TECHNICAL SPECIFICATION

ISO/TS 17450-1

First edition
2005-02-01

Geometrical product specifications (GPS) — General concepts —

Part 1:
Model for geometrical specification and verification

Spécification géométrique des produits (GPS) — Concepts généraux —

Partie 1: Modèle pour la spécification et la vérification géométriques

Reference number
ISOTS 17450-1:2005(E)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

In other circumstances, particularly when there is an urgent market requirement for such documents, a technical committee may decide to publish other types of normative document:

— an ISO Publicly Available Specification (ISO/PAS) represents an agreement between technical experts in an ISO working group and is accepted for publication if it is approved by more than 50 % of the members of the parent committee casting a vote;

— an ISO Technical Specification (ISO/TS) represents an agreement between the members of a technical committee and is accepted for publication if it is approved by 2/3 of the members of the committee casting a vote.

An ISO/PAS or ISO/TS is reviewed after three years in order to decide whether it will be confirmed for a further three years, revised to become an International Standard, or withdrawn. If the ISO/PAS or ISO/TS is confirmed, it is reviewed again after a further three years, at which time it must either be transformed into an International Standard or be withdrawn.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO/TS 17450-1 was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification*.

ISO/TS 17450 consists of the following parts, under the general title *Geometrical product specifications (GPS) — General concepts*:

— *Part 1: Model for geometrical specification and verification*

— *Part 2: Basic tenets, specifications, operators and uncertainties*

Introduction

This part of ISO/TS 17450 is a Geometrical Product Specification (GPS) document and is to be regarded as a global GPS document (see ISO/TR 14638). It influences all chain links of the chains of standards.

For more detailed information on the relationship of this part of ISO/TS 17450 to other standards and to the GPS matrix model, see annex E.

In a market environment of increased globalization, the exchange of technical product information is of high importance and the need to express unambiguously the geometry of mechanical workpieces of vital urgency. Consequently, codification associated with the macro- and micro-geometry of workpiece specifications must be unambiguous and complete if the functional geometrical variation of parts is to be limited; in addition, the language ought to be applicable to CAX systems.

The aim of ISO/TC 213 is to provide the tools for a global and "top-down" approach to GPS. These tools are the basis of new standards for a common language for geometrical definition, able to be used by design (assemblies and individual workpieces), manufacturing and inspection, including for description of the measurement procedure, regardless of the media (e.g. paper drawing, numerical drawing or exchange file) used. These tools are based on the characteristics of features, as well as on the constraints between the features and on feature operations, used for the creation of different geometrical features.

Geometrical product specifications (GPS) — General concepts —

Part 1: Model for geometrical specification and verification

1 Scope

This part of ISO/TS 17450 provides a model for geometrical specification and verification and defines the corresponding concepts. It also explains the mathematical basis of the concepts associated with the model.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14660-1:1999, *Geometrical Product Specifications (GPS) — Geometrical features — Part 1: General terms and definitions*

International Vocabulary of Basic and General Terms in Metrology (VIM). BIPM, IFCC, IEC, ISO, IUPAC, IUPAP, OIML, 2nd edition, 1993

3 Terms and definitions

For the purposes of the present document, the terms and definitions given in ISO 14660-1 and VIM, and the following apply.

3.1
associated feature
ideal feature established from a non-ideal surface model (skin model) or from a real surface through an association operation

NOTE The relationship between this term and ISO 14660-1 is given in Figure 1.

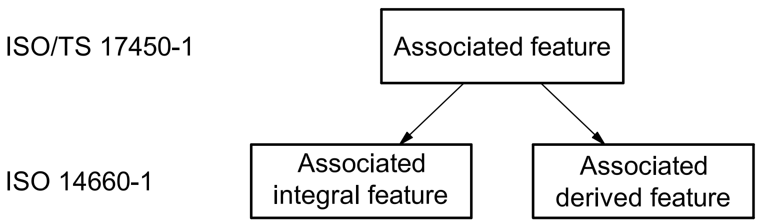


Figure 1 — Relationships of the term associated feature

3.2
association
operation used to fit ideal feature(s) to non-ideal feature(s) according to a criterion

NOTE See 8.1.5.

3.3
bounded feature
feature contained within a sphere of finite radius

3.4
characteristic
single property of one or more feature(s) expressed in linear or angular units

NOTE See annex D.

3.5
collection
operation used to identify more than one feature together, in accordance with the function of the workpiece

NOTE See 8.1.6.

3.6
construction
operation used to build ideal feature(s) from other ideal features, within constraints

NOTE See 8.1.7.

3.7
deviation
difference between the value of a characteristic obtained from the non-ideal surface model (skin model) and the corresponding nominal value

3.8
evaluation
operation used to identify either the value of a characteristic, or its nominal value and its limit(s)

NOTE See 8.2.

3.9
extraction
operation used to identify specific points from a non-ideal feature

NOTE See 8.1.3.

3.10
feature
geometric feature
point, line or surface

[ISO 14660-1]

3.11
feature operation
specific tool required for obtaining features

3.12
filtration
operation used to create a non-ideal feature by reducing the level of information of a non-ideal feature

NOTE See 8.1.4.

3.13
ideal feature
feature defined by a parametrized equation

NOTE The expression of the parametrized equation depends on the type of ideal feature and on the intrinsic characteristics.

3.14
intrinsic characteristic
characteristic of an ideal feature

NOTE 1 See 7.2.

NOTE 2 Ideal features have only dimensional characteristics as intrinsic characteristics.

NOTE 3 The intrinsic characteristics are the parameters of the parametrized equation of the ideal feature.

3.15
invariance class
a group of ideal features defined by the same invariance degree

3.16
invariance degree of an ideal feature
displacement(s) of the ideal feature for which the feature is kept identical in the space

NOTE It corresponds to the degree of freedom used in kinematics.

3.17
nominal feature
ideal feature independent of the non-ideal surface model (skin model)

NOTE The relationship between this term and ISO 14660-1 is given in Figure 2.

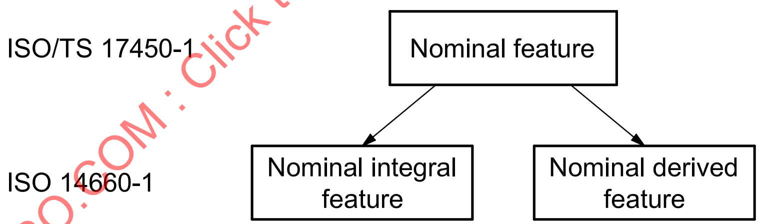


Figure 2 — Relationships of the term nominal feature

3.18
nominal model
model of the workpiece of perfect shape defined by the designer (design intent)

3.19
non-ideal feature
imperfect feature fully dependent on the non-ideal surface model (skin model)

3.20
operation
specific tool required to obtain features or values of characteristics, their nominal value and their limit(s)

3.21
partition
operation used to identify bounded feature(s) from non-ideal feature(s) or from ideal feature(s)

NOTE See 8.1.2

3.22
real surface of a workpiece
set of features which physically exist and separate the entire workpiece from the surrounding medium

[ISO 14660-1]

3.23
situation characteristic
characteristic defining the relative location or orientation between two features

3.24
situation characteristic between ideal features
characteristic defining the relative location or orientation between two situation features

3.25
situation characteristic between non-ideal and ideal features
characteristic defining the relative location between a non-ideal feature and an ideal feature

3.26
situation feature
feature of type point, straight line, plane or helix, which allows the location and/or orientation of a feature to be defined

3.27
non-ideal surface model (of a workpiece)
skin model (of a workpiece)
model of the physical interface of the workpiece with its environment

NOTE See clause 5.

3.28
specification
expression of permissible limits on a characteristic

3.29
specification by dimension
specification that limits the permissible value of an intrinsic characteristic or of a situation characteristic between ideal features

3.30
specification by zone
specification that limits the permissible variation of a non-ideal feature inside a space limited by an ideal feature or by ideal features

3.31
type (of ideal feature)
name given for a set of shapes of an ideal feature

NOTE 1 See Tables 2 and 3.

NOTE 2 From a type of ideal feature, a particular feature can be defined by giving value(s) to intrinsic characteristic(s).

NOTE 3 The type defines the parametrized equation of the ideal feature.

3.32
unbounded feature
feature that cannot be contained within a sphere of finite radius

3.33
variation
phenomenon whereby the value of a characteristic is not constant within one individual feature or within a set of workpieces

4 Application and future prospects

4.1 The model proposed in this part of ISO/TS 17450 is aimed at

a) expressing the fundamental concepts on which the geometrical specification of workpieces can be based, with a global approach including all the geometrical tools (e.g. operations) needed in GPS, and

b) providing a mathematization of the concepts (see annex B), in order to facilitate standardization inputs to

- software designers for CAD-systems,
- software designers for computing algorithms in metrology, and
- standards makers on STEP (computerized exchange of product data between CAD-systems).

4.2 This part of ISO/TS 17450 is not intended to be used directly as a standard way to specify the geometry of a workpiece, but should serve as a basis for revising and completing the existing standards according to a unified and systematic approach, in order to

a) provide a non-ambiguous GPS language, to be used and understood by people involved in design, manufacturing and inspection, and

b) identify correctly features, characteristics, and rules, thereby providing the capacity to

- propose default definitions, for example, definition of a least square surface,
- propose rules for expressing non-default definitions (special definitions),
- propose a simplified symbology,
- develop consistent rules for deviation assessment and measurement methods — the proposed tools allow the definition, without any ambiguity, of the quantity to be evaluated for each characteristic and also allow the explicit description of the measurement sequence — and
- use statistical tools — as each characteristic is defined without any ambiguity, it is possible to consider it as deterministic or statistical (e.g. statistical process control or statistical tolerance functional analysis).

5 General

The geometrical specification is the design step where the field of permissible deviations of a set of characteristics of a workpiece is stated, accommodating the required functional performance of the workpiece (functional need). It will also define a level of quality in conformance with manufacturing processes, the limits permissible for manufacturing, and the definition of the conformity of the workpiece (see Figure 3).

Functional need —— **Functional specification** —— **Geometrical specification**

Figure 3 — Relationship between functional needs and geometrical specification

The designer first defines a “workpiece” of perfect form with shape and dimensions that fit the functions of the mechanism. This “workpiece” of perfect form is called the nominal model (see Figure 4).

This first step establishes a representation of the workpiece with only nominal values that is impossible to produce or inspect (each manufacturing or measuring process has its own variability or uncertainty).

The real surface of the workpiece, which is the physical interface of the workpiece with its environment, is imperfect geometry; it is impossible to completely capture the dimensional variation of the real surface of the workpiece in order to completely understand the complete extent of all variation.

From the nominal geometry, the designer imagines a model of this real surface, which represents the variations that could be expected on the real surface of the workpiece. This model representing the imperfect geometry of the workpiece is called the non-ideal surface model (skin model) (see Figure 5).

The non-ideal surface model (skin model) is used to simulate variations of the surface at a conceptual level. On this model the designer will be able to optimize the maximum permissible limit values for which the function is downgraded but still ensured. These maximum permissible limit values define the tolerances of each characteristic of the workpiece.

NOTE This document does not include a methodology to evaluate how close the geometrical specification is to the functional specifications.

