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INTERNATIONAL ORGANIZATION FOR STANDARDIZATION • МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ • ORGANISATION INTERNATIONALE DE NORMALISATION

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.

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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apply verification principles and methods on geometrical tolerances, it was decided that the results of the work would not be published as an International Standard for the time being.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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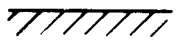
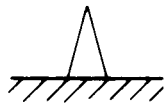
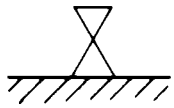
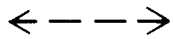
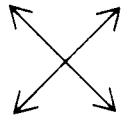
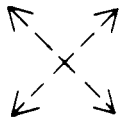
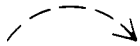
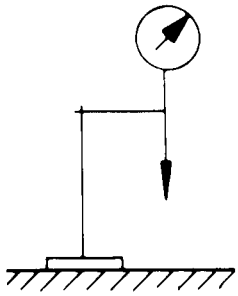
4 Symbols

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.

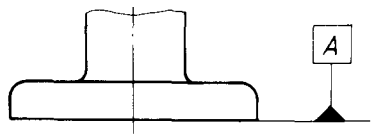
The datum feature is a real feature of a part which is marked on the drawing as a datum.

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)].



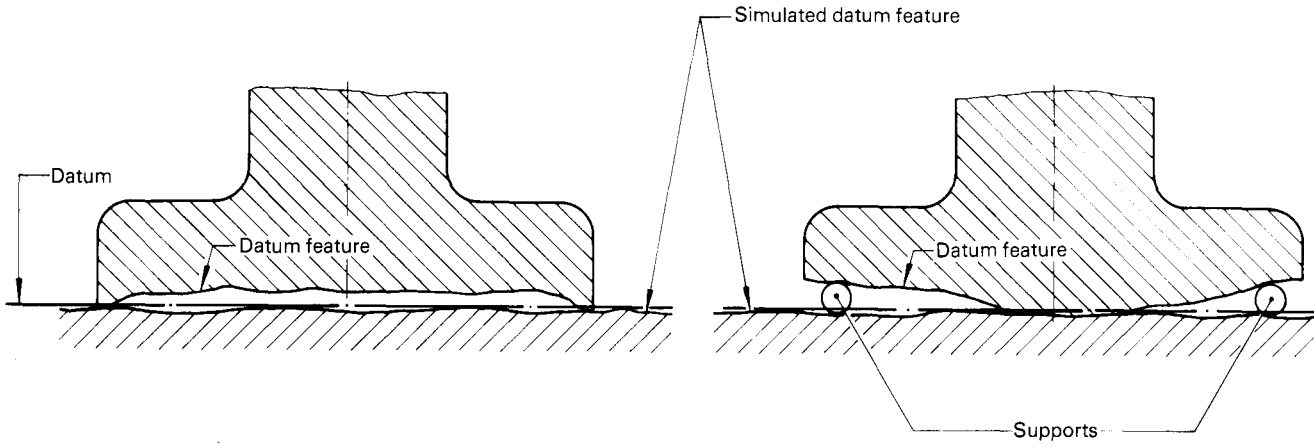


Figure 1 a)

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).

