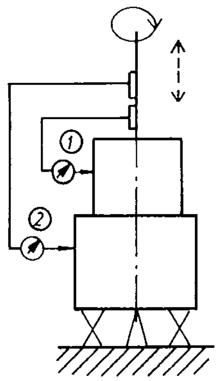
18 Verification of coaxiality

18.1 Principle 1 — Verifying coaxiality deviations by measuring variation in radius from a fixed common axis

Symbol	Tolerance zone and application example	Verification method	Comments
◎	 	**Method 18.1.1**  Align the object with the measuring equipment so that the axis of the datum cylinder is coincident with the rotating axis. (1) Determine the axis of the feature by recording the variation in radius at the required number of sections on the toleranced feature. (2) The deviation from coaxiality is calculated from the centres of the recordings, taking into account the position of the section in the axial direction. The deviation shall not exceed half the tolerance value.	Applicable for both external and internal surfaces. Equipment for measurement of radius variation from a fixed common centre with a recorder for polar diagrams and/or computer to be used.

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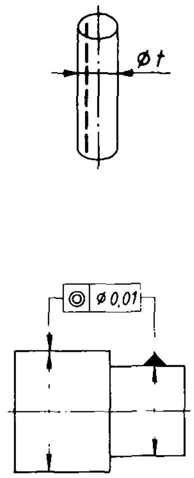
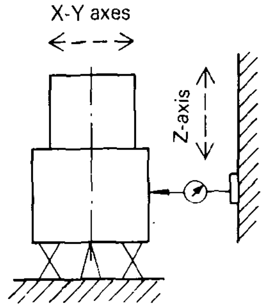
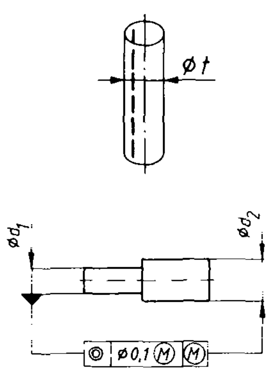
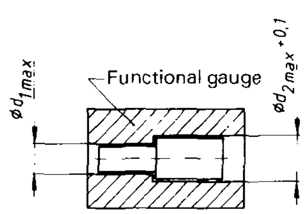
18.2 Principle 2 — Verifying coaxiality deviations by measuring coordinates or distances

Symbol	Tolerance zone and application example	Verification method	Comments
◎		**Method 18.2.1**  Align the object with the measuring equipment. The axis of the datum cylinder shall be perpendicular to the X- and Y-axes of the measuring device. In every section of the feature, measure the contact points of the diameters along the X-axis and Y-axis and record the results together with the level of the section. By means of these points, four generators are constructed, and the co-axiality deviation is determined from the axis of the circumscribing/inscribed element. The deviation shall not exceed half the tolerance value.	Applicable for both external and internal surfaces.

18.3 Principle 3 — Verifying coaxiality deviations by using maximum material principle

Symbol	Tolerance zone and application example	Verification method	Comments
◎		**Method 18.3.1**  Check the object using a functional gauge. Indicate the datum and feature axis with coaxial cylinders.	

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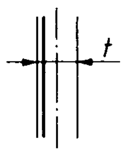
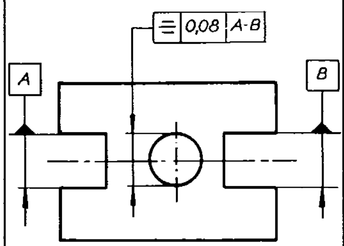
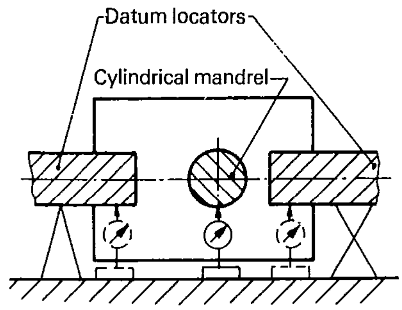
19 Verification of symmetry