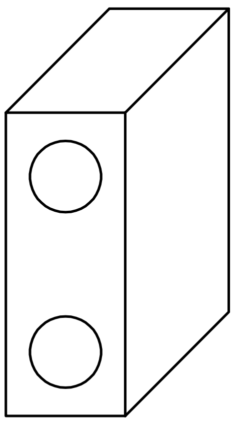


Figure 4 — Nominal model

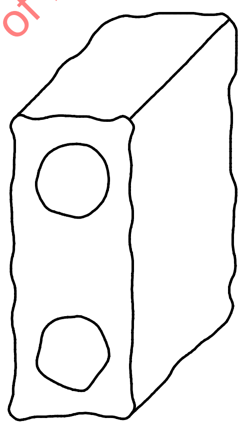


Figure 5 — Non-ideal surface model (skin model)

Verification is the manufacturing step at which a metrologist determines whether the real surface of a workpiece conforms to the field of permissible deviations that have been specified.

The definition of this geometrical deviation will be used to adjust the manufacturing process.

The metrologist begins by reading the specification, taking into account the non-ideal surface model (skin model), in order to know the specified characteristics. From the real surface of the workpiece, the metrologist defines the individual steps of the verification plan, depending on the measuring equipment.

Conformance is then determined by comparing the specified characteristics with the result of measurement (see Figure 6).

Geometrical specification —— **Quantity (to be measured)** —— **Result of measurement**

Figure 6 — Relationship between geometrical specification and result of measurement

6 Features

6.1 General

According to the definition of a feature, its nature is point, line or surface.

Two kinds of features can be distinguished:

a) ideal features (see 6.2);

b) non-ideal features (see 6.3).

6.2 Ideal features

6.2.1 Ideal features are defined by their type and by their intrinsic characteristics.

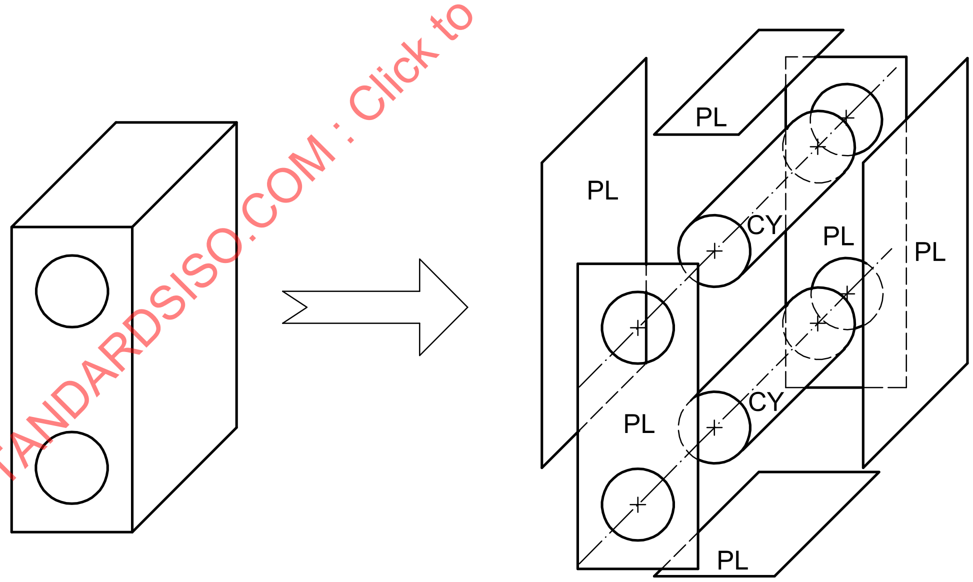
A feature is generally called by its type, for example, straight line, plane, cylinder, cone, sphere or torus.

Characteristics are defined in clause 7. A characteristic is, for example, the diameter of a cylinder, a distance between a plane and the centre point of a sphere, or the angle between the axis of a cylinder and a plane.

6.2.2 Ideal features used to define the nominal model are called nominal features. They are independent of the non-ideal surface model (skin model).

Ideal features, the characteristics of which are dependent on the non-ideal surface model (skin model), are called associated features.

For instance, the nominal model shown in Figure 7 is built with several ideal features of types plane and cylinder. The location and orientation between the features are given by situation characteristics, and the diameters of the cylinders are given by intrinsic characteristics (see clause 7).



a) Nominal model **b) Ideal features of types plane (PL) and cylinder (CY) constituting the nominal model**

Figure 7 — Building the nominal model

6.2.3 Ideal features can be unbounded or bounded by ideal boundaries (e.g. nominal features are bounded, associated features are bounded or unbounded).

6.2.4 All ideal features belong to one of the seven invariance classes defined in Table 1.

Table 1 — Table of invariance classes

Invariance class[a]	Invariance degree[b]
complex	None
prismatic	1 translation along a straight line
revolute	1 rotation around a straight line
helical	1 translation along and 1 rotation combined around a straight line
cylindrical	1 translation along and 1 rotation around a straight line
planar	1 rotation around a straight line and 2 translations in a plane perpendicular to the straight line
spherical	3 rotations around a point

[a] As defined in 3.15.

[b] As defined in 3.16.

EXAMPLE 1 A cylinder is invariant either by translation along its axis or by rotation around its axis; it belongs to the cylindrical invariance class.

EXAMPLE 2 A cone is invariant by rotation around its axis; it belongs to the revolute invariance class.

EXAMPLE 3 A prism with elliptical section is invariant by a translation along a straight line; it belongs to the invariance class prismatic.

6.2.5 For each ideal feature, one or more situation features can be defined: a situation feature is an ideal feature, which is a point, a straight line, a plane, or a helix, from which the location or orientation of a feature can be defined with characteristics. Examples of situation features are given in Table 2.

Table 2 — Examples of situation features of ideal features

Invariance class	Type	Examples of situation features
complex	elliptic curve hyperbolic paraboloid ...	ellipse plane, symmetry planes symmetry planes, tangent point ...
prismatic	prism with an elliptic basis ...	symmetry planes, axis
revolute	circle cone torus ...	the plane containing the circle, the circle centre the symmetry axis, apex the plane perpendicular to the torus axis, the torus centre ...
helical	helical line helical surface with a basis of involute to a circle ...	helix helix ...
cylindrical	straight line cylinder	the straight line [a] the symmetry axis [a]
planar	plane	the plane
spherical	point sphere	the point [a] the centre [a]

[a] No alternative situation feature can be chosen, because the result would be a different invariance class for the considered feature.

6.3 Non-ideal features

Non-ideal features are fully dependent of the non-ideal surface model (skin model). They can be

- the non-ideal surface model (skin model) itself (see Figure 5),
- part of the non-ideal surface model (skin model) (features called partition features) (see Figure 11),
- the derived partition features [features not included in the non-ideal surface model (skin model) but created by operation (see clause 8) from part of the non-ideal surface model (skin model)] (see Figure 8), or
- the intersection between the “non-ideal surface model (skin model)” and an ideal feature.

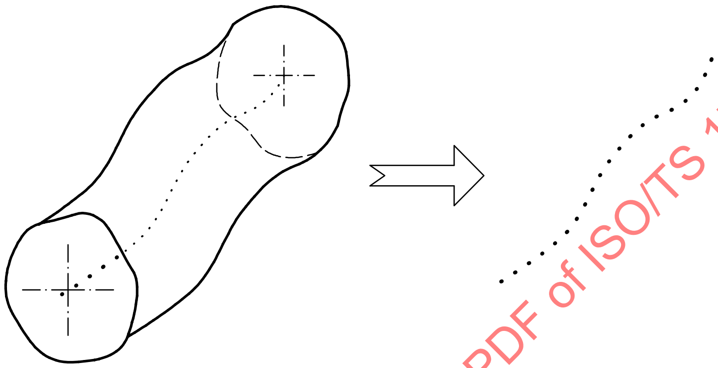


Figure 8 — Derived partition feature

Non-ideal features are bounded and are composed of an infinite or finite set of points.

7 Characteristics

7.1 General

Characteristics are defined either

- on ideal features and called intrinsic characteristics (see B.3.1), or
- between ideal features and called situation characteristics (see B.3.2), or
- between ideal and non-ideal features and also called situation characteristics (see B.3.3).

7.2 Intrinsic characteristics of ideal features

The intrinsic characteristics of an ideal feature are specific to the type of the feature itself. Examples of intrinsic characteristics are given in Table 3.

Table 3 — Examples of intrinsic characteristics of ideal features

Invariance class	Type	Examples of intrinsic characteristics
complex	elliptic curve polar surface ...	length of major and minor axes relative location of poles ...
prismatic	prism with an elliptic basis prism with a basis of involute to a circle ...	length of major and minor axes pressure angle, basis radius ...
revolute	circle cone torus ...	diameter apex angle generatrix and directrix diameters ...
helical	helical line helical surface with a basis of involute to a circle ...	helix pitch and radius helix angle, pressure angle, basis radius ...
cylindrical	straight line cylinder	none diameter
planar	plane	none
spherical	point sphere	none diameter

7.3 Situation characteristics between ideal features

The situation characteristic or characteristics define the relative situation (location or orientation) between two situation features. These characteristics are length and angle.

The situation characteristics can be separated into location characteristics and orientation characteristics (see Table 4).

Table 4 — Situation characteristics

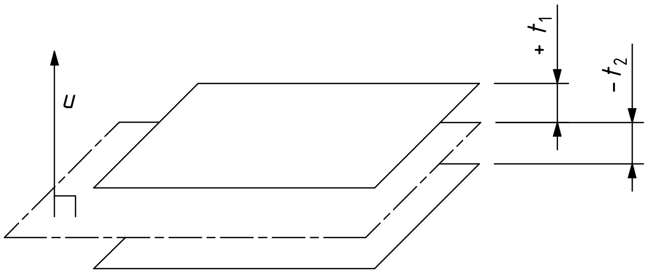
Location
point-point distance
point-straight line distance
point-plane distance
straight line-straight line distance
straight line-plane distance
plane-plane distance

Orientation
straight line-straight line angle
straight line-plane angle
plane-plane angle

EXAMPLE 1 The relative location between a sphere and a plane is given by the point-plane distance between the situation feature of the sphere (centre of the sphere) and the situation feature of the plane (the plane itself).

EXAMPLE 2 The relative orientation between a cylinder and a plane is given by the straight line-plane angle between the situation feature of the cylinder (axis of the cylinder) and the situation feature of the plane (the plane itself).

In some cases (e.g. asymmetric tolerancing), it is necessary to identify a part of the space, for instance, in order to identify on which side of a symmetry plane is the largest part of the tolerance zone; the corresponding situation characteristics are called signed characteristics (see Figure 9). They can be the following: point-plane distance, straight line-straight line (non-parallel) distance, straight line-plane distance, plane-plane distance, straight line-straight line angle, straight line-plane angle, plane-plane angle.



u Unit vector

t_1 Signed characteristic 1

t_2 Signed characteristic 2

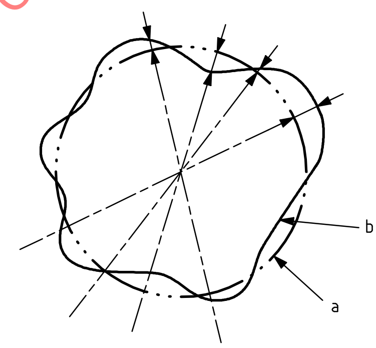
Figure 9 — Signed characteristics

These signed characteristics are defined by vector, depending on the orientation of the plane and straight line (see B.1 for the mathematical definition).

7.4 Situation characteristics between non-ideal and ideal features

Situation characteristics are also used to define the situation between non-ideal and ideal features.