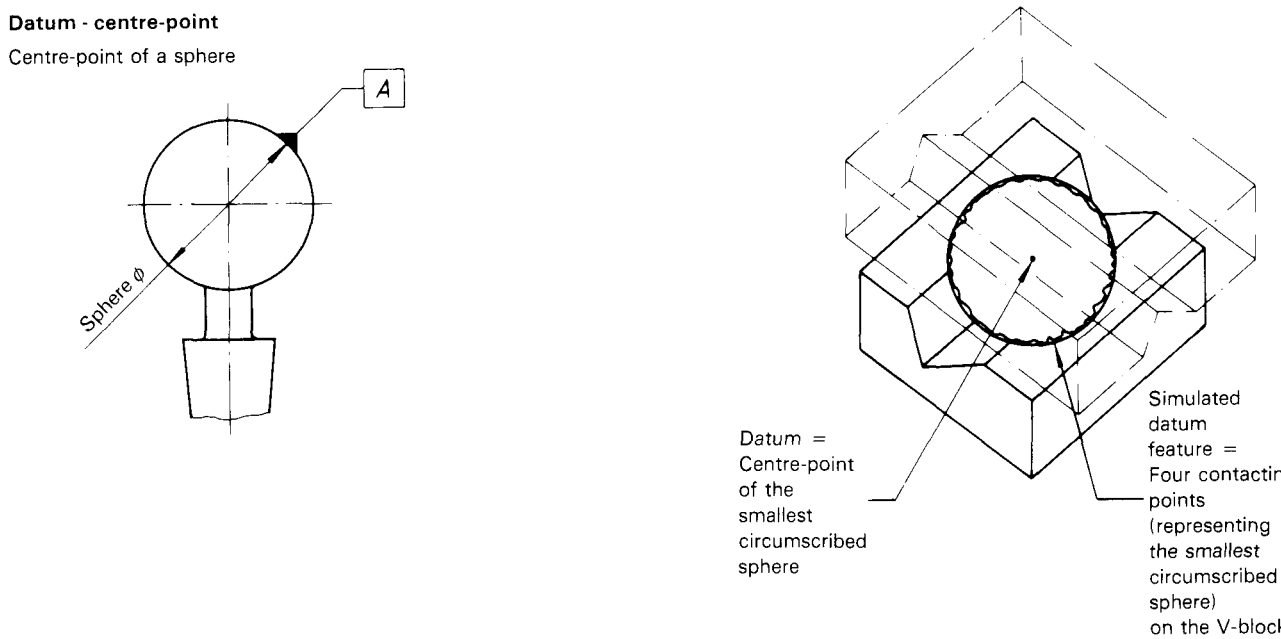

Figure 2 — Establishment of a point as the datum

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.

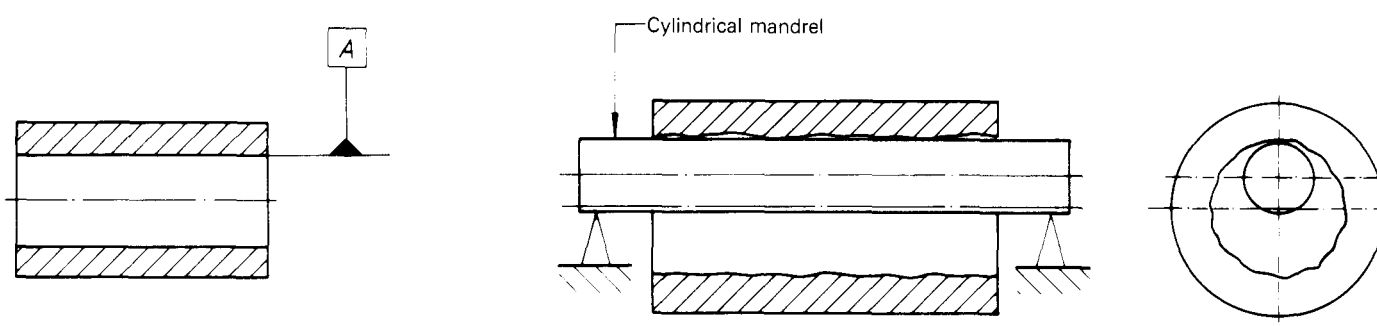

Figure 3 — Practical way of establishing a generating line as the datum

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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).

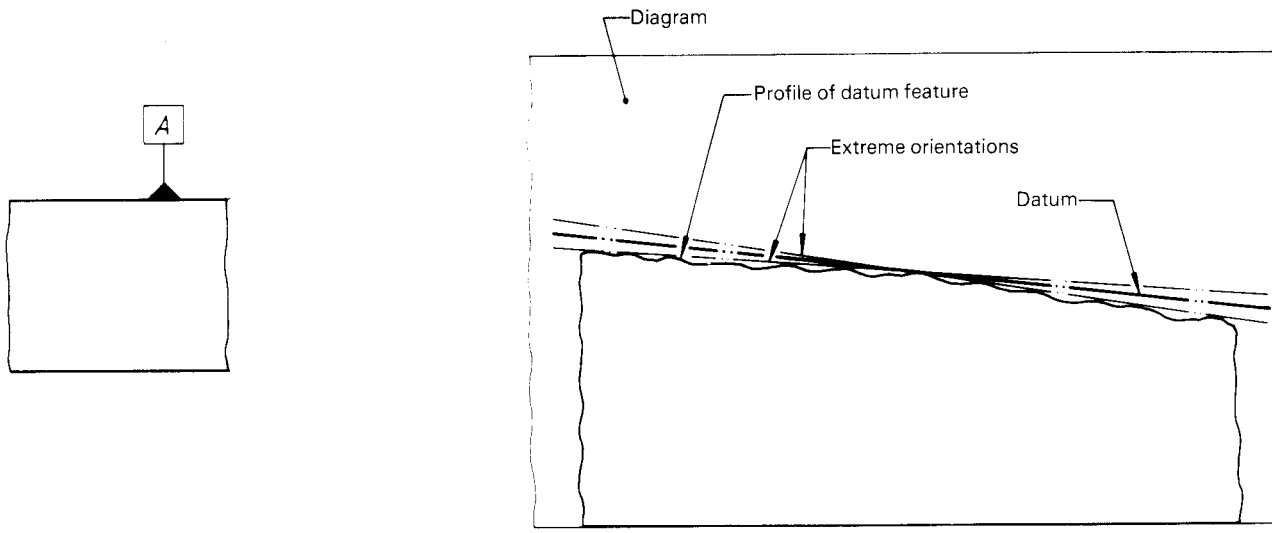

Figure 4 — Profile diagram for graphical evaluation of datum

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).

