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Geometrical product specifications (GPS) — Geometrical tolerancing — Maximum material requirement (MMR), least material requirement (LMR) and reciprocity requirement (RPR)

Spécification géométrique des produits (GPS) — Tolérancement géométrique — Exigence du maximum de matière (MMR), exigence du minimum de matière (LMR) et exigence de réciprocité (RPR)

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Foreword

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

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

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 213, *Dimensional and geometrical product specifications and verification*.

This third edition cancels and replaces the second edition (ISO 2692:2006), of which subclauses 3.10, 4.1, 4.2.1 (rule D), 4.2.2 (rule G), 4.3.1 (rule K), 4.3.2 (rule N) and Annex A have been revised.

Introduction

0.1. General

This International Standard is a geometrical product specification (GPS) standard and is to be regarded as a general GPS standard (see ISO/TR 14638). It influences the chain links 1, 2 and 3 of the chain of standards on size of linear "features of size" and form of a line (independent/dependent of a datum), form of a surface (independent/dependent of a datum), orientation and location of derived features based on "features of size" and datums also based on "features of size".

The ISO GPS Masterplan given in ISO/TR 14638 gives an overview of the ISO GPS system of which this document is a part. The fundamental rules of ISO GPS given in ISO 8015 apply to this document and the default decision rules given in ISO 14253-1 apply to specifications made in accordance with this document, unless otherwise indicated.

For more detailed information on the relation of this International Standard to the GPS matrix model, see Annex C.

This International Standard covers some frequently occurring workpiece functional cases in design and tolerancing. The "maximum material requirement", MMR, covers "assembleability" and the "least material requirement", LMR, covers, for example, "minimum wall thickness" of a part. Each requirement (MMR and LMR) combines two independent requirements into one collective requirement, which more accurately simulates the intended function of the workpiece. In some cases of both MMR and LMR, the "reciprocity requirement", RPR, can be added.

NOTE In ISO GPS standards, threaded features are often considered as features of size of type cylinder. However, no rules are defined in this International Standard for how to apply MMR, LMR and RPR to threaded features. Consequently, the tools defined in this International Standard cannot be used for threaded features.

0.2 Information about maximum material requirement, MMR

The assembly of parts depends on the combined effect of

a) the size (of one or more extracted features of size), and

b) the geometrical deviation of the (extracted) features and their derived features, such as the pattern of bolt holes in two flanges and the bolts securing them.

The minimum assembly clearance occurs when each of the mating features of size is at its maximum material size (e.g. the largest bolt size and the smallest hole size) and when the geometrical deviations (e.g. the form, orientation and location deviations) of the features of size and their derived features (median line or median surface) are also at their maximum. Assembly clearance increases to a maximum when the sizes of the assembled features of size are furthest from their maximum material sizes (e.g. the smallest shaft size and the largest hole size) and when the geometrical deviations (e.g. the form, orientation and location deviations) of the features of size and their derived features are zero. It therefore follows that if the sizes of one mating part do not reach their maximum material size, the indicated geometrical tolerance of the features of size and their derived features may be increased without endangering the assembly to the other part.

This assembly function is controlled by the maximum material requirement. This collective requirement is indicated on drawings by the symbol Ⓜ.

0.3 Information about least material requirement, LMR

The least material requirement is designed to control, for example, the minimum wall thickness, thereby preventing breakout (due to pressure in a tube), the maximum width of a series of slots, etc. It is indicated on drawings by the symbol Ⓛ. The least material requirement is also characterized by a collective requirement for the size of a feature of size, the geometrical deviation of the feature of size (form deviations) and the location of its derived feature.

0.4 Information about reciprocity requirement, RPR

The reciprocity requirement is an additional requirement, which may be used together with the maximum material requirement and the least material requirement in cases where it is permitted — taking into account the function of the toleranced feature(s) — to enlarge the size tolerance when the geometrical deviation on the actual workpiece does not take full advantage of, respectively, the maximum material virtual condition or the least material virtual condition.

The reciprocity requirement is indicated on the drawing by the symbol Ⓡ.

0.5 General information about terminology and figures

The terminology and tolerancing concepts in this International Standard have been updated to conform to GPS terminology, notably that in ISO 286-1, ISO 14405-1, ISO 14660-2:1999 and ISO 17450-1:2011.

Geometrical product specifications (GPS) — Geometrical tolerancing — Maximum material requirement (MMR), least material requirement (LMR) and reciprocity requirement (RPR)

1 Scope

This International Standard defines the maximum material requirement, the least material requirement and the reciprocity requirement. These requirements can only be applied to features of size.