19.1 Principle 1 — Verifying symmetry deviations by measuring coordinates or distances

Symbol	Tolerance zone and application example	Verification method	Comments
⌯	 	**Method 19.1.1**  Simulate the datum plane with the median plane of two inscribed locators. Determine the position and the size of the locators and adjust the common datum plane parallel to the surface plate. Simulate the feature axis with the inscribed cylinder. The symmetry deviation is the difference in distance between the centre of the inscribed cylinder and the common datum plane. The deviation shall not exceed half the tolerance value.	The cylindrical mandrel and the datum locators may be either expanded or selected to fit in the hole (or in the grooves) without clearance. If the hole deviates from cylindrical form in such a way that the mandrel can be placed in different directions, it should be placed in that direction where the movement in the actual opposite directions is the same. As the measurements are taken outside the feature, the actual deviation shall be calculated for the relevant length of the feature. This method is applicable to both external and internal surfaces.

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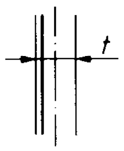
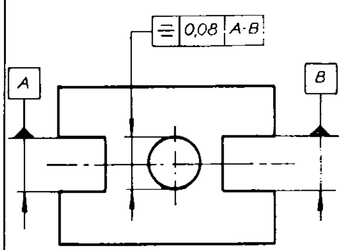
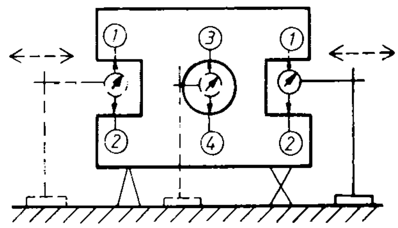
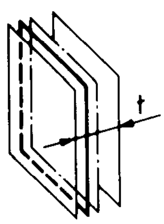
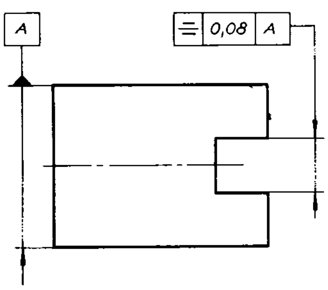
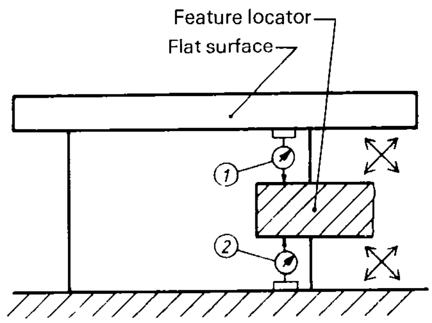
19.1 Principle 1 — Verifying symmetry deviations by measuring coordinates or distances *(continued)*

Symbol	Tolerance zone and application example	Verification method	Comments
	 	**Method 19.1.2**  Align the object in the following way : Determine the position of the datum features (1) (2) and calculate and adjust the median planes of the datum parallel to the surface plate. The symmetry deviation is the difference in distance between the common plane and the calculated feature axis (3) (4). The deviation shall not exceed half the tolerance value.	This method is applicable to both external and internal surfaces. The adjustment of the datums could also be performed by mathematical calculation. Coordinate measuring device or measuring microscope to be used.
⌯	 	**Method 19.1.3**  Place the object on a surface plate. Place a flat surface on the opposite surface. Simulate the median plane of the toleranced feature with a feature locator. The symmetry deviation is half the difference in distance (1) (2) between the feature locator and the surface plate and the flat surface, respectively. The deviation shall not exceed half the tolerance value.	This method is applicable to both external and internal surfaces. The feature locator may be either expanded or selected to fit in the groove without clearance. As the measurements are taken outside the feature, the actual deviation shall be calculated for the relevant length of the feature.