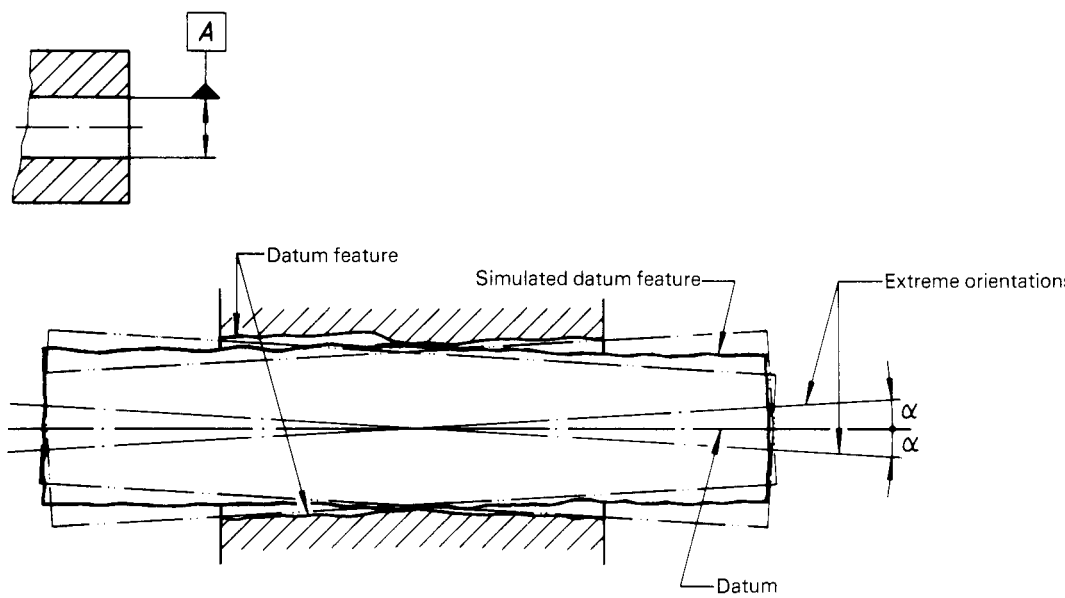

Figure 5 — Alignment of simulated datum feature in a hole

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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.

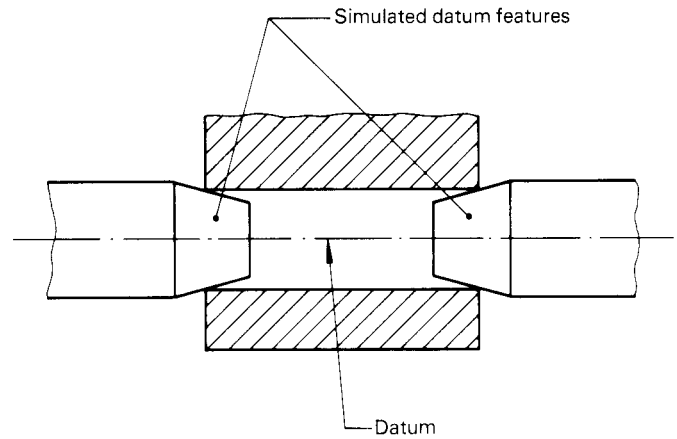

Figure 6 — Simplified alignment of an axis as the datum (internal features)

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).