These requirements are used to control specific functions of workpieces where size and geometry are interdependent, e.g. to fulfil the functions "assembly of parts" (for maximum material requirement) or "minimum wall thickness" (for least material requirement). However, the maximum material requirement and least material requirement are also used to fulfil other functional design requirements.

Considering this interdependence between size and geometry, the *principle of independency* defined in ISO 8015 does not apply when the maximum material requirement, least material requirement, or reciprocity requirement, are used.

2 Normative references

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

ISO 1101:2012, *Geometrical product specifications (GPS) — Geometrical tolerancing — Tolerances of form, orientation, location and run-out*

ISO 5459:2011, *Geometrical product specifications (GPS) — Geometrical tolerancing — Datums and datum systems*

ISO 14405-1:2010, *Geometrical product specifications (GPS) — Dimensional tolerancing — Part 1: Linear sizes*

ISO 14660-2:1999, *Geometrical Product Specifications (GPS) — Geometrical features — Part 2: Extracted median line of a cylinder and a cone, extracted median surface, local size of an extracted feature*

ISO 17450-1:2011, *Geometrical product specifications (GPS) — General concepts — Part 1: Model for geometrical specification and verification*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5459:2011, ISO 14405-1:2010, ISO 14660-2:1999, ISO 17450-1:2011 and the following apply.

3.1
integral feature
geometrical feature belonging to the real surface of the workpiece or to a surface model

Note 1 to entry: An integral feature is intrinsically defined, e.g. skin of the workpiece.

Note 2 to entry: Adapted from ISO 17450-1:2011, definition 3.3.5.

3.2
feature of size
feature of linear size
geometrical feature, having one or more intrinsic characteristics, only one of which may be considered as variable parameter, that additionally is a member of a “one parameter family”, and obeys the monotonic containment property for that parameter

Note 1 to entry: Adapted from ISO 17450-1:2011, definition 3.3.1.5.1. See also ISO 22432:2011, definitions 3.2.5.1.1.1 and 3.2.5.1.1.2 for “one parameter family” and “monotonic containment property”.

EXAMPLE 1 A single cylindrical hole or shaft is a feature of linear size. Its linear size is its diameter.

EXAMPLE 2 Two opposite parallel plane surfaces are a feature of linear size. Its linear size is the distance between the two parallel planes.

3.3
derived feature
geometrical feature, which does not exist physically on the real surface of the workpiece and which is not natively a nominal integral feature

Note 1 to entry: A derived feature can be established from a nominal feature, an associated feature, or an extracted feature. It is qualified respectively as a nominal derived feature, an associated derived feature, or an extracted derived feature.

Note 2 to entry: The centre point, the median line and the median surface defined from one or more integral features are types of derived features.

Note 3 to entry: Adapted from ISO 17450-1:2011, definition 3.3.6.

EXAMPLE 1 The median line of a cylinder is a derived feature obtained from the cylinder surface, which is an integral feature. The axis of the nominal cylinder is a nominal derived feature.

EXAMPLE 2 The median surface of two opposite parallel plane surfaces is a derived feature obtained from the two parallel plane surfaces, which constitute an integral feature. The median plane of the nominal two opposite parallel planes is a nominal derived feature.

3.4
maximum material condition
MMC
state of the considered extracted feature, where the feature of size is at that limit of size where the material of the feature is at its maximum everywhere, e.g. minimum hole diameter and maximum shaft diameter

Note 1 to entry: The term maximum material condition, MMC, is used in this International Standard to indicate, at ideal or nominal feature level (see ISO 17450-1), which limit of the requirement (upper or lower) is concerned.

Note 2 to entry: The size of the extracted feature at maximum material condition, MMC, can be defined by default, or by several special definitions of the size of the extracted feature (see ISO 14405-1).

Note 3 to entry: The maximum material condition, MMC, as defined in this International Standard, can be used unambiguously with any definition of size of the extracted feature.

3.5
maximum material size
MMS
l_{MMS}
dimension defining the maximum material condition of a feature

Note 1 to entry: Maximum material size, MMS, can be defined by default or by one of several special definitions of the size of the extracted feature (see ISO 14405-1 and ISO 14660-2).

Note 2 to entry: In this International Standard, maximum material size, MMS is used as a numerical value, therefore no specific definition of the extracted size is needed to permit unambiguous use of maximum material size, MMS.

Note 3 to entry: See Annex A.