These situation characteristics are only distances and are defined as functions of the distance between each point of the non-ideal feature and the ideal feature (see example in Figure 10). These functions are, for instance, the maximum, the minimum, or the sum of the squares of the distance of each point to the ideal feature. The situation characteristics will be used for operations of association.



a Ideal feature (circle)

b Non-ideal feature (“circle” with form errors)

Figure 10 — Situation characteristics between non-ideal and ideal features

8 Operations

8.1 Feature operations

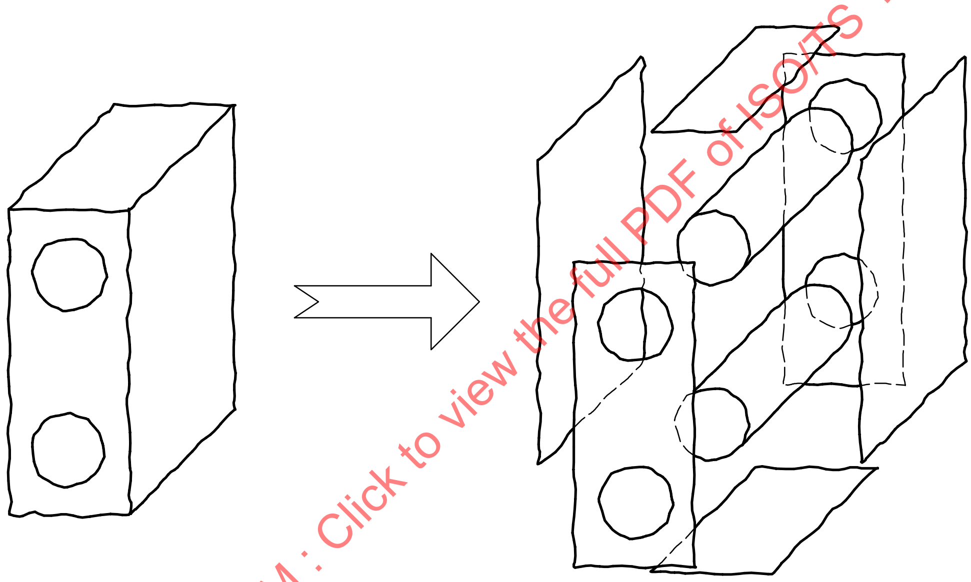
8.1.1 General

Specific operations are required if ideal or non-ideal features are to be obtained. These operations can be used in any order. They are as indicated in 8.1.2 to 8.1.7.

8.1.2 Partition

A feature operation called partition is used to identify bounded features.

It is used to obtain from the non-ideal surface model (skin model) or real surface the non-ideal features corresponding to the nominal features (see Figure 11). It is also used to obtain limited parts of ideal features (e.g. a segment of a straight line) or non-ideal features (e.g. a section of a non-ideal surface).



a) Skin model

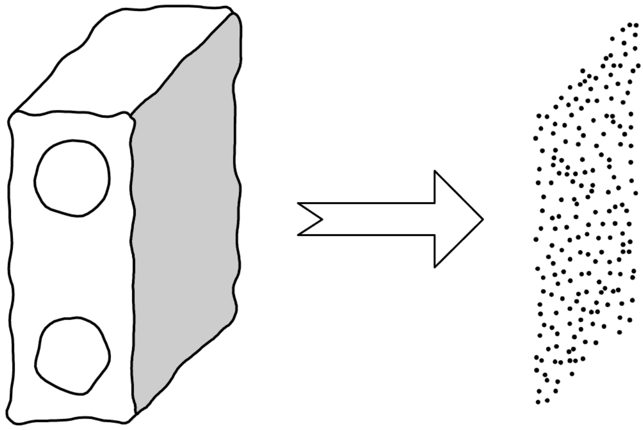
b) Non-ideal features obtained by partition of skin model

Figure 11 — Partition of a skin model

For each non-ideal feature, there is a corresponding ideal feature (e.g. ideal planes and ideal cylinders) of the nominal model (compare Figures 7 and 11). The non-ideal features are obtained from the non-ideal surface model (skin model), with specific rules.

8.1.3 Extraction

A feature operation called extraction is used to identify a finite number of points from a feature, with specific rules (see Figure 12).



a) Skin model

b) Extracted points from a feature of the skin model

Figure 12 — Extracted points from a feature of the skin model

8.1.4 Filtration

A feature operation called filtration is used to distinguish between roughness, waviness, structure and form etc. (see Figure 13).

a) Unfiltered profile

b) Waviness profile

c) Roughness profile

Figure 13 — Example of separation of a profile

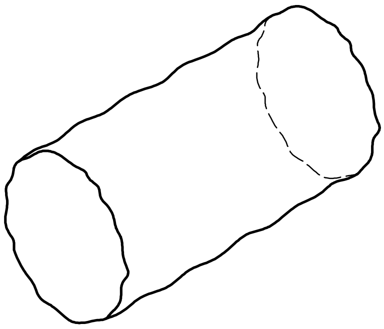
This operation permits the obtaining, from a non-ideal feature, of the feature that represents the considered characteristics.

This operation is done with specific rules.

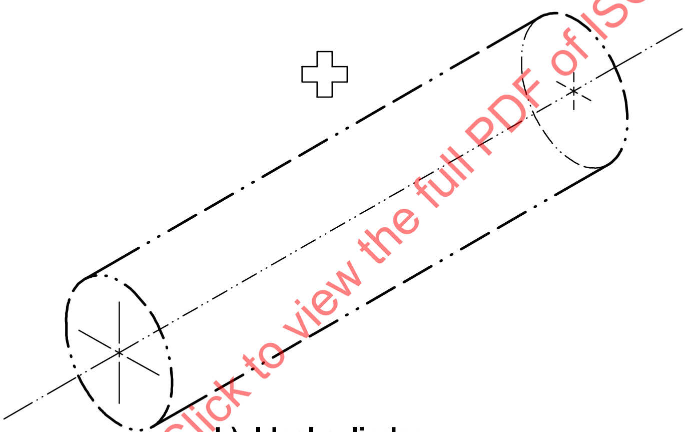
8.1.5 Association

A feature operation called association is used to fit ideal features to non-ideal features according to specific rules called criteria (see Figure 14).

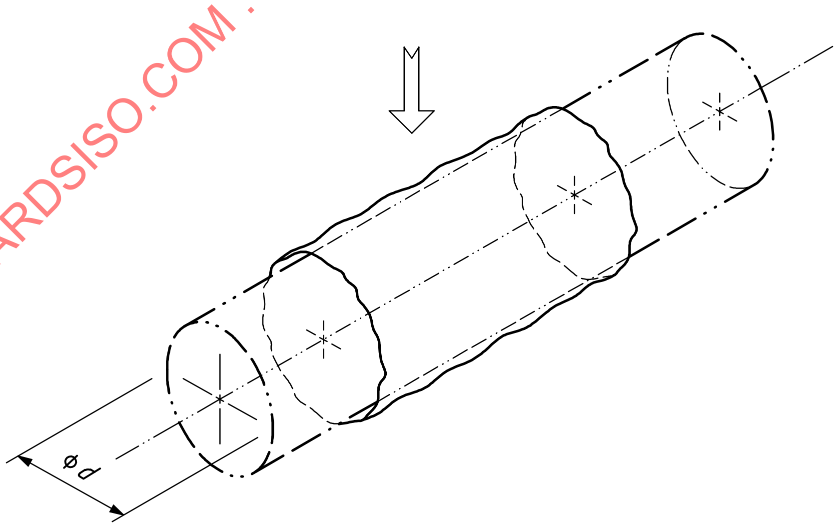
The criteria of association give an objective for a characteristic and can set constraints. The constraints fix the value of the characteristics or set limits to the characteristic.



a) Non-ideal feature



b) Ideal cylinder



c) Association of ideal cylinder with the non-ideal feature having criterion "maximize the diameter of the inscribed cylinder"

Figure 14 — Example of association

Constraints can apply to intrinsic characteristics, situation characteristics between ideal features, or situation characteristics between ideal and non-ideal features.

An ideal feature is associated to the non-ideal feature; for example, in the case of a cylinder, the association criteria could be:

— minimize the sum of the squares of the distance between each point of the non-ideal feature to the ideal cylinder, or

— maximize the diameter of the inscribed cylinder (see Figure 14), or

— minimize the diameter of circumscribed cylinder, or

— other criteria.

8.1.6 Collection

A feature operation called collection is used to identify and consider some features together which together play a functional role (see Figure 15). It is possible to build the collection of ideal features or the collection of non-ideal features. All ideal features built with 2 collection operation fall within one of the seven invariance classes of Table 1.

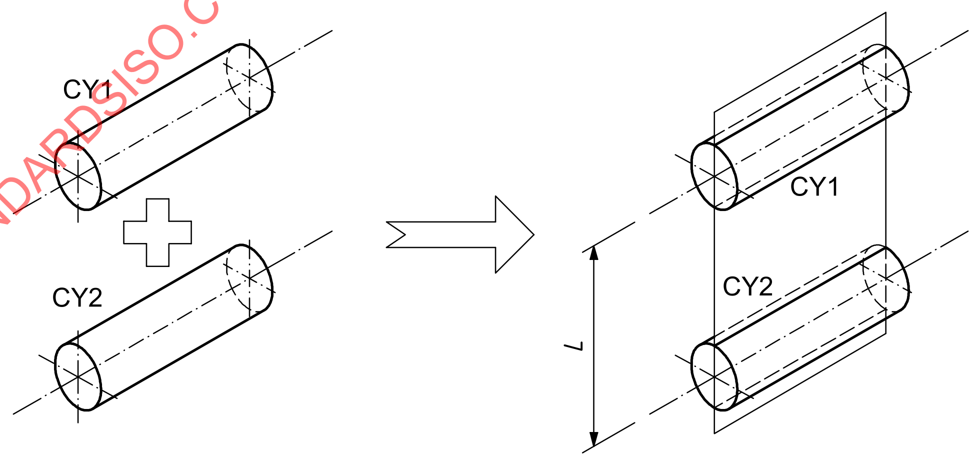
The effect of the collection operation can change the type and the degree of invariance of the collection feature compared to the simple features composing the collection.

NOTE 1 A single feature is a continuous feature for which there does not exist any subset of the same dimensionality (point, line or surface) with an invariance degree greater than the invariance degree of the considered feature. For example, a cylinder is a single feature, while a collection surface consisting of two parallel cylinders is not, because a single cylinder has a greater invariance degree.

NOTE 2 A situation characteristic between two features becomes an intrinsic characteristic of the feature obtained by collection.

NOTE 3 Features considered in a collection feature need not be in contact.

In Figure 15, two parallel cylinders (whose axes lie in a plane and are parallel) are considered together (e.g. for building a common datum). The feature collection of the two cylinders is to be defined. This collection of two cylinders is only invariant by translation along a straight line. It belongs to the prismatic invariance class.

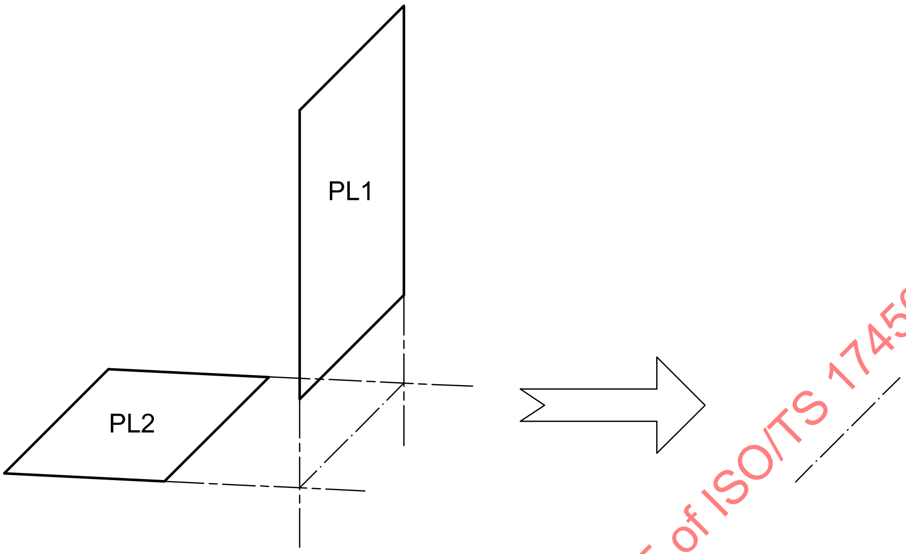


CY1 Ideal cylinder 1
CY2 Ideal cylinder 2

Figure 15 — Example of collection of two ideal cylinders

8.1.7 Construction

A feature operation called construction is used to build ideal features from other features (see Figure 16). This operation shall respect constraints.