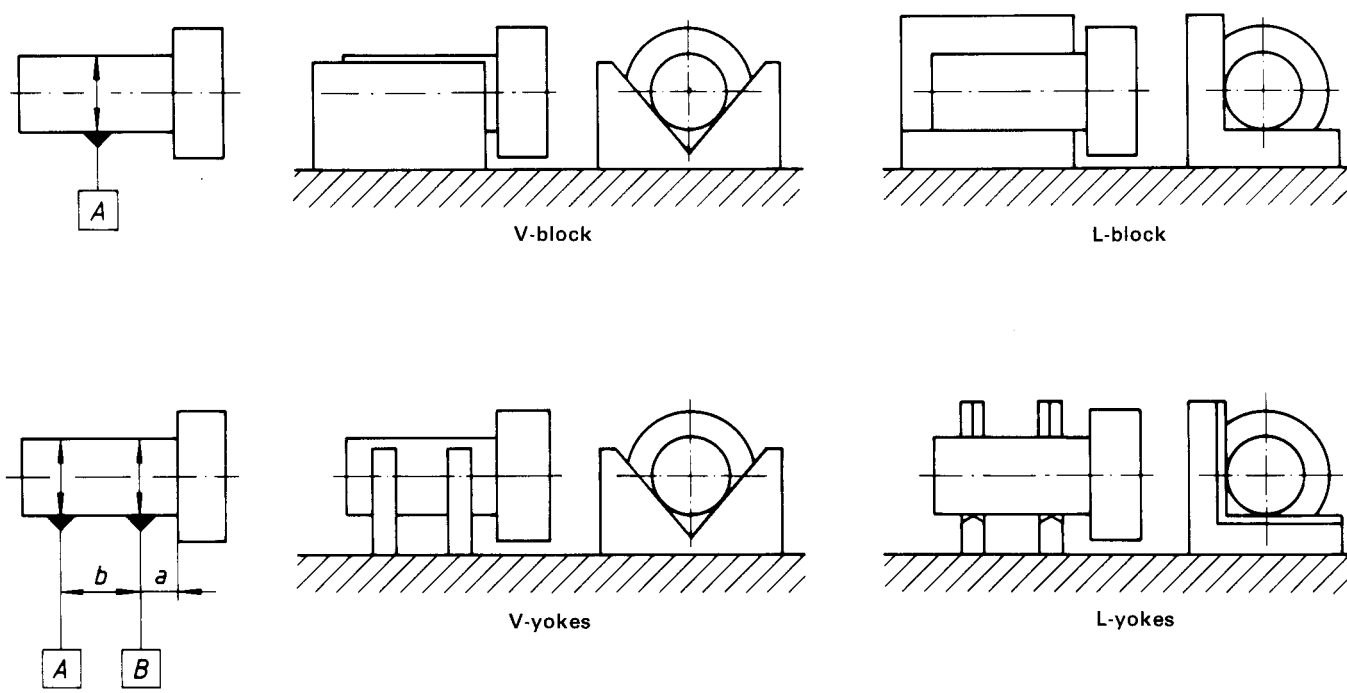

Figure 7 — Simplified alignment of an axis as the datum (external features)

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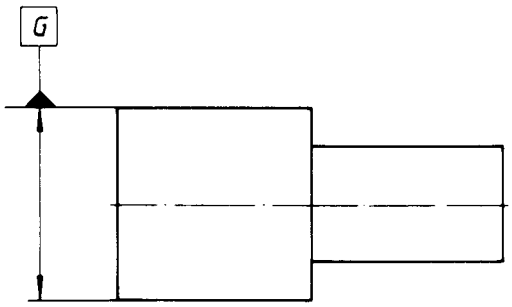
Depending on the form deviations of the datum feature, the angle in the V-block and the V-yokes can affect the position of the datum, which also affects the measured value.

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



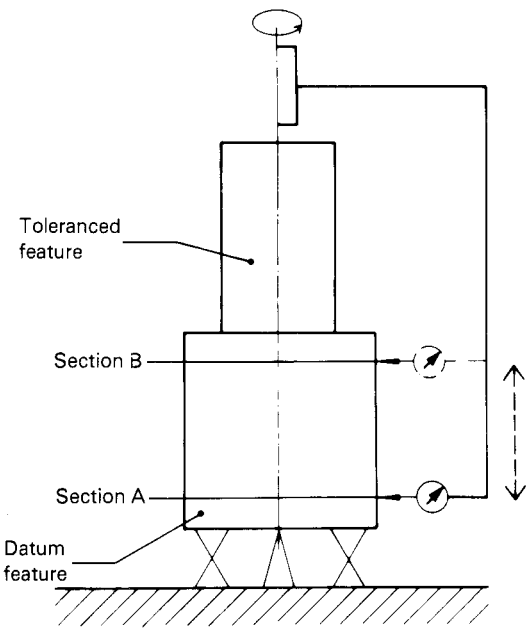


Figure 8a) — Measurement of simulated datum feature from a fixed axis

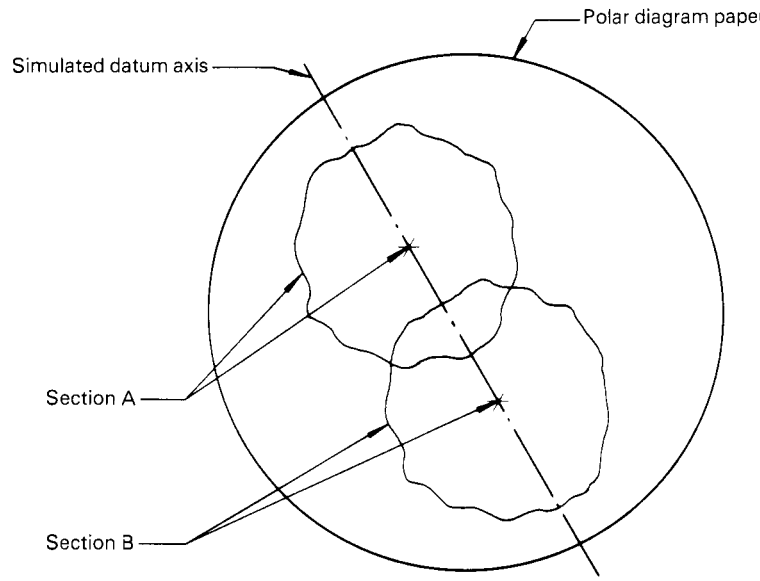


Figure 8b) — Graphical evaluation of the datum axis

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).