3.6
least material condition
LMC
state of the considered extracted feature, where the feature of size is at that limit of size where the material of the feature is at its minimum everywhere, e.g. maximum hole diameter and minimum shaft diameter

Note 1 to entry: The term least material condition, LMC, is used in this International Standard to indicate, at the ideal or nominal feature level (see ISO 17450-1), which limit of the requirement (upper or lower) is concerned.

Note 2 to entry: The size at least material condition, LMC, can be defined by default or by several special definitions of the size of extracted feature (see ISO 14405-1 and ISO 14660-2).

Note 3 to entry: The least material condition, LMC, as defined in this International Standard, can be used unambiguously with any definition of size of the extracted feature.

3.7
least material size
LMS
l_{LMS}
dimension defining the least material condition of a feature

Note 1 to entry: Least material size, LMS, can be defined by default or by one of several special definitions of the size of the extracted feature (see ISO 14405-1 and ISO 14660-2).

Note 2 to entry: In this International Standard, least material size, LMS, is used as a numerical value, therefore no specific definition of the extracted size is needed to permit unambiguous use of least material size, LMS.

Note 3 to entry: See Annex A.

3.8
maximum material virtual size
MMVS
l_{MMVS}
size generated by the collective effect of the maximum material size, MMS, of a feature of size and the geometrical tolerance (form, orientation or location) given for the derived feature of the same feature of size

Note 1 to entry: Maximum material virtual size, MMVS, is a parameter for size used as a numerical value connected to maximum material virtual condition, MMVC.

Note 2 to entry: For external features, MMVS is the sum of MMS and the geometrical tolerance, whereas for internal features, it is the difference between MMS and the geometrical tolerance.

Note 3 to entry: The MMVS for external features of size, $l_{\mathrm{MMVS,e}}$, is given by Formula (1):

$$l_{\mathrm{MMVS,e}} = l_{\mathrm{MMS}} + \delta \quad (1)$$

and the MMVS for internal features of size, $l_{\mathrm{MMVS,i}}$, is given by Formula (2):

$$l_{\mathrm{MMVS,i}} = l_{\mathrm{MMS}} - \delta \quad (2)$$

where

l_{MMS} is the maximum material size;

δ is the geometrical tolerance.

3.9
maximum material virtual condition
MMVC
state of associated feature of maximum material virtual size, MMVS

Note 1 to entry: Maximum material virtual condition, MMVC, is a perfect form condition of the feature.

Note 2 to entry: Maximum material virtual condition, MMVC, includes an orientation constraint (in accordance with ISO 1101 and ISO 5459) of the associated feature when the geometrical specification is an orientation specification (see Figure A.3). Maximum material virtual condition, MMVC, includes a location constraint (in accordance with ISO 1101 and ISO 5459) of the associated feature when the geometrical specification is a location specification (see Figure A.4).

Note 3 to entry: See Figures A.1-A.4, A.6. A.7 and A.10-A.13.

3.10
least material virtual size
LMVS
l_{LMVS}
size generated by the collective effect of the least material size, LMS, of a feature of size and the geometrical tolerance (form, orientation or location) given for the derived feature of the same feature of size

Note 1 to entry: Least material virtual size, LMVS, is a parameter for size used as a numerical value connected to least material virtual condition, LMVC.

Note 2 to entry: For external features, LMVS is the difference between LMS and the geometrical tolerance, whereas for internal features, it is the sum of LMS and the geometrical tolerance.

Note 3 to entry: The LMVS for external features of size, $l_{LMVS,e}$, is given by Formula (3):

$$l_{LMVS,e} = l_{LMS} - \delta \tag{3}$$

and the LMVS for internal features of size, $l_{LMVS,i}$, is given by Formula (4):

$$l_{LMVS,i} = l_{LMS} + \delta \tag{4}$$

where

l_{LMS} is the least material size;

δ is the geometrical tolerance.

3.11
least material virtual condition
LMVC
state of associated feature of least material virtual size, LMVS

Note 1 to entry: Least material virtual condition, LMVC, is a perfect form condition of the feature.

Note 2 to entry: Least material virtual condition, LMVC, includes an orientation constraint (in accordance with ISO 1101 and ISO 5459) of the associated feature when the geometrical specification is an orientation specification. Least material virtual condition, LMVC, includes a location constraint (in accordance with ISO 1101 and ISO 5459) of the associated feature when the geometrical specification is a location specification (see Figure A.5).

Note 3 to entry: See Figures A.5, A.8 and A.9.

3.12
maximum material requirement
MMR
requirement for a feature of size, defining a geometrical feature of the same type and of perfect form, with a given value for the intrinsic characteristic (dimension) equal to MMVS, which limits the non-ideal feature on the outside of the material

Note 1 to entry: Maximum material requirement, MMR, is used to control the assemblability of a workpiece.