PL1 Ideal plane 1

PL2 Ideal plane 2

Figure 16 — Example of construction of a straight line by the intersection of two planes

8.2 Evaluation

An operation called evaluation is used to identify either the value of a characteristic or its nominal value and its limit or limits. The evaluation is always used after the feature operation or operations defining one specification or verification.

9 Specification

9.1 General

A specification consists in expressing the field of permissible deviations of a characteristic of a workpiece as permissible limits.

There are two ways to specify the permissible limits: by dimension (see 9.2) and by zone (see 9.3).

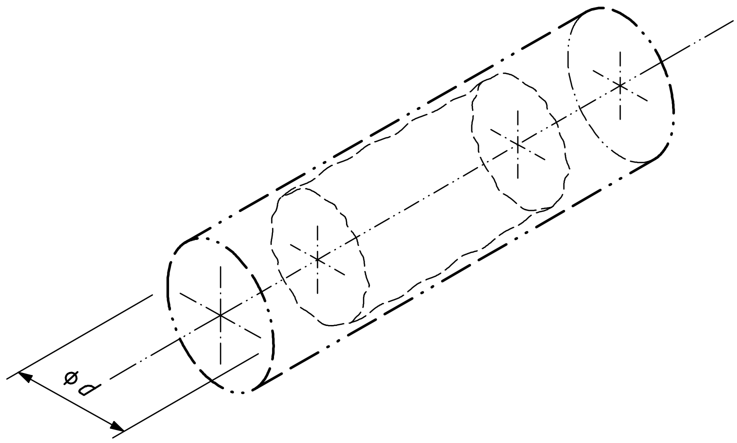
9.2 Specification by dimension

A specification by dimension limits the permissible value of an intrinsic characteristic (Table 3) or of a situation characteristic between ideal features (Table 4).

For instance, a specification by dimension can limit

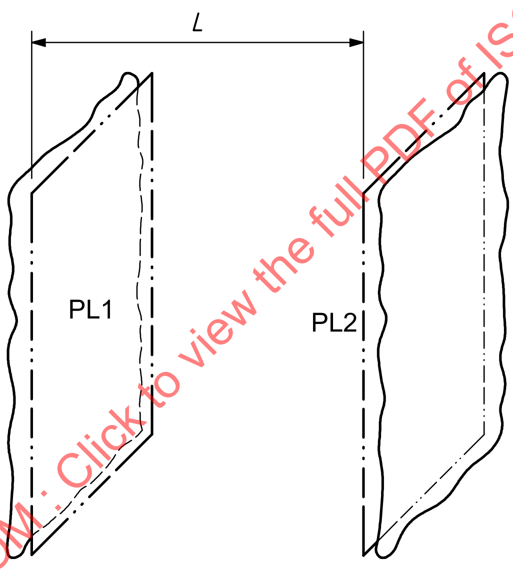
— the diameter of a cylinder associated to a non-ideal feature (see Figure 17), or

— the distance between two parallel planes associated to two non-ideal features (see Figure 18).



NOTE The non-ideal feature and the ideal cylinder are in contact.

Figure 17 — Example of specification by dimension (diameter of a cylinder, *d*)



NOTE The non-ideal features and the ideal plane are in contact.

PL1 Ideal plane 1

PL2 Ideal plane 2

Figure 18 — Example of specification by dimension (distance between two parallel planes, *L*)

9.3 Specification by zone

A specification by zone limits the permissible deviation of a non-ideal feature inside a space. This space is limited by an ideal feature or by ideal features and can thus be characterized by

— the intrinsic characteristic of the ideal feature or ideal features, for instance the diameter of a cylinder, the distance between two planes or the identical diameter of a set of cylinders, and

— situation features of the ideal feature or ideal features, for instance the axis of a cylinder, the symmetry plane of two planes or the axis and plane of a set of parallel cylinders.

NOTE A specification by zone can also be defined as follows: the permissible value of the situation characteristic between a non-ideal feature (partition feature for instance) and an ideal feature (situation features of the zone).

9.4 Deviation

In the case of specification by dimension, the deviation is either

— the difference between the value of the intrinsic characteristic of the associated feature and the value of the intrinsic characteristic of the corresponding nominal feature, or

— the difference between the value of the situation characteristic between two associated features and the value of the situation characteristic between the two corresponding nominal features.

In the case of specification by zone, the deviation is the minimum possible value of the intrinsic characteristic of the ideal feature limiting the zone containing the non-ideal feature.

NOTE In the case of specification by zone, the deviation can also be defined as the value of the maximum distance of each point of a non-ideal feature to the ideal feature (e.g. the situation feature of the zone).

10 Verification

Geometrical verification consists in determining a value of a quantity that is a characteristic.

This value is called "result of measurement" and its statement includes information about the uncertainty of measurement.

The quantity to be measured should be directly issued from the geometrical specification. The gap between specified characteristic and result of measurement is analysed through the operators concept (which is the subject of ISO/TS 17450-2).

Verification is the manufacturing step at which a metrologist determines whether the real surface of a workpiece conforms to the field of permissible deviations specified. When a specification of a workpiece is verified, the metrologist begins planning by considering the nominal model (perfect workpiece). Individual steps in the verification plan are developed from tolerances that specify allowable geometrical deviation for each surface on the nominal model. While particular surfaces and tolerances may require very different measurement techniques, until collection, construction and evaluation, most verification procedures include the following initial steps.

a) A particular subset of the real surface is identified for each surface to be verified (partition).

b) Via a measurement procedure, a subset of the real feature is approximated using a physical extraction process. This yields a finite set of points; each point is in the neighbourhood of a point on the real surface.

c) A filtration operation, either embedded within the physical extraction process or applied subsequently, reduces the information of the set of points to describe only the frequencies of merit for the verification of the particular surface-tolerance combination.

d) The filtered point set is used to estimate the closest fitting substitute geometry through a process of association. When two or more surfaces are influenced by one tolerance, the collection operation is used to consider all applicable surfaces at the same time. When tolerance specifications depend on features coming from two or more surfaces, the construction operation is used to define these other ideal features. The tolerances specified for any particular feature define maximum or minimum values of characteristics, or both.

   — A specification by dimension limits the permissible values of a characteristic. Each specification by dimension is evaluated by first locating and orienting the ideal feature or ideal features with the filtered set of points extracted from the real surface. Conformance is then determined by comparing the unique value of the intrinsic characteristic of an ideal feature, or of the situation characteristic between two ideal features, with the tolerance.

   — A specification by zone limits the permissible values of a situation characteristic between a non-ideal feature and an ideal feature. This zone may be located or oriented, or both, further with respect to other features or collections of features. Each tolerance is evaluated by first locating and orienting the tolerance zone with respect to toleranced features or collections of features estimated from points on the real surface. The filtered point set controlled by the tolerance is then evaluated with respect to this zone. Unique values are calculated from the situation feature or situation features of the zone in order to verify that the filtered point set falls within the zone. Conformance is then determined by comparing these unique values of characteristics with tolerances specified for a nominal model.

Annex A
(informative)

Examples of application to ISO 1101

A.1 Form tolerance

Consider an example of flatness tolerance according to ISO 1101 (see Figure A.1):

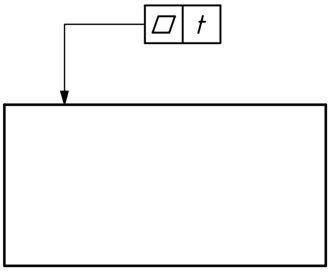
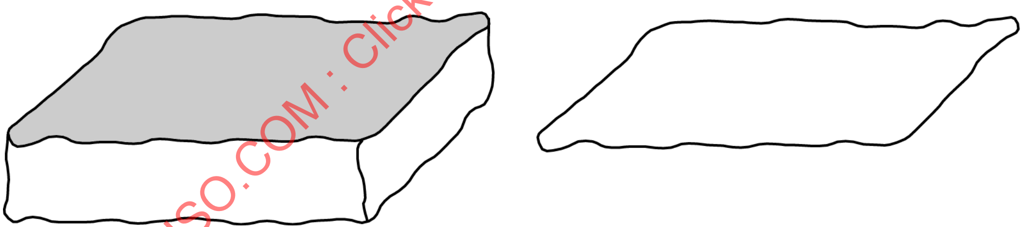


Figure A.1

The following feature operations apply:

a) The surface is obtained by partition, from the non-ideal surface model (skin model), of the non-ideal planar surface [see Figure A.2 a) and b)].



a) b)

Figure A.2

b) The symmetry plane of the tolerance zone is obtained by the association of an ideal feature of type plane with the partition feature; the maximum distance between each point of the partition feature and the situation feature of the plane shall be minimum (see Figure A.3).

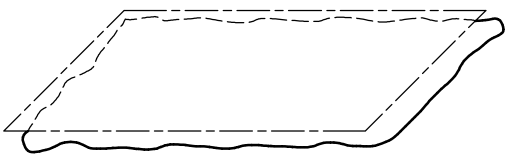


Figure A.3

The specification is the following:

— by using the symmetry plane of the tolerance zone as the basis for the deviation of flatness, the form tolerance is obtained by evaluation of a characteristic, i.e. the maximum of the distances between each point of the partition feature and the associated plane; this maximum shall be less than or equal to $t/2$ (which is the limit).

A.2 Orientation tolerance

Consider an example of perpendicularity tolerance according to ISO 1101 (see Figure A.4).