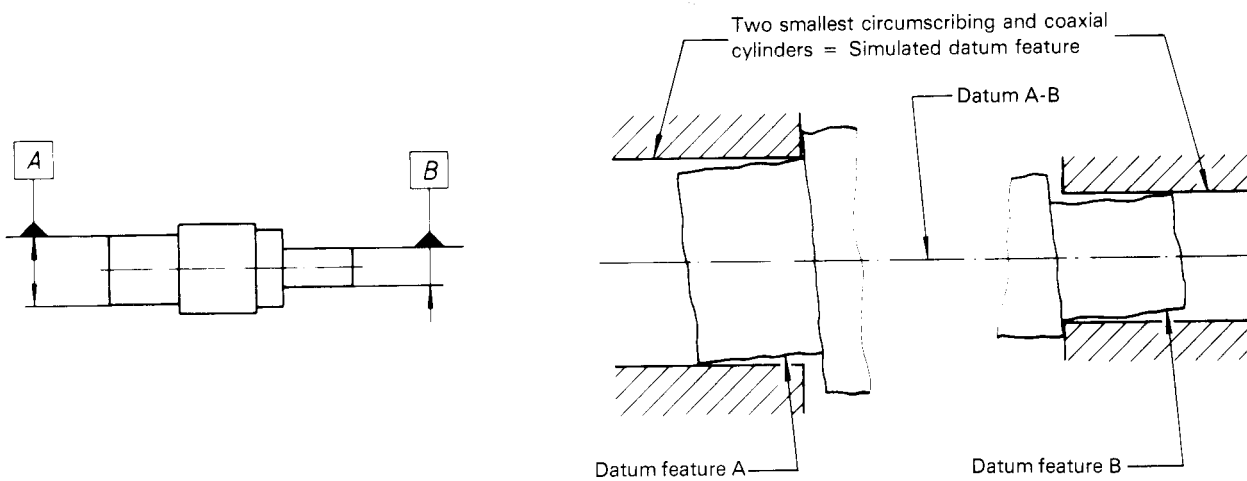

Figure 9 — Guidance of two datum features when the datum is a common axis

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).

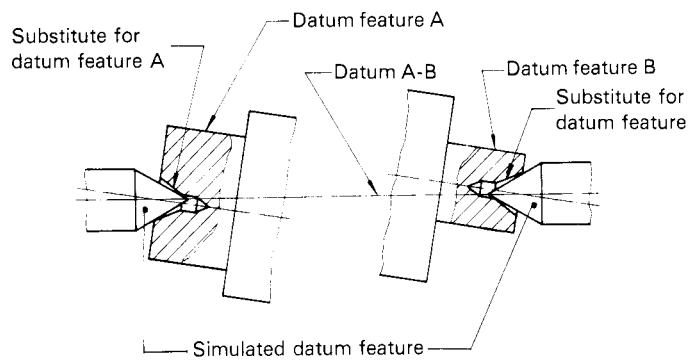

Figure 10 — Conical centres used as substitutes for cylindrical datum features

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).