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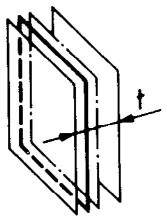
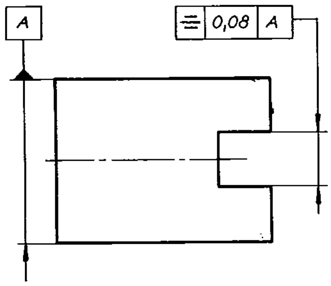
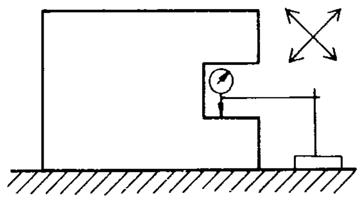
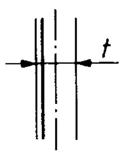
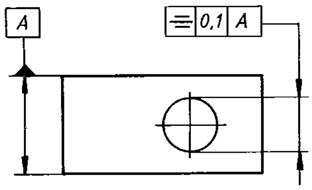
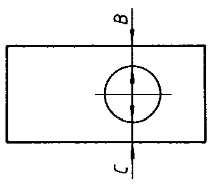
19.1 Principle 1 — Verifying symmetry deviations by measuring coordinates or distances *(concluded)*

Symbol	Tolerance zone and application example	Verification method	Comments
⌯	 	**Method 19.1.4**  Place the object on a surface plate. Measure the distance between the surface plate and the feature. Turn the object and repeat the measurement. The symmetry deviation is half the difference between the distances measured. The deviation shall not exceed half the tolerance value.	This method is applicable to both external and internal surfaces.
	 	**Method 19.1.5**  Measure the distances from the feature surface to points on the datum surface. The symmetry deviation is half the difference between the distances B and C. The deviation shall not exceed half the tolerance value.	Calliper to be used.

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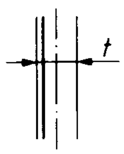
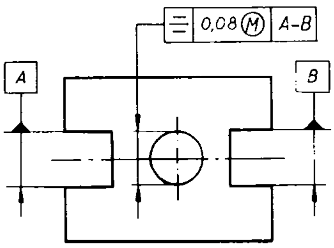
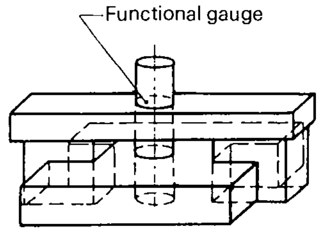
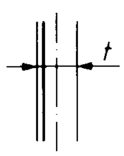
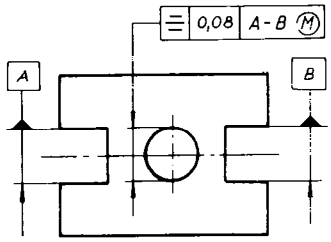
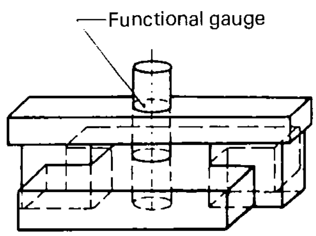
19.2 Principle 2 — Verifying symmetry deviations by using maximum material principle

Symbol	Tolerance zone and application example	Verification method	Comments
⌯	 	**Method 19.2.1**  Check the object using a functional gauge. Simulate the datums using two tabs. Check the symmetry deviation using a cylinder of appropriate size.	The two tabs shall be expanded or selected to fit without clearance. The cylindrical mandrel shall have the minimum size of the hole minus the symmetry tolerance.
	 	**Method 19.2.2**  Check the object using a functional gauge. Simulate the datums using two tabs. Check the symmetry deviation using a cylinder of appropriate size.	The width of the two gauge tabs shall have the maximum material size of the slots minus the symmetry tolerance. The cylindrical mandrel shall be expanded or selected to fit without clearance.