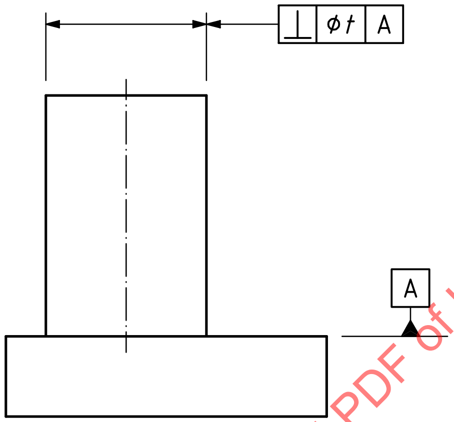
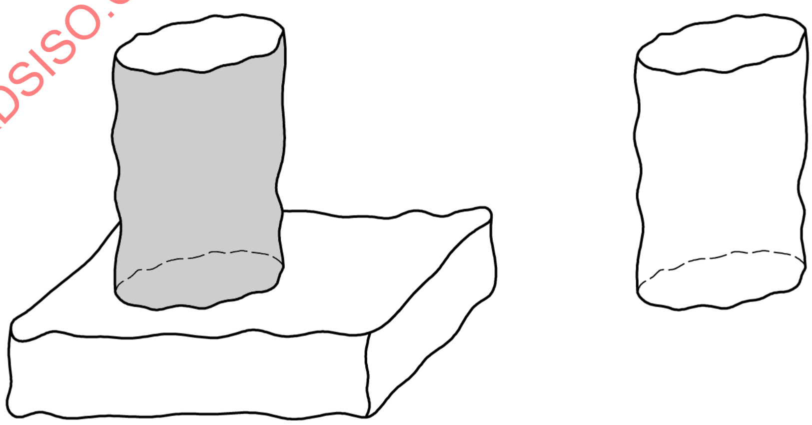


Figure A.4

The following feature operations apply:

a) the axis of the cylinder is obtained by

1) partition, from the non-ideal surface model (skin model), of the non-ideal cylindrical surface [see Figure A.5 a) and b)]



a) b)

Figure A.5

2) association of an ideal feature of type cylinder [see Figure A.6 a) and b)]

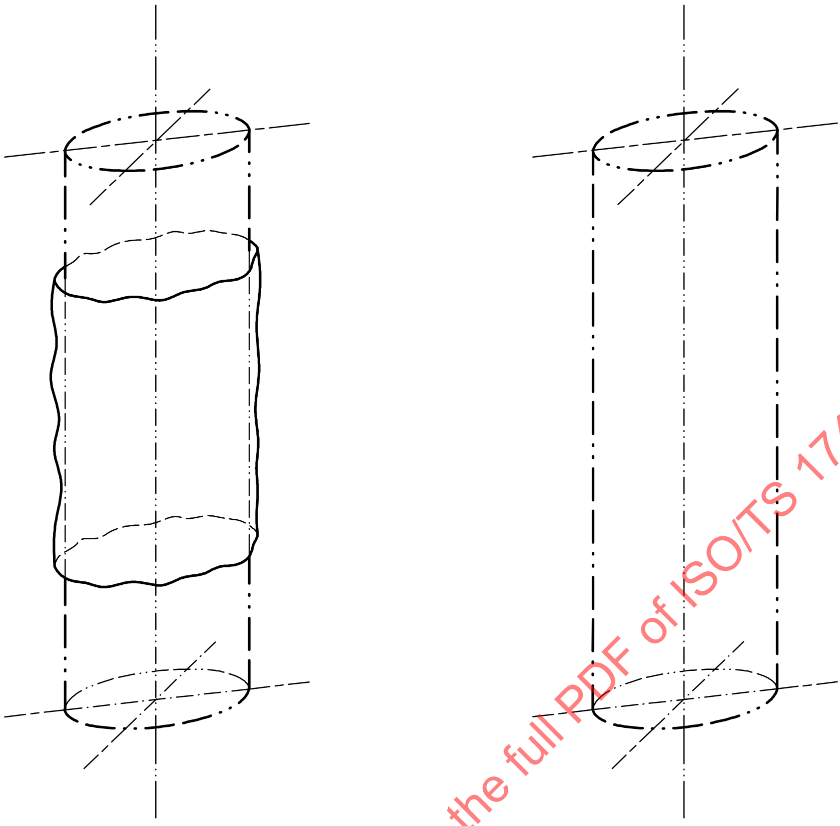
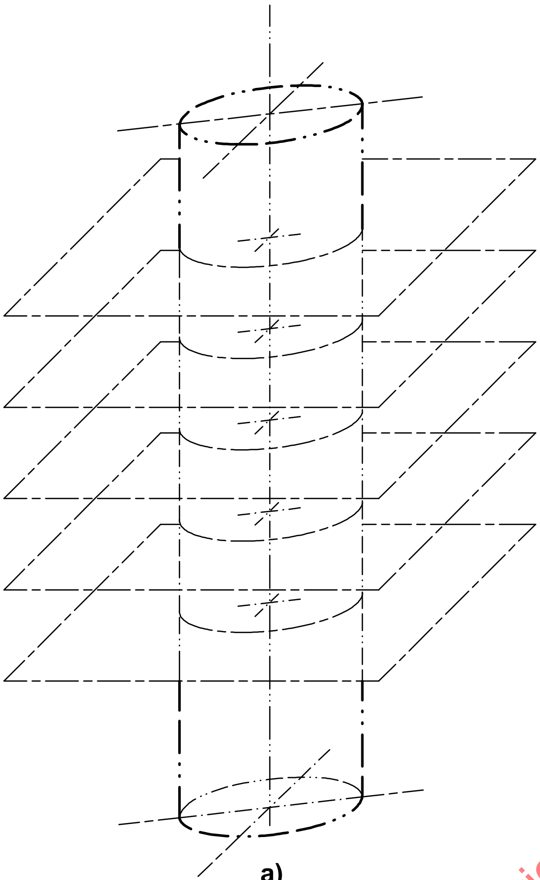
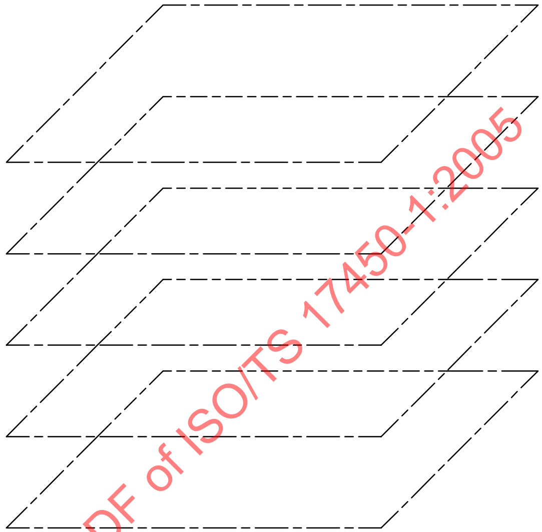


Figure A.6

3) construction of planes perpendicular to the axis of the associated cylinder [see Figure A.7 a) and b)]



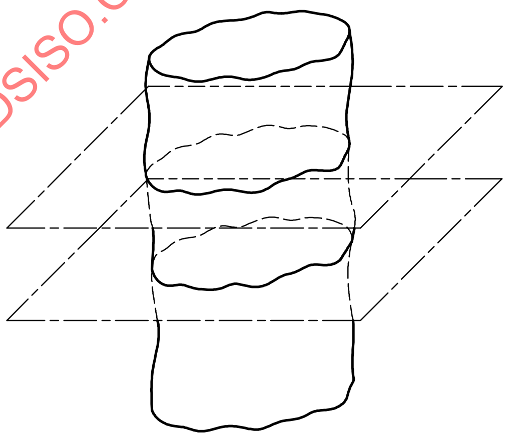
a)



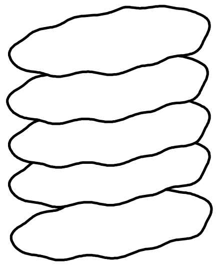
b)

Figure A.7

4) partition of non-ideal circular lines [see Figure A.8 a) and b)]



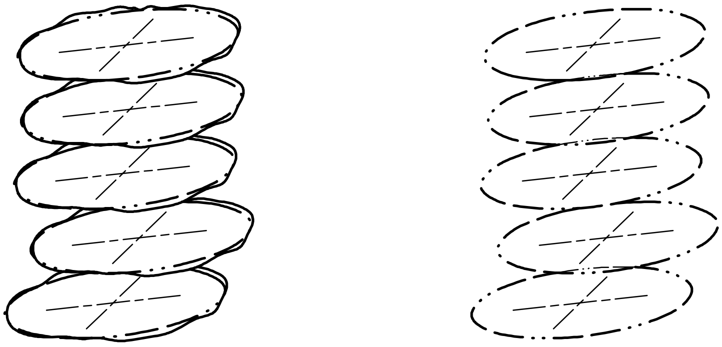
a)



b)

Figure A.8

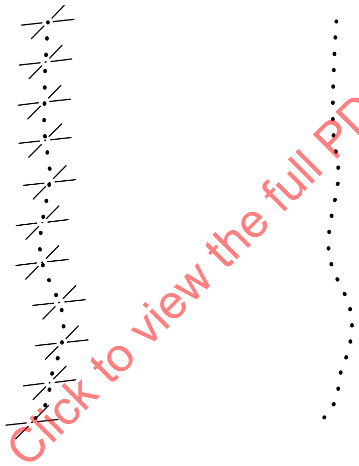
5) association of ideal features of type circle [see Figure A.9 a) and b)]



a) b)

Figure A.9

6) collection of all the centres of the ideal circles [see Figure A.10 a) and b)]

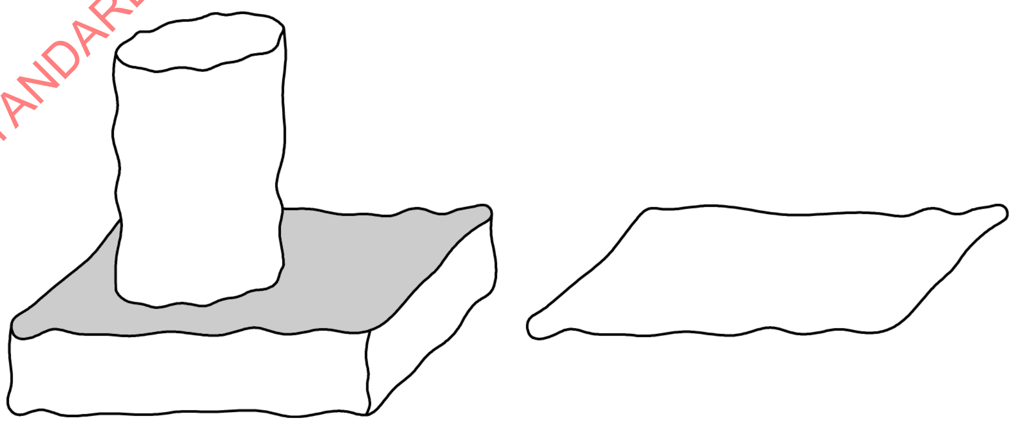


a) b)

Figure A.10

b) the datum surface A is obtained by

1) partition, from the non-ideal surface model (skin model), of the non-ideal planar surface corresponding to A [see Figure A.11 a) and b)],



a) b)

Figure A.11

2) association of an ideal feature of type plane, the situation feature of which is the datum [see Figure A.12 a) and b)]

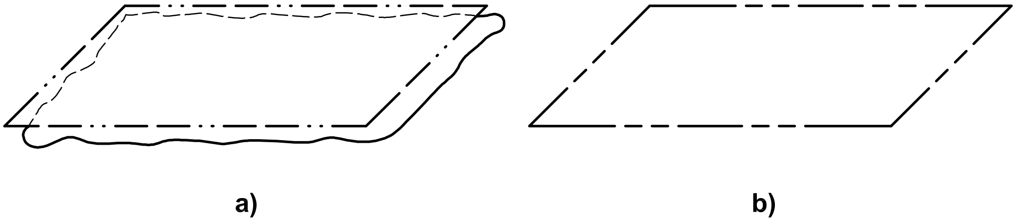


Figure A.12

c) the axis of the tolerance zone is obtained by association of an ideal feature of type straight line with the collected feature, the situation feature of the straight line is constrained to be perpendicular to the datum A, and the maximum distance between each point of the collection feature and the associated straight line shall be minimum (see Figure A.13).