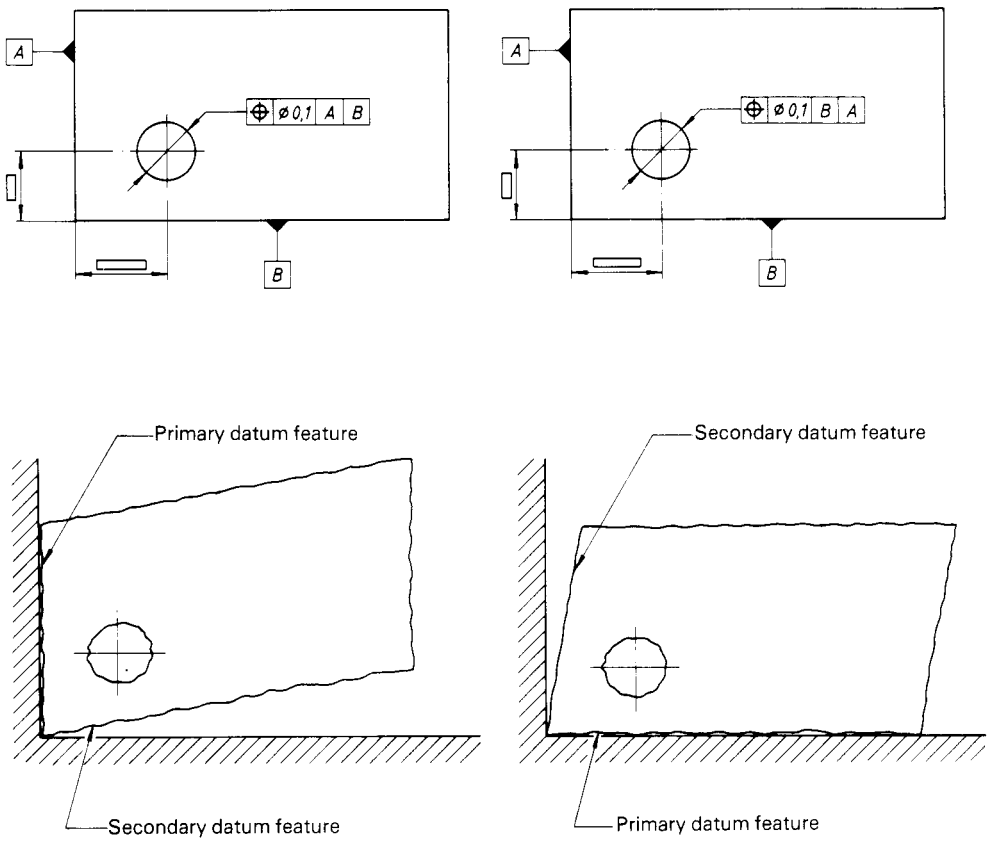

Figure 11 — Influence on the toleranced feature depending on the sequence of the datum features used on the toleranced feature

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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)].

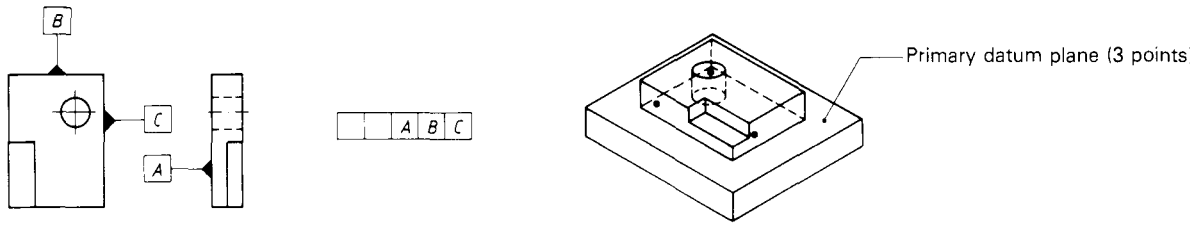

Figure 12a)

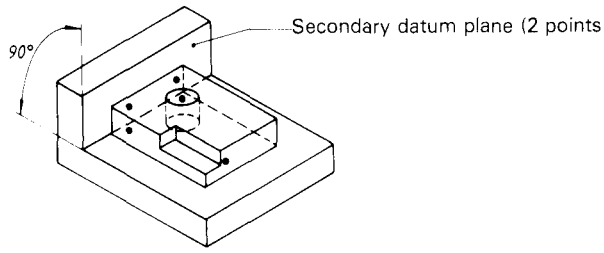

Figure 12b)

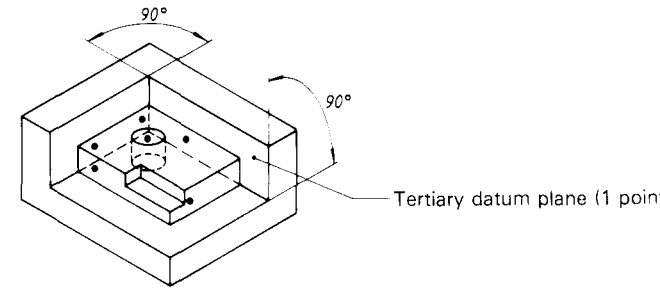

Figure 12c)

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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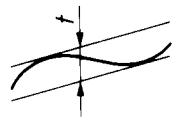
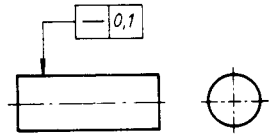
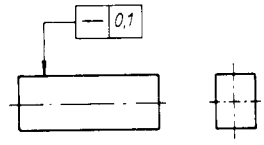
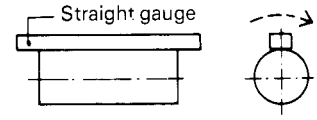
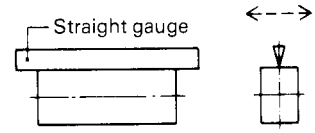
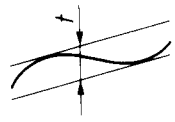
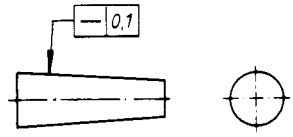
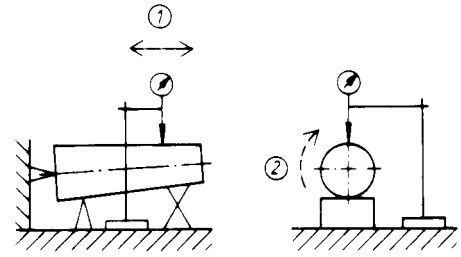
7 Verification of straightness