Note 2 to entry: See also 4.2.

3.13
least material requirement
LMR
requirement for a feature of size, defining a geometrical feature of the same type and of perfect form, with a given value for the intrinsic characteristic (dimension) equal to LMVS, which limits the non-ideal feature on the inside of the material

Note 1 to entry: Least material requirements, LMR, are used in pairs, e.g. to control the minimum wall thickness between two symmetrical or coaxially located similar features of size.

Note 2 to entry: See also 4.3.

3.14
reciprocity requirement
RPR
additional requirement for a feature of size used as an addition to the maximum material requirement, MMR, or the least material requirement, LMR to indicate that the size tolerance is increased by the difference between the geometrical tolerance and the actual geometrical deviation

4 Maximum material requirement, MMR and least material requirement, LMR

4.1 General

The maximum material requirement, MMR, and the least material requirement, LMR, can be applied to a set of one or more feature(s) of size as toleranced feature(s), or datum(s), or both. They create a combined requirement between the size of feature(s) of size and the geometry requirements (form, orientation or location) specified for its (their) derived feature(s).

NOTE 1 This edition of this International Standard only covers features of size of type cylinder and type two opposite parallel plane surfaces. Consequently, the only possible derived features are median lines and median surfaces.

NOTE 2 In ISO GPS standards, threaded features are often considered as features of size of type cylinder. However, no rules are defined in this International Standard for how to apply MMR, LMR and RPR to threaded features. Consequently, the tools defined in this International Standard cannot be used for threaded features.

When maximum material requirement, MMR, or least material requirement, LMR, is used, the two specifications (size specification and geometrical specification) are transformed into one collective requirements specification. The collective specification concerns only the integral feature, which in this International Standard relates to the surface(s) of the feature(s) of size(s).

NOTE 3 In the past, the maximum material requirement, MMR, was referred to as the maximum material principle, MMP.

When no modifiers (Ⓛ, Ⓜ, Ⓡ) are applied to the toleranced feature, the definitions of size of extracted feature in ISO 14405-1 and ISO 14660-2 apply.

When no modifiers (Ⓛ, Ⓜ) are applied to the datum, ISO 5459 applies. The modifier Ⓡ does not apply to datums.

4.2 Maximum material requirement, MMR

4.2.1 Maximum material requirement for toleranced features

The maximum material requirement for toleranced features results in four independent requirements:

— a requirement for the upper limit of the local size [see Rules A 1) and A 2)];

— a requirement for the lower limit of the local size [see Rules B 1) and B 2)];

— a requirement for the surface non-violation of the MMVC (see Rule C);

— a requirement for when more than one feature is involved (see Rule D).

When the maximum material requirement, MMR, applies to the toleranced feature, it shall be indicated on drawings by the symbol Ⓜ placed after the geometrical tolerance of the derived feature of the feature of size (toleranced feature) in the tolerance indicator.

In this case, it specifies for the surface(s) (of the feature of size) the following rules.

a) **Rule A** The extracted local sizes of the toleranced feature shall be:

1) equal to or smaller than the maximum material size, MMS, for external features;

2) equal to or larger than the maximum material size, MMS, for internal features.

NOTE 1 This rule can be altered by the indication of reciprocity requirement, RPR, with the symbol Ⓡ after the symbol Ⓜ (see Clause 5 and Figure A.1).

b) **Rule B** The extracted local sizes of the toleranced feature shall be:

1) equal to or larger than the least material size, LMS, for external features [see Figures A.2 a), A.3 a), A.4 a), A.6 a), A.7 a), A.10 and A.11];

2) equal to or smaller than the least material size, LMS, for internal features [see Figures A.2 b), A.3 b), A.4 b), A.6 b), A.7 b), A.10 and A.11].

c) **Rule C** The maximum material virtual condition, MMVC, of the toleranced feature shall not be violated by the extracted (integral) feature (see Figures A.2, A.3, A.4, A.6, A.7, A.10 and A.11).

NOTE 2 Use of the envelope requirement Ⓔ (previously also known as the Taylor Principle) usually leads to superfluous constraints regarding the function of the feature(s) (assembleability). Use of such constraints and size definitions reduces the technical and economic advantage of maximum material requirement, MMR.