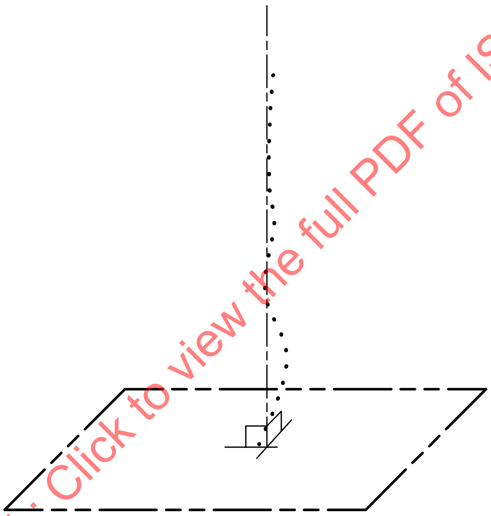


Figure A.13

The specification is the following:

— the orientation tolerance is obtained by evaluation of a characteristic, i.e., the maximum of the distances between each point of the collected feature and the associated straight line; this maximum shall be less than or equal to $t/2$ (which is the limit).

A.3 Location tolerance

Consider an example of position tolerance according to ISO 1101 (see Figure A.14).

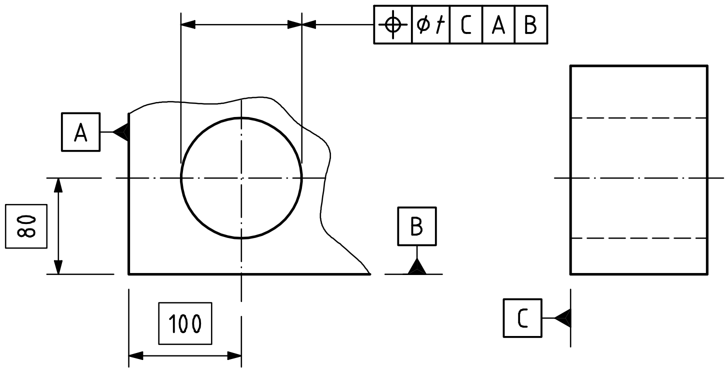
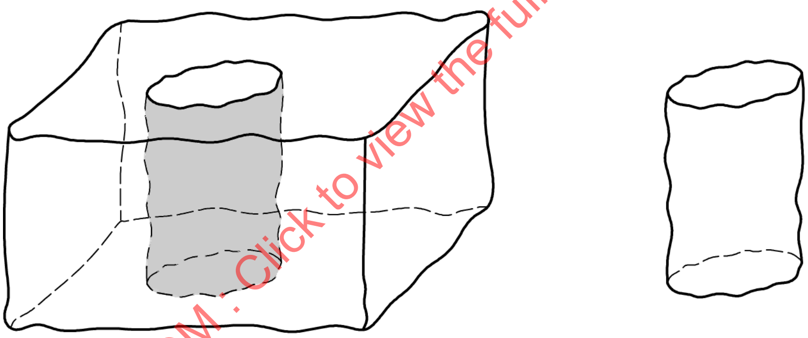


Figure A.14

The following feature operations apply:

a) the axis of the cylinder is obtained by

1) partition, from the non-ideal surface model (skin model), of the non-ideal cylindrical surface [see Figure A.15 a) and b)]



a) b)

Figure A.15

2) association of an ideal feature of type cylinder [see Figure A.16 a) and b)]

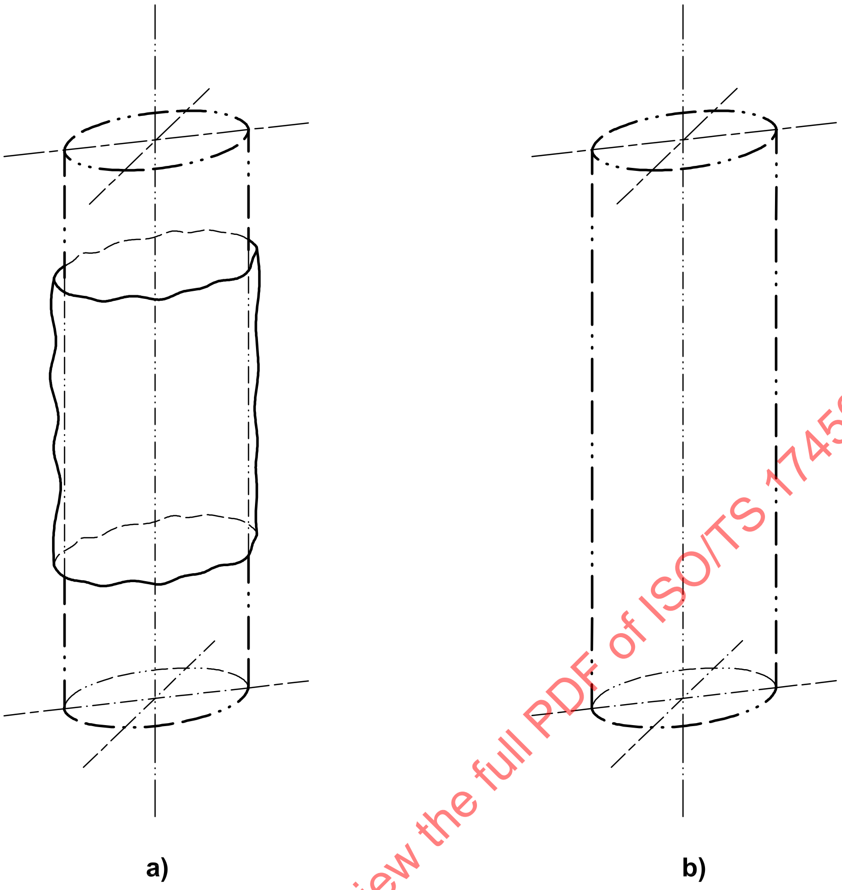


Figure A.16

3) construction of planes perpendicular to the axis of the associated cylinder [see Figure A.17 a) and b)]

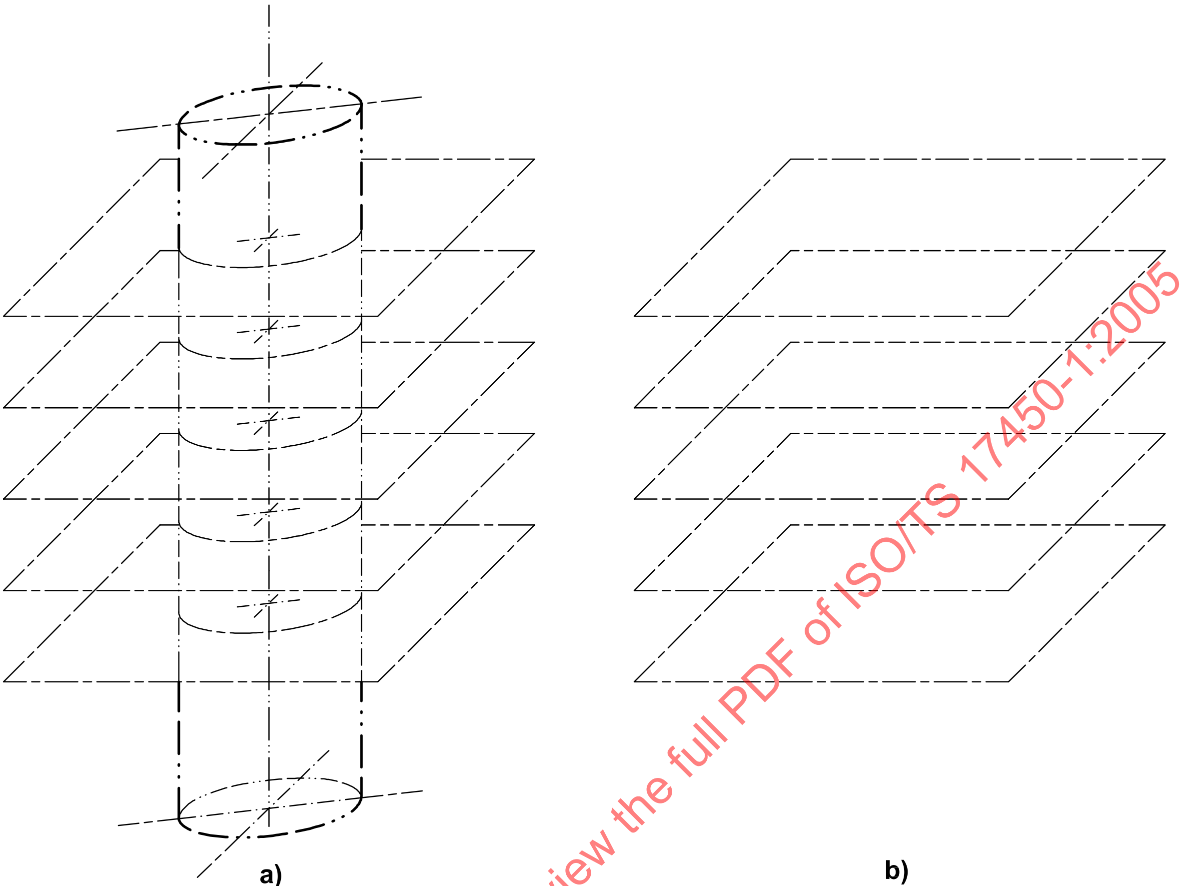


Figure A.17

4) partition of non-ideal circular lines [see Figure A.18 a) and b)]

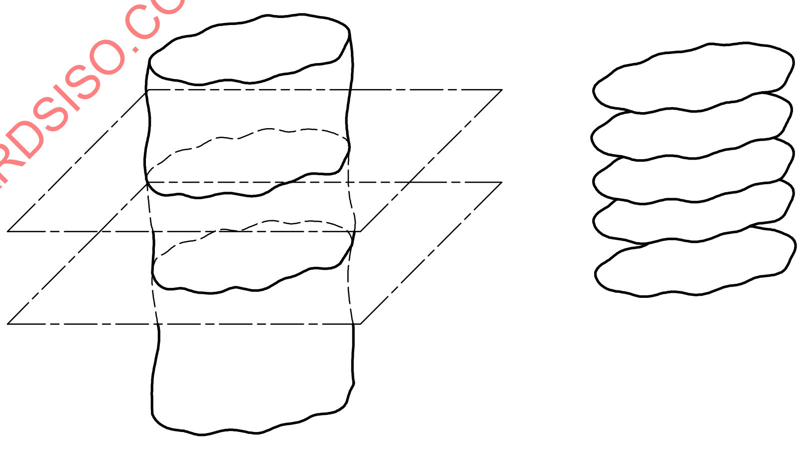
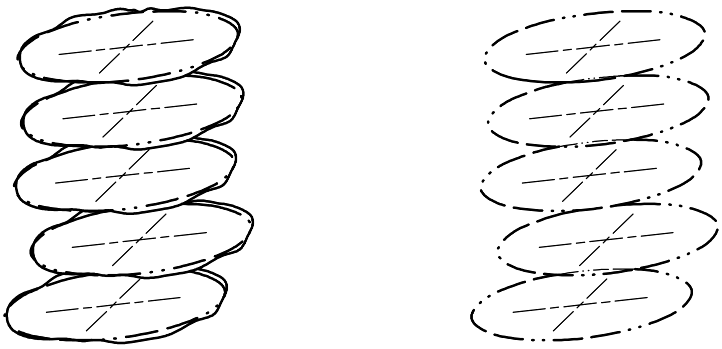


Figure A.18

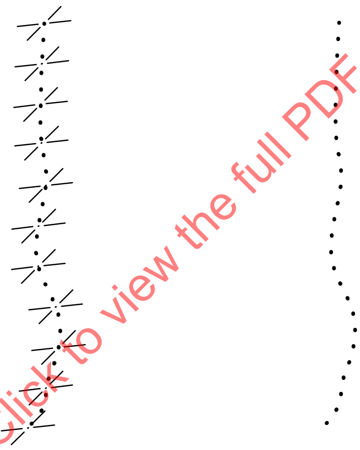
5) association of ideal features of type circle [see Figure A.19 a) and b)],



a) b)