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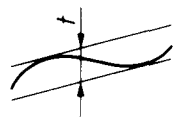
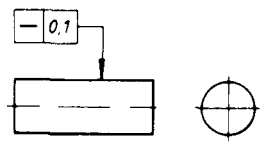
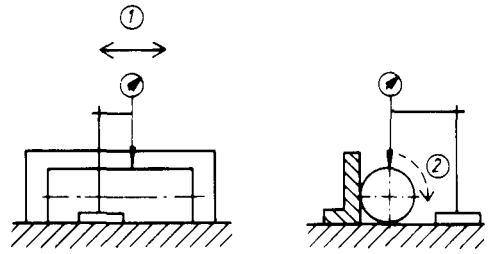
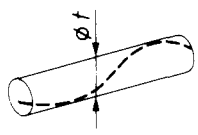
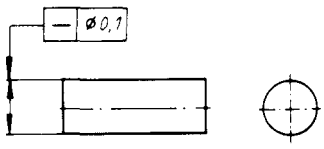
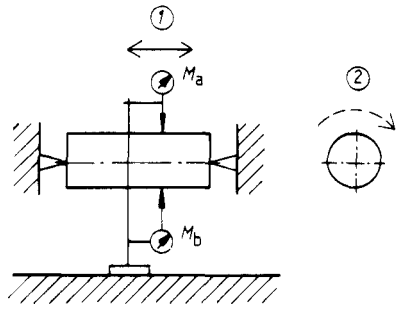
7.1 Principle 1 — Verifying straightness deviations by comparing with a straight element *(continued)*

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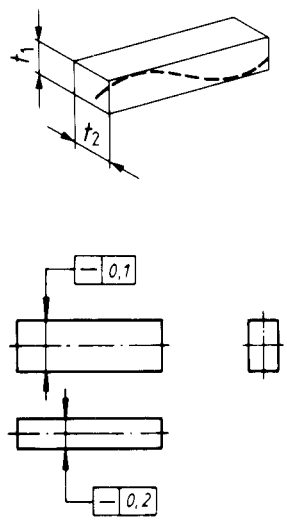
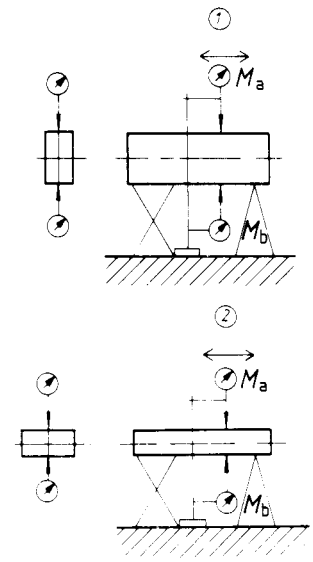
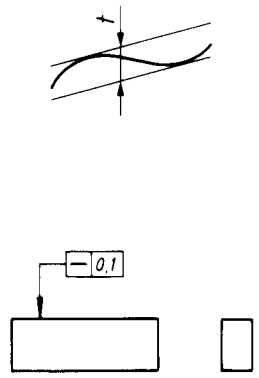
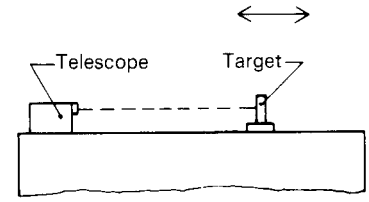
7.1 Principle 1 — Verifiying straightness deviations by comparing with a straight element *(continued)*

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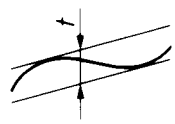
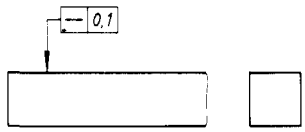
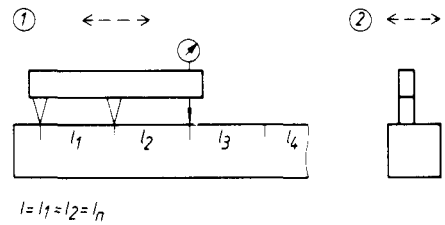
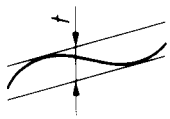
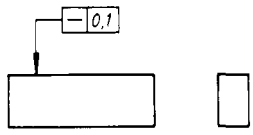
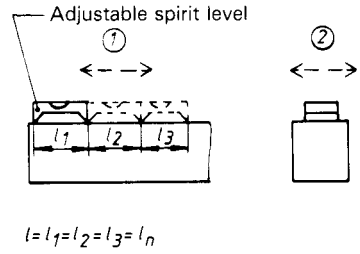
7.1 Principle 1 — Verifying straightness deviations by comparing with a straight element *(concluded)*