NOTE 3 The indication 0 Ⓜ applied to a form specification has the same meaning as the envelope requirement Ⓔ applied to a size.

d) **Rule D** When the geometrical specification is an orientation or a location relative to a (primary) datum or a datum system, the maximum material virtual condition, MMVC, of the toleranced feature shall be in theoretically exact orientation or location relative to the datum or the datum system, in accordance with ISO 1101 and ISO 5459 (see 3.9 NOTE 2 and Figures A.3, A.4, A.6, and A.7). Moreover, in the case of several toleranced features controlled by the same tolerance indication, the maximum material virtual conditions, MMVCs, shall also be in theoretically exact orientation and location relative to each other [in addition to the possible constraints relative to the datum(s)] (see Figures A.1, A.10, A.11 and A.13).

NOTE 4 In the case of several toleranced features controlled by the same toleranced indication, the maximum material requirement, MMR, without any other modifier than Ⓜ has exactly the same meaning as the same requirement with both Ⓜ and CZ modifiers.

To specify requirements that apply separately, the SZ[1)] modifier shall be used after the Ⓜ modifier.

4.2.2 Maximum material requirement for related datum features

The maximum material requirement for datum features results in three independent requirements:

— a requirement for the surface non-violation of the MMVC (see Rule E);

— a requirement for MMS when there is no geometrical specification or when there is only geometrical specifications whose tolerance value is not followed by the symbol Ⓜ (see Rule F);

— a requirement for MMS when there is a geometrical specification whose tolerance value is followed by the symbol Ⓜ and whose “datum” section (third and subsequent compartments) of the tolerance indicator meets a property defined in Rule G.

When the maximum material requirement, MMR, applies to the datum feature, it shall be indicated on drawings by the symbol Ⓜ placed after the datum letter(s) in the tolerance indicator.

NOTE 1 The use of Ⓜ after the datum letter is only possible if the datum is obtained from a feature of size.

NOTE 2 When maximum or least material requirement applies to all elements of the collection of surfaces of a common datum, the corresponding sequence of letters identifying the common datum are indicated within parentheses (see Figure A.13 and ISO 5459:2011, Rule 9) and maximum material virtual conditions, MMVCs, are by default constrained in location and orientation relative to each other (see ISO 5459:2011, Rule 7). When maximum or least material requirement applies only to one surface of the collection of features involved in a common datum, the sequence of letters identifying the common datum is not indicated within parentheses, and the requirement applies only to the feature identified by the letter placed just before the modifier.

In this case, it specifies for the surface(s) (of the feature of size) the following rules.

a) **Rule E** The maximum material virtual condition, MMVC, of the related datum feature shall not be violated by the extracted (integral) datum feature from which the datum is derived (see Figures A.6 and A.7).

b) **Rule F** The size of the maximum material virtual condition, MMVC, of the related datum feature shall be the maximum material size, MMS, when the related datum feature has no geometrical specification (see Figure A.6), or has only geometrical specifications whose tolerance value is not followed by the symbol Ⓜ, or has no geometrical specification complying with Rule G.

NOTE 3 In these cases, the MMVS for external and internal features of size, l_{MMVS}, is given by Formula (5):

$$l_{MMVS} = l_{MMS} \pm 0 = l_{MMS} \quad (5)$$

where l_{MMS} is the maximum material size.

c) **Rule G** The size of the maximum material virtual condition, MMVC, of the related datum feature shall be the maximum material size, MMS, plus (for external features of size) or minus (for internal features of size) the geometrical tolerance, when the datum feature is controlled by a geometrical specification with the following properties:

1) its tolerance value is followed by the symbol Ⓜ, and

i) it is a form specification and the related datum corresponds to the primary datum of the tolerance indicator where the Ⓜ symbol is indicated next to the datum letter (see Figure A.7), or

ii) it is an orientation/location specification whose datum or datum system contains exactly the same datum(s) in the same order as the one(s) called before the related datum in

1) SZ will be incorporated in the revision of ISO 1101:2012.

the tolerance indicator where the Ⓜ symbol is indicated next to the datum letter (see Figure A.12 and Figure A.13).

NOTE 4 In this case, the MMVS for external features of size is as given in Formula (1), and the MMVS for internal features of size is as given in Formula (2). See 3.8, Note 3.

NOTE 5 When above properties are not observed, Rule F applies.

In the case of Rule G, the datum feature indicator shall be directly connected to that geometrical tolerance indicator from which maximum material virtual condition, MMVC, of the datum feature is controlled (see ISO 5459:2011, Rule 1, dash 2).

4.3 Least material requirement, LMR

4.3.1 Least material requirement for toleranced features

When the least material requirement, LMR, applies to the toleranced feature, it shall be indicated on the drawing by the symbol Ⓛ placed after the geometrical tolerance of the derived feature of the feature of size (toleranced feature) in the tolerance indicator.