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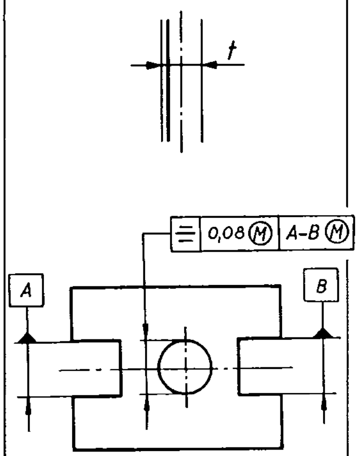
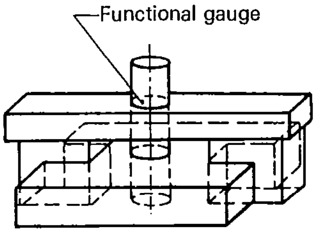
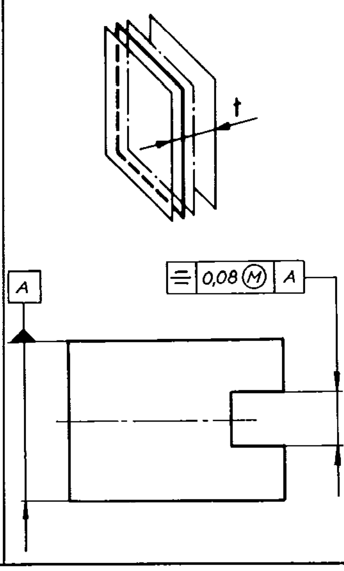
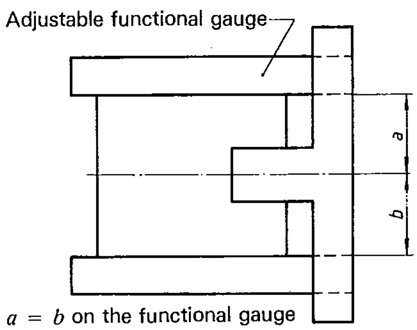
19.2 Principle 2 — Verifying symmetry deviations by using maximum material principle *(concluded)*

<table>
<tr><th>Symbol</th><th>Tolerance zone and application example</th><th>Verification method</th><th>Comments</th></tr>
<tr><td rowspan="2">⌯</td><td>
</td><td>Method 19.2.3


Check the object using a functional gauge.
Simulate the datums using two tabs.
Check the symmetry deviation using a cylinder of appropriate size.</td><td>The width of the two gauge tabs shall have the maximum material size of the slots.
The cylinder shall have the minimum size of the hole minus the symmetry tolerance.</td></tr>
<tr><td>
</td><td>Method 19.2.4


Check the object using a functional gauge.
Simulate the datum plane with two adjustable plates.
Check the symmetry deviation using a tab.</td><td>This principle is applicable to both external and internal surfaces.
For internal surfaces, the width of the tab shall have the minimum size of the slot minus the symmetry tolerance.</td></tr>
</table>

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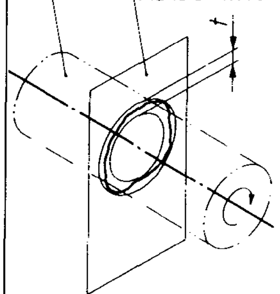
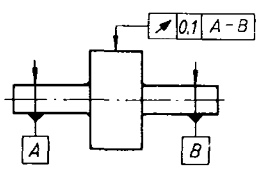
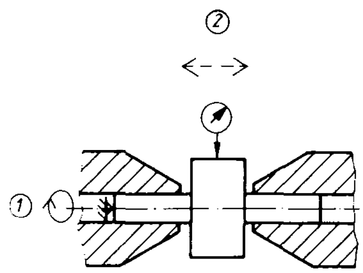
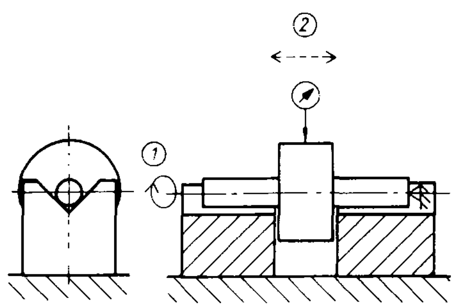
20 Verification of circular run-out

20.1 Principle 1 — Verifying circular run-out deviations by measuring distance variations from a fixed point during rotation around the datum axis

Symbol	Tolerance zone and application example	Verification method	Comments
↗	  	**Method 20.1.1**  Align the object in two coaxial circumscribing guide cylinders. Fix the object axially. The radial run-out deviation is the full indicator movement measured during one complete revolution at each cross-section. (1) Repeat this procedure at the required number of cross-sections. (2)	
		Method 20.1.2  Simulate the datum axis with two identical V-blocks. Fix the object axially. The radial run-out deviation is the full indicator movement measured during one complete revolution at each cross-section. (1) Repeat this procedure at the required number of cross-sections. (2)	The measurement is affected by the combined effects of the V-block angle and the form deviations of the datum features.