Symbol	Tolerance zone and application example	Verification method	Comments
—	 	**Method 7.1.7**  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**  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 × 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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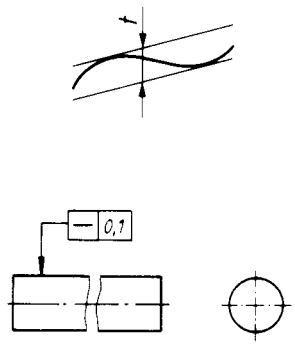
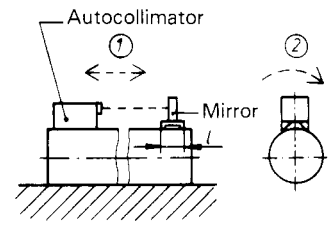
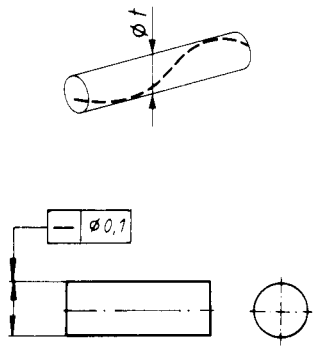
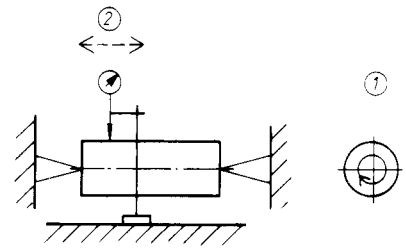
7.2 Principle 2 — Verifying straightness deviations by measuring angle deviations *(concluded)*

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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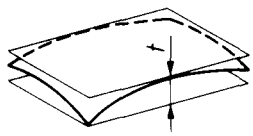
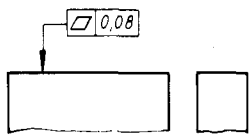
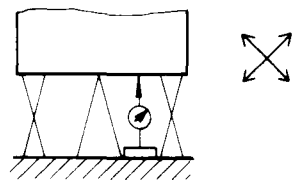
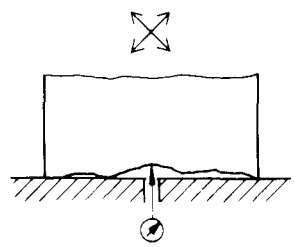
8 Verification of flatness

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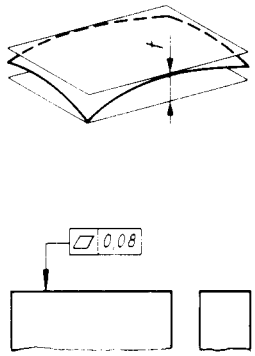
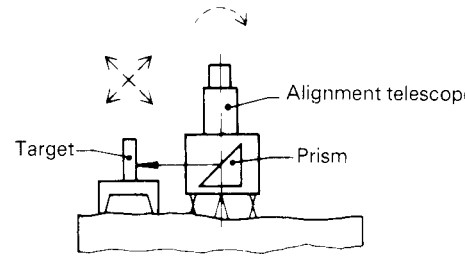
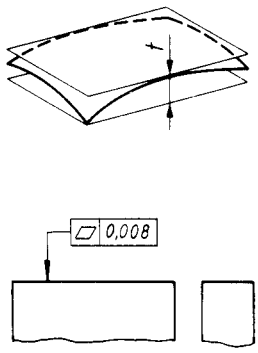
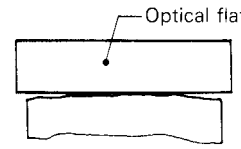
8.1 Principle 1 — Verifying flatness deviations by comparing with a flat element *(concluded)*

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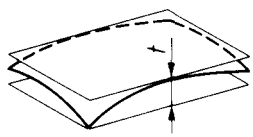
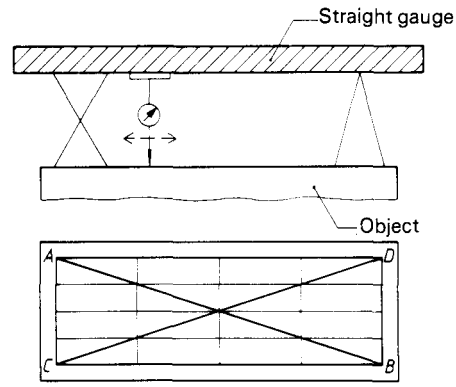
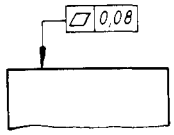
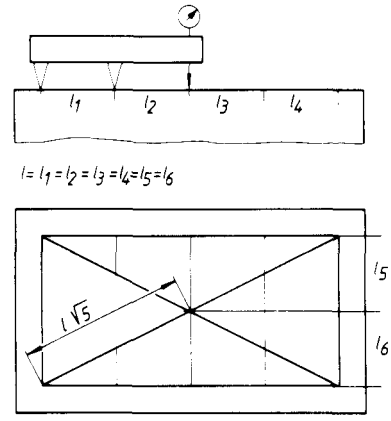
8.2 Principle 2 — Verifying flatness deviations by comparing with a straight element in several directions

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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