EXAMPLE To fully control the minimum wall thickness, the symbol Ⓛ is applied to the tolerancing of the features on both sides of the wall. Least material requirement, LMR can be implemented in two different ways, as follows.

— The location requirements for the two different sides of the wall can refer to the same datum axis or datum system (see Figure A.8). In this case, Ⓛ applies to the two toleranced features.

— The location requirement of the derived feature for one of the sides of the wall can refer to the derived feature of the other as the datum. In this case, the tolerance for the toleranced feature and the datum letter are followed by the symbol Ⓛ (see Figure A.9).

NOTE 1 This possibility only applies if the features on the two sides are features of size.

When the least material requirement, LMR, applies to the toleranced feature, it specifies for the surface(s) (of the feature of size) the following rules.

a) **Rule H** The extracted local sizes of the toleranced feature shall be:

   1) equal to or larger than the least material size, LMS, for external features;

   2) equal to or smaller than the least material size, LMS, for internal features.

   NOTE 2 This rule can be altered by the indication of reciprocity requirement, RPR, with the symbol Ⓡ after the symbol Ⓛ [see 5.3, Figure A.5 e) and Figure A.5 f)].

b) **Rule I** The extracted local sizes of the toleranced feature shall be:

   1) equal to or smaller than the maximum material size, MMS, for external features [see Figures A.5 a), A.8 and A.9];

   2) equal to or larger than the maximum material size, MMS, for internal features [see Figures A.5 b) and A.8].

c) **Rule J** The least material virtual condition, LMVC, of the toleranced feature shall not be violated by the extracted (integral) feature (see Figures A.5, A.8 and A.9).

   NOTE 3 Use of the envelope requirement Ⓔ (previously also known as the Taylor Principle) usually leads to superfluous constraints regarding the function of the feature(s) (minimum wall thickness). Use of such constraints and size definitions for size reduces the technical and economic advantage of LMR.

d) **Rule K** When the geometrical specification is an orientation or a location relative to a (primary) datum or a datum system, the least material virtual condition, LMVC, of the toleranced feature shall be in theoretically exact orientation or location relative to the datum or the datum system, in accordance with ISO 1101 and ISO 5459 (see 3.11 NOTE 2 and Figures A.5, A.8, and A.9). Moreover, in the case of several toleranced features controlled by the same tolerance indication, the least material virtual conditions, LMVCs, shall also be in theoretically exact orientation and location relative to each other [in addition to the possible constraints relative to the datum(s)].

NOTE 4 In the case of several toleranced features controlled by the same toleranced indication, the least material requirement, LMR, without any other modifier than Ⓛ has exactly the same meaning as the same requirement with both Ⓛ and CZ modifiers.

To specify requirements that apply separately, the SZ[2)] modifier shall be used after the Ⓛ modifier.

4.3.2 Least material requirement for related datum features

When the least material requirement, LMR, applies to the datum feature, it shall be indicated on the drawing by the symbol Ⓛ placed after the datum letter in the tolerance indicator.

NOTE 1 The use of Ⓛ after the datum letter is only possible if the datum is obtained from a feature of size.

NOTE 2 When maximum or least material requirement applies to all elements of the collection of surfaces of a common datum, the corresponding sequence of letters identifying the common datum are indicated within parentheses (see Figure A.13 and ISO 5459:2011, Rule 9) and maximum material virtual conditions, MMVCs, are by default constrained in location and orientation relative to each other (see ISO 5459:2011, Rule 7). When maximum or least material requirement applies only to one surface of the collection of features involved in a common datum, the sequence of letters identifying the common datum is not indicated within parentheses, and the requirement applies only to the feature identified by the letter placed just before the modifier.

In this case, it specifies for the surface(s) (of the feature of size) the following rules.

a) **Rule L** The least material virtual condition, LMVC, of the related datum feature shall not be violated by the extracted (integral) datum feature from which the datum is derived (see Figure A.9).

b) **Rule M** The size of the least material virtual condition, LMVC, of the related datum feature shall be the least material size, LMS, when the related datum feature has no geometrical specification (see Figure A.9), or has only geometrical specifications whose tolerance value is not followed by the symbol Ⓛ, or has no geometrical specification complying with Rule N.