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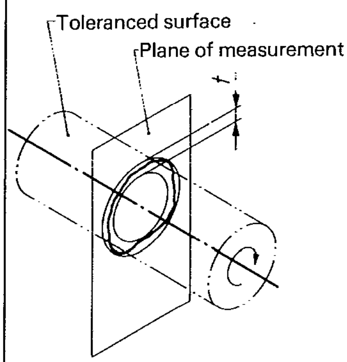
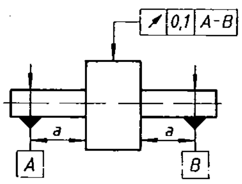
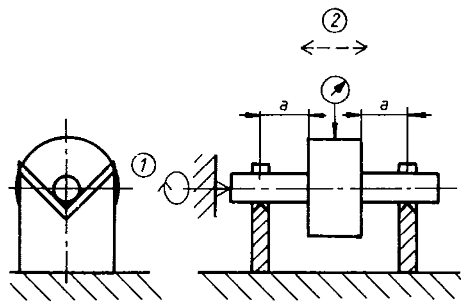
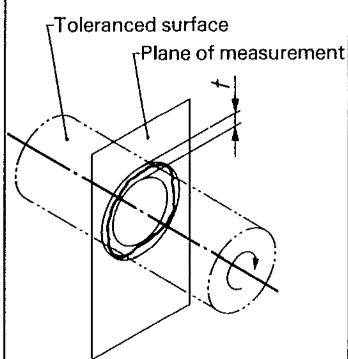
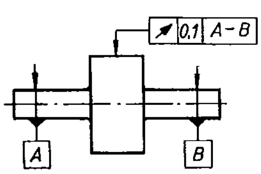
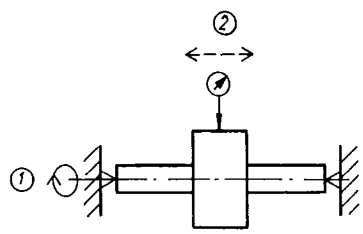
20.1 Principle 1 — Verifying circular run-out deviations by measuring distance variations from a fixed point during rotation around the datum axis *(continued)*

Symbol	Tolerance zone and application example	Verification method	Comments
	 	**Method 20.1.3**  Simulate the datum axis with two identical knife edge V-blocks. Fix the object axially. The radial run-out deviation is the full indicator movement measured during one complete revolution at each cross-section. (1) Repeat this procedure at the required number of cross-sections. (2)	The measurement is affected by the combined effects of the V-edge angle and the form deviations of the datum features.
	 	**Method 20.1.4**  Clamp the object between centres. Measure the radial run-out deviation of the feature and make corrections for the corresponding run-out of the datums A and B relative to the centres. (1) Repeat the measurement at the required number of cross-sections. (2)	Measurement in working machine tool between centres. The measuring results are affected by the run-out of the centres with regard to the datum features.

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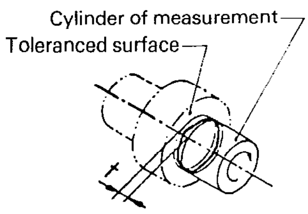
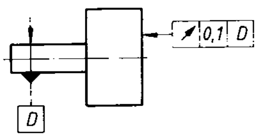
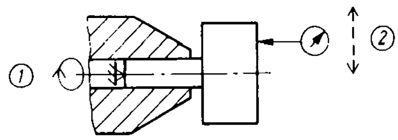
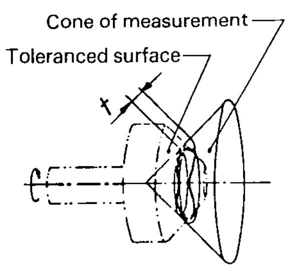
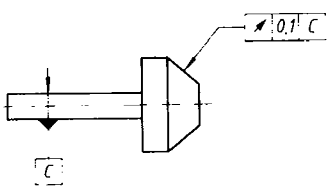
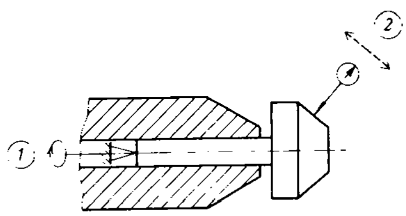
20.1 Principle 1 — Verifying circular run-out deviations by measuring distance variations from a fixed point during rotation around the datum axis *(concluded)*