Figure A.19

6) collection of all the centres of the ideal circles [see Figure A.20 a) and b)]

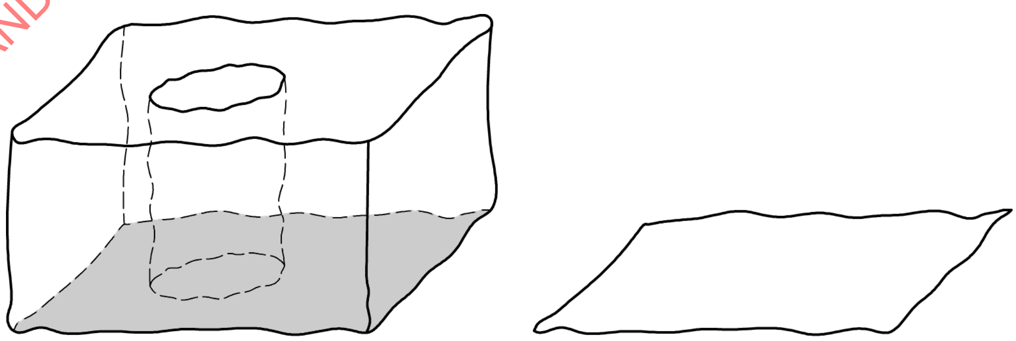


a) b)

Figure A.20

b) the datum surfaces C, A and B are obtained by

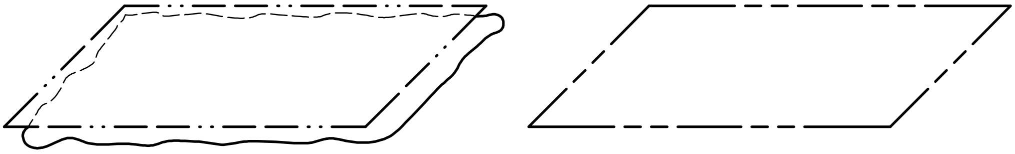
1) partition, from the non-ideal surface model (skin model), of the non-ideal planar surface corresponding to C [see Figure A.21 a) and b)]



a) b)

Figure A.21

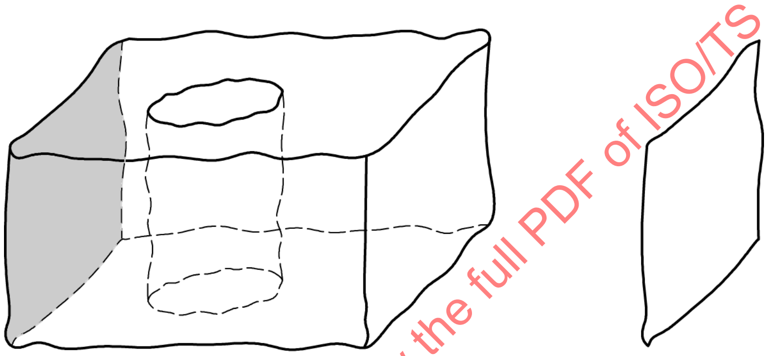
2) association of an ideal feature of type plane, the situation feature of which is the datum C [see Figure A.22 a) and b)]



a) b)

Figure A.22

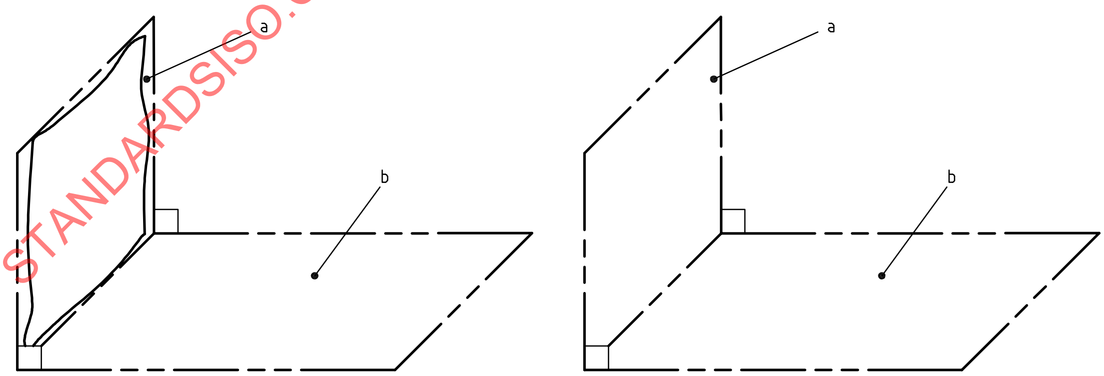
3) partition from the non-ideal surface model (skin model) of the non-ideal planar surface corresponding to A [see Figure A.23 a) and b)]



a) b)

Figure A.23

4) association of an ideal feature of type plane, with a constraint of perpendicularity with the plane associated with C, the situation feature of which is the datum A [see Figure A.24 a) and b)]

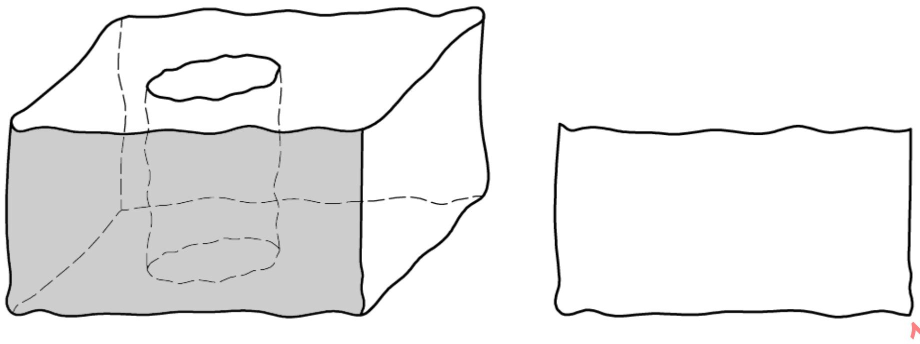


a) b)

a Datum A
b Datum C

Figure A.24

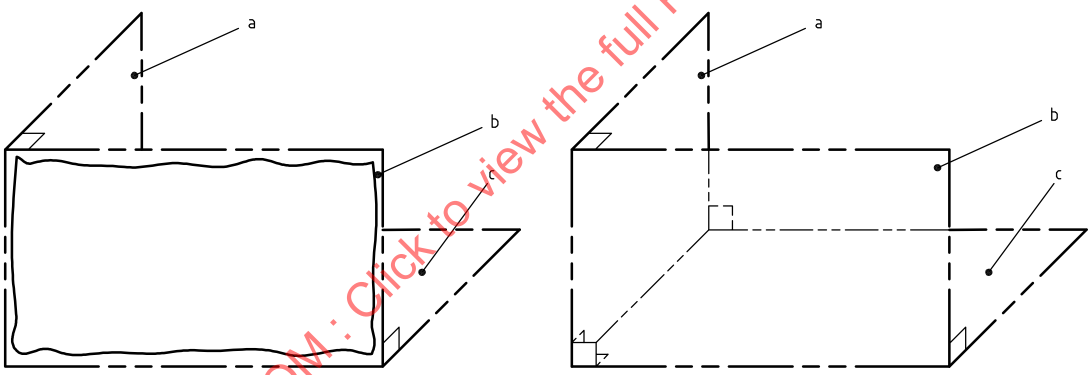
5) partition from the non-ideal surface model (skin model) of the non-ideal planar surface corresponding to B [see Figure A.25 a) and b)], and



a) b)

Figure A.25

6) association of an ideal feature of type plane, with a constraint of perpendicularity with the planes associated to C and A, the situation feature of which is the datum B [see Figure A.26 a) and b)]



a) b)

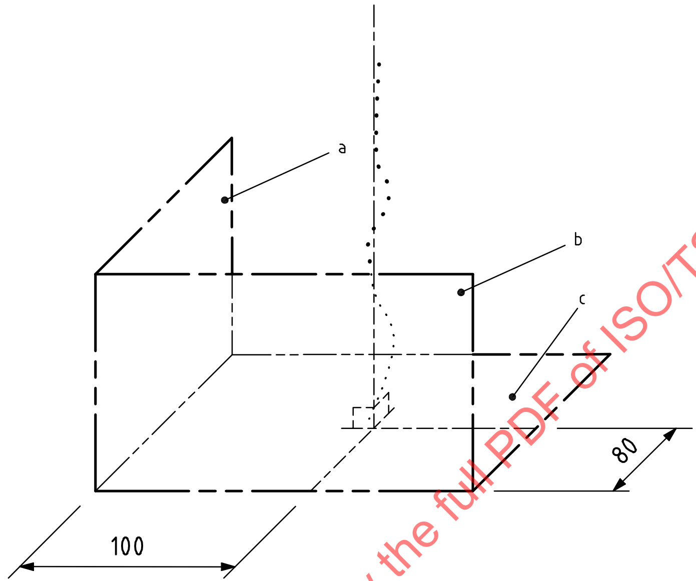
a Datum A
b Datum B
c Datum C

Figure A.26

c) the axis of the tolerance zone is obtained by construction of an ideal feature; the situation feature of the straight line is constrained to be

- perpendicular to the datum C,
- at a distance of 100 mm from the plane A, and
- at a distance of 80 mm from the plane B;

see Figure A.27.



a Datum A
b Datum B
c Datum C

Figure A.27

The specification is the following:

- the location tolerance is obtained by evaluation of a characteristic, i.e. the maximum of the distances between each point of the collected feature and the constructed straight line; this maximum shall be less than or equal to $t/2$ (which is the limit).

Annex B
(informative)

Mathematical symbols and definitions

B.1 General

This annex develops a mathematical system of notation and definition of the concepts of this part of ISO/TS 17450. Some basic mathematical notations used to describe the different concepts of specification are given in Table B.1.

Table B.1 — Basic mathematical notations

Quantity	Symbol
Vectors	"Times New Roman" italic bold-face ($\boldsymbol{T}$, $\boldsymbol{u}$, ...)
Location vector	A pair of points (O, P), where O is the origin of a coordinate system and P is a point, is denoted by **P**
Functions	A real number or vector symbol followed by the parameters of the function in parentheses [r(P), dia(CY), ...]
Sets	"Times New Roman" italic upper-case letters (E, F, ...)

The symbol may be subscripted to distinguish between distinct quantities.

A set of elements is denoted in parentheses { } and each element is subscripted preferably with i, j, k or l. Thus, a set of vectors is denoted by

— $\{\boldsymbol{u}_i\}$ if the set is not denumerable (infinite set), or

— $\{\boldsymbol{u}_i, i = 1, ..., n\}$ if the set is denumerable and the number of elements is n (finite set).

Basic mathematical operators are given in Table B.2.

Table B.2 — Basic mathematical operators

Operator	Symbol
Norm 2	The norm 2 (magnitude) of a vector $\boldsymbol{u}$ is denoted $\|\boldsymbol{u}\|$
Scalar product	The scalar product (dot product) of two vectors $\boldsymbol{u}$ and $\boldsymbol{v}$ is denoted $\boldsymbol{u} \cdot \boldsymbol{v}$
Vector product	The vector product (cross product) of two vectors $\boldsymbol{u}$ and v is denoted $\boldsymbol{u} \times \boldsymbol{v}$

The nominal model of the workpiece is denoted by N. The non-ideal surface model (skin model) of the workpiece is denoted by S_{P}.

B.2 Features

B.2.1 Ideal features

B.2.1.1 Type

Ideal features are characterized by type (see Table B.3), consequently, the most commonly used ideal features are denoted by two letters identifying their type.