   NOTE 3 In these cases, the LMVS for external and internal features of size, l_{LMVS}, is given by Formula (6):

$$l_{\text{LMVS}} = l_{\text{LMS}} \pm 0 = l_{\text{LMS}} \qquad (6)$$

   where l_{LMS} is the least material size.

c) **Rule N** The size of the least material virtual condition, LMVC, of the related datum feature shall be the least material size, LMS, minus (for external features of size) or plus (for internal features of size) the geometrical tolerance, when the datum feature is controlled by a geometrical specification with the following properties:

   1) its tolerance value is followed by the symbol Ⓛ, and

      i) it is a form specification and the related datum corresponds to the primary datum of the tolerance indicator where the Ⓛ symbol is indicated next to the datum letter, or

      ii) It is an orientation/location specification whose datum or datum system contains exactly the same datum(s) in the same order as the one(s) called before the related datum in the tolerance indicator where the Ⓛ symbol is indicated next to the datum letter.

NOTE 4 In this case, the LMVS for external features of size is as given in Formula (3), and the LMVS for internal features of size is as given in Formula (4). See 3.10, Note 3.

2) SZ will be incorporated in the revision of ISO 1101:2012.

NOTE 5 When above properties are not observed, Rule M applies.

In the case of Rule N, the datum feature indicator shall be directly connected to that geometrical tolerance indicator from which the least material virtual condition, LMVC, of the datum feature is controlled (see ISO 5459:2011, Rule 1, dash 2).

5 Reciprocity requirement, RPR

5.1 General

Reciprocity requirement, RPR, shall be indicated on drawings as an additional requirement to maximum material requirement, MMR, or least material requirement, LMR, by the symbol Ⓡ placed after the symbol Ⓜ, or by the symbol Ⓡ placed after the symbol Ⓛ, respectively. Reciprocity requirement is only applicable for the toleranced feature.

The additional requirement, RPR alters the size tolerance of the feature of size in the collective requirements MMR and LMR. By means of RPR, the size can take full advantage of the MMVC and the LMVC. RPR allows for the choice of distribution of variation allowance between dimensional and geometrical tolerances based on manufacturing capabilities.

NOTE Reciprocity requirement can express the same workpiece functions as the indication “0 Ⓜ”.

5.2 Reciprocity requirement and maximum material requirement

When the reciprocity requirement, RPR, is indicated by the symbol Ⓡ placed after the symbol Ⓜ, it alters the maximum material requirement for the surface(s) (of the feature of size) in the following ways [see Figure A.1 b)]:

— Rule A is not valid.

— Rules B to D are still valid.

NOTE The reciprocity requirement, RPR, allows an increase in the dimensional tolerance when the geometrical deviation does not take full advantage of the maximum material virtual condition, MMVC.

5.3 Reciprocity requirement and least material requirement

When the reciprocity requirement, RPR, is indicated by the symbol Ⓡ placed after the symbol Ⓛ, it alters the least material requirement for the surface(s) (of the feature of size) in the following ways [see Figures A.5 e) and A.5 f)]:

— Rule H is not valid.

— Rules I to K are still valid.

NOTE The reciprocity requirement, RPR, allows an increase in the dimensional tolerance when the geometrical deviation does not take full advantage of the least material virtual condition, LMVC.

Annex A
(informative)

Examples of tolerancing with Ⓜ, Ⓛ and Ⓡ

The figures in this International Standard are intended only as illustrations to aid the user in understanding the maximum material requirement, the least material requirement and the reciprocity requirement. In some instances, figures provide added details for emphasis; in other instances, figures have deliberately been left incomplete. Numerical values of dimensions and tolerances have been given for illustrative purposes only.