Symbol	Tolerance zone and application example	Verification method	Comments
	 	**Method 20.1.5**  Clamp the object in a circumscribing guide. Fix the object axially. The axial run-out deviation is the full indicator movement measured during one complete revolution at each position. (1) Repeat this procedure at the required number of positions. (2)	
	 	**Method 20.1.6**  Clamp the object in circumscribing guides. Fix the object axially. The run-out deviation in the direction of the arrow is the full indicator movement measured during one complete revolution at each cross-section. (1) Repeat this procedure at the required number of cross-sections. (2)	Instead of adjustable cylinders, for example a chuck may be used. In such cases, the measurement is affected by the errors of the chuck. This method is used also for radial and axial run-out.

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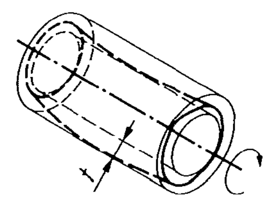
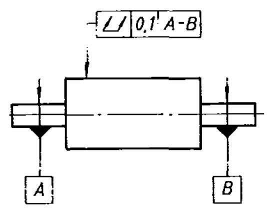
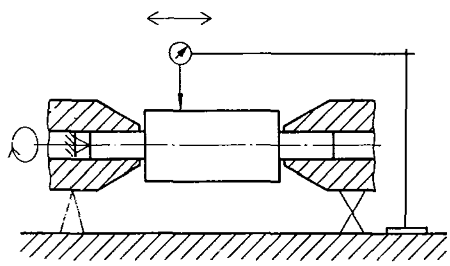
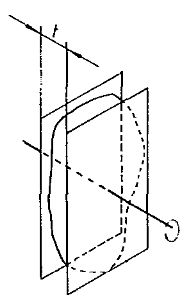
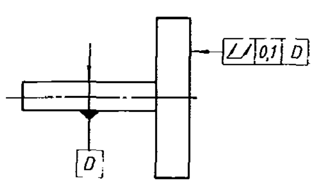
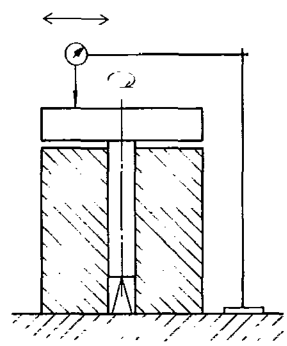
21 Verification of total run-out

21.1 Principle 1 — Verifying total run-out deviations by measuring distance variations from the basic geometry during rotation around the datum axis

<table>
<tr><th>Symbol</th><th>Tolerance zone and application example</th><th>Verification method</th><th>Comments</th></tr>
<tr><td rowspan="2">⌰</td><td>
</td><td>Method 21.1.1

Place the object in two coaxial circumscribing guides aligned parallel to the surface plate.
Fix the object axially.
The radial total run-out is the full indicator movement during several revolutions of the object while the indicator is moved along one (straight) line element of the theoretically exact geometric form relative to the datum axis.</td><td>The datum can be established in a simple way using V-blocks, centres, etc.</td></tr>
<tr><td>
</td><td>Method 21.1.2

Align the object in one circumscribing guide perpendicular to the surface plate.
Fix the object axially.
The axial total run-out is the full indicator movement during several revolutions of the object while the indicator is moved along one radial line element of the theoretically exact geometric form relative to the datum axis.</td><td>The datum can be established in a simple way using V-blocks, V-yokes, etc.</td></tr>
</table>

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