Table B.3 — Type

Type	Symbol	Type	Symbol
Point	PT	Circle	CR
Cylinder	CY	Cone	CO
Straight line	SL	Plane	PL
Sphere	SP	Torus	TO
...	...	...	...

A set of plane is denoted by

— {PL_i} if the set is not denumerable, or

— {PL_i, i = 1, ..., n} if the set is denumerable and the number of elements is n.

B.2.1.2 Invariance class

An ideal feature belongs to one of the seven invariance classes denoted by the symbols listed in Table B.4.

Table B.4 — Invariance class

Invariance class	Symbol
Complex	C_X
Prismatic	C_T
Revolute	C_R
Helical	C_H
Cylindrical	C_C
Planar	C_P
Spherical	C_S
NOTE For the prismatic class the chosen symbol is C_T for translation.	

B.2.1.3 Situation feature

The situation features are of type point, straight line, plane or helix and are functions of features: thus, they are denoted as functions, specifically as described in Table B.5.

Table B.5 — Situation feature

Invariance class		Type	Feature	Situation feature	Type of situation feature	Symbol
C_R	Revolute	Circle	CR	Axis Plane (of the circle) Centre	Straight line Plane Point	axis(CR) plane(CR) centre(CR)
		Cone	CO	Axis Apex	Straight line Point	axis(CO) apex(CO)
		Torus	TO	Axis Centre	Straight line Point	axis(TO) centre(TO)
C_C	Cylindrical	Cylinder	CY	Axis	Straight line	axis(CY)
C_S	Spherical	Sphere	SP	Centre	Point	centre(SP)
	...	...	...	...	...	...

B.2.2 Non-ideal features

Non-ideal features are denoted symbolically as sets of points in space. If the nature of the non-ideal features is known, they are denoted by

— P if the nature is point,

— L if the nature is line, or

— S if the nature is surface.

B.3 Characteristics

B.3.1 Intrinsic characteristics of ideal features

The intrinsic characteristics are functions of features, so they are denoted as functions of these features, particularly as described in Table B.6.

Table B.6 — Intrinsic characteristics

Type	Feature	Intrinsic characteristics	Symbol
Circle	CR	radius diameter	rad(CR) dia(CR)
Cylinder	CY	radius diameter	rad(CY) dia(CY)
Sphere	SP	radius diameter	rad(SP) dia(SP)
Cone	CO	apex angle	a(CO)
...	...	...	...

B.3.2 Situation characteristics between ideal features

B.3.2.1 Location characteristics

The distances (see Table B.7) to be defined are as follows:

— Distance(PT, PT) = d(PT, PT),

— Distance(PT, SL) = d(PT, SL),

— Distance(PT, PL) = d(PT, PL),

— Distance(SL, SL) = d(SL, SL),

— Distance(SL, PL) = d(SL, PL),

— Distance(PL, PL) = d(PL, PL).

B.3.2.2 Orientation characteristics

The angles (see Table B.8) to be defined are as follows:

— Angle(SL, SL) = a(SL, SL),

— Angle(SL, PL) = a(SL, PL),

— Angle(PL, PL) = a(PL, PL).

These angles are angles between the vectors collinear or normal to the situation features. First, the angle between two vectors shall be defined.

Let $\boldsymbol{u}_1$ be a unit vector, and

let $\boldsymbol{u}_2$ be a unit vector,

then

Angle($\boldsymbol{u}_1$, $\boldsymbol{u}_2$) = $a(\boldsymbol{u}_1, \boldsymbol{u}_2)$ = Arccos($|\boldsymbol{u}_1 \cdot \boldsymbol{u}_2|$) with $a(\boldsymbol{u}_1, \boldsymbol{u}_2) \in [0, \pi/2]$

Subsequently, the angles between situation features can be defined.

Table B.7 — Distances

Features	Distances
Let PT_1 be a point. Let PT_2 be a point.	$d(PT_1, PT_2) = \lvert \mathbf{PT}_1 - \mathbf{PT}_2 \rvert$
Let PT_1 be a point. Let SL_2 be a straight line passing through the point A_2 and collinear to the unit vector $\boldsymbol{u}_2$.	$d(PT_1, SL_2) = \lvert(\mathbf{A}_2 - \mathbf{PT}_1) \times \boldsymbol{u}_2\rvert$
Let PT_1 be a point. Let PL_2 be a plane passing through the point A_2 and normal to the unit vector $\boldsymbol{u}_2$.	$d(PT_1, PL_2) = \lvert(\mathbf{A}_2 - \mathbf{PT}_1) \cdot \boldsymbol{u}_2\rvert$

Let SL_1 be a straight line passing through the point A_1 and collinear to the unit vector $\boldsymbol{u}_1$.
Let SL_2 be a straight line passing through the point A_2 and collinear to the unit vector $\boldsymbol{u}_2$.
	If $\boldsymbol{u}_1 \times \boldsymbol{u}_2 \neq 0$, then
	$d(SL_1, SL_2) = \lvert(\mathbf{A}_2 - \mathbf{A}_1) \cdot (\boldsymbol{u}_1 \times \boldsymbol{u}_2)\rvert / \lvert \boldsymbol{u}_1 \times \boldsymbol{u}_2\rvert$
	If $\boldsymbol{u}_1 \times \boldsymbol{u}_2 = 0$, then
	$d(SL_1, SL_2) = \lvert(\mathbf{A}_2 - \mathbf{A}_1) \times \boldsymbol{u}_1\rvert$

Let SL_1 be a straight line passing through the point A_1 and collinear to the unit vector $\boldsymbol{u}_1$.
Let PL_2 be a plane passing through the point A_2 and normal to the unit vector $\boldsymbol{u}_2$.
	If $\boldsymbol{u}_1 \cdot \boldsymbol{u}_2 = 0$, then
	$d(SL_1, PL_2) = \lvert(\mathbf{A}_2 - \mathbf{A}_1) \cdot \boldsymbol{u}_2\rvert$
	If $\boldsymbol{u}_1 \cdot \boldsymbol{u}_2 \neq 0$, then
	$d(SL_1, PL_2) = 0$

Let PL_1 be a plane passing through the point A_1 and normal to the unit vector $\boldsymbol{u}_1$.
Let PL_2 be a plane passing through the point A_2 and normal to the unit vector $\boldsymbol{u}_2$.
	If $\boldsymbol{u}_1 \times \boldsymbol{u}_2 = 0$, then
	$d(PL_1, PL_2) = \lvert(\mathbf{A}_2 - \mathbf{A}_1) \cdot \boldsymbol{u}_2\rvert$
	If $\boldsymbol{u}_1 \times \boldsymbol{u}_2 \neq 0$, then
	$d(PL_1, PL_2) = 0$

Table B.8 — Angles

Features	Angles
Let SL_1 be a straight line passing through the point A_1 and collinear to the unit vector $\boldsymbol{u}_1$. Let SL_2 be a straight line passing through the point A_2 and collinear to the unit vector $\boldsymbol{u}_2$.	$a(SL_1, SL_2) = a(\boldsymbol{u}_1, \boldsymbol{u}_2)$
Let SL_1 be a straight line passing through the point A_1 and collinear to the unit vector $\boldsymbol{u}_1$. Let PL_2 be a plane passing through the point A_2 and normal to the unit vector $\boldsymbol{u}_2$.	$a(SL_1, PL_2) = \pi/2 - a(\boldsymbol{u}_1, \boldsymbol{u}_2)$
Let PL_1 be a plane passing through the point A_1 and normal to the unit vector $\boldsymbol{u}_1$. Let PL_2 be a plane passing through the point A_2 and normal to the unit vector $\boldsymbol{u}_2$.	$a(PL_1, PL_2) = a(\boldsymbol{u}_1, \boldsymbol{u}_2)$

B.3.2.3 Signed characteristics

(See 7.2).

The signed distances (see Table B.9) to be defined are

— signed distance(PT, PL) = d_S (PT, PL),

— signed distance(SL, PL) = d_S(SL, PL), and

— signed distance(PL, PL) = d_S(PL, PL).

Table B.9 — Signed distances

Features	Signed distances

Let SL_1 be a straight line passing through the point A_1 and collinear to the unit vector $\boldsymbol{u}_1$.
 	
Let SL_2 be a straight line passing through the point A_2 and collinear to the unit vector $\boldsymbol{u}_2$.
	If $\boldsymbol{u}_1 \times \boldsymbol{u}_2 \neq 0$, then
	$d_s(SL_1, SL_2) = d_s(SL_2, SL_1) = (\mathbf{A}_2 - \mathbf{A}_1) \cdot (\boldsymbol{u}_1 \times \boldsymbol{u}_2) / \lvert\boldsymbol{u}_1 \times \boldsymbol{u}_2\rvert$
	
	If $\boldsymbol{u}_1 \times \boldsymbol{u}_2 = 0$, then
	$d_s(SL_1, SL_2)$ and $d_s(SL_2, SL_1)$ are undefined.

Let PT_1 be a point. Let PL_2 be a plane passing through the point A_2 and normal to the unit vector $\boldsymbol{u}_2$.	$d_s(PT_1, PL_2) = d_s(PL_2, PT_1) = (\mathbf{PT}_1 - A_2) \cdot \boldsymbol{u}_2$

Let SL_1 be a straight line passing through the point A_1 and collinear to the unit vector $\boldsymbol{u}_1$.
 	
Let PL_2 be a plane passing through the point A_2 and normal to the unit vector $\boldsymbol{u}_2$.
	If $\boldsymbol{u}_1 \cdot \boldsymbol{u}_2 = 0$, then
	$d_s(SL_1, PL_2) = d_s(PL_2, SL_1) = (\mathbf{A}_1 - \mathbf{A}_2) \cdot \boldsymbol{u}_2$
	
	If $\boldsymbol{u}_1 \cdot \boldsymbol{u}_2 \neq 0$, then
	$d_s(SL_1, PL_2) = d_s(PL_2, SL_1) = 0$

Let PL_1 be a plane passing through the point A_1 and normal to the unit vector $\boldsymbol{u}_1$.
 	
Let PL_2 be a plane passing through the point A_2 and normal to the unit vector $\boldsymbol{u}_2$.
	If $\boldsymbol{u}_1 \times \boldsymbol{u}_2 = 0$, then
	$d_s(PL_1, PL_2) = (\mathbf{A}_2 - \mathbf{A}_1) \cdot \boldsymbol{u}_1$
	$d_s(PL_2, PL_1) = (\mathbf{A}_1 - \mathbf{A}_2) \cdot \boldsymbol{u}_2$
	
	If $\boldsymbol{u}_1 \times \boldsymbol{u}_2 \neq 0$, then
	$d_s(PL_1, PL_2) = d_s(PL_2, PL_1) = 0$

NOTE The function of signed distance between two parallel planes is not symmetric. It is so, because it is preferable to have a change of sign when the planes cross themselves, and that is antinomic with the symmetry of the function.	

The signed angles (see Table B.10) to be defined are

— signed angle(SL, SL) = $a_s(SL, SL)$,

— signed angle(SL, PL) = $a_s(SL, PL)$, and

— signed angle(PL, PL) = $a_s(PL, PL)$.

First, the signed angle between two vectors is to be defined.

Let $\boldsymbol{u}_1$ be a unit vector, and

let $\boldsymbol{u}_2$ be a unit vector,

then

Angle($\boldsymbol{u}_1, \boldsymbol{u}_2$) = $a_s(\boldsymbol{u}_1, \boldsymbol{u}_2) = \arccos(\boldsymbol{u}_1 \cdot \boldsymbol{u}_2)$ with $a(\boldsymbol{u}_1, \boldsymbol{u}_2) \in [0, \pi]$