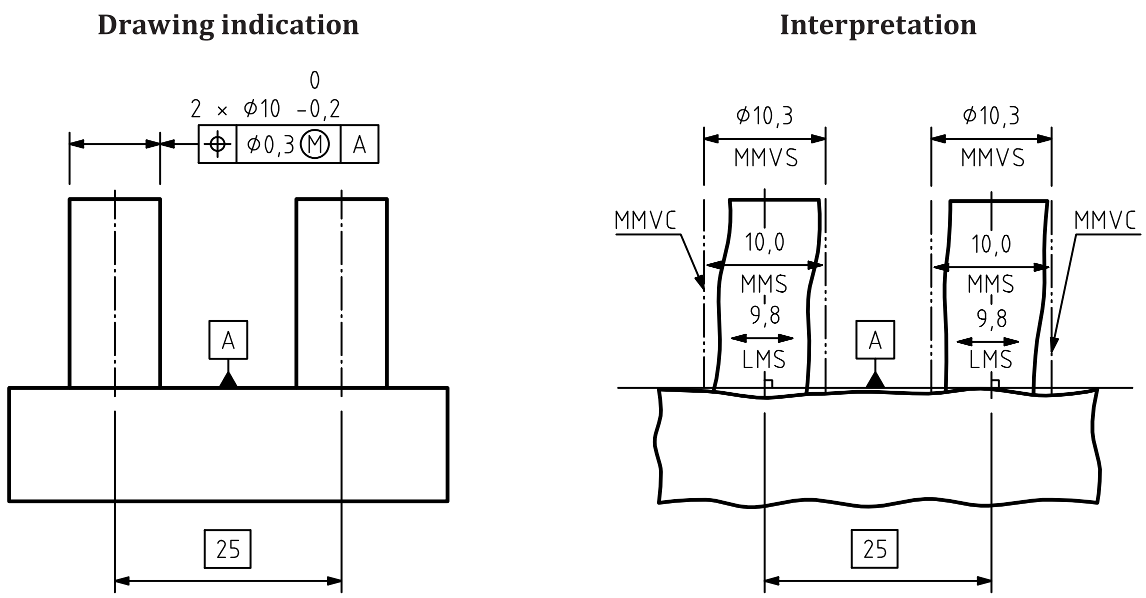
In the interpretation figures, the dimension lines (with arrows) for the interpretation of MMS and LMS are only shown in a symbolic way. The orientation of the local sizes (two-point sizes) on the real workpiece is not necessarily perpendicular to the axis of the MMVC or LMVC.

For uniformity in this International Standard, all dimensions are given in millimetres and all figures are in first angle projection.

It should be understood that the third angle projection method 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 7083:1983.

In every explanation under figures, conditions on local diameters and local sizes systematically include the limit value (“equal to” is therefore implied every time the expression “larger than”/“smaller than” is employed).

Dimensions in millimetres



The intended function of the part illustrated in Figure A.1 a) is an assembly with a plate with two holes 25 mm apart. The holes are required to be perpendicular to the contact surface of the plate.

The interpretation is based on the following rules and definitions given in this International Standard.

i. The extracted feature of the toleranced pins shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 10,3 mm [see Rule C, 3.8 and 3.9].

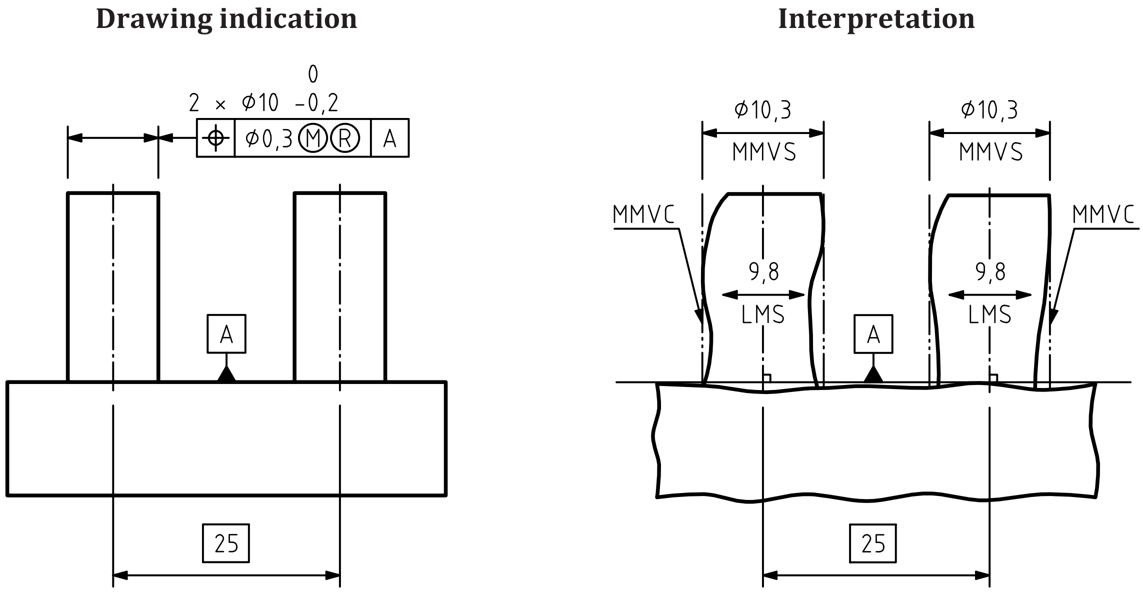
ii. The extracted feature of the toleranced pins shall have everywhere a local diameter larger than LMS = 9,8 mm [see Rule B 1) and 3.7] and smaller than MMS = 10,0 mm [see Rule A 1) and 3.5].

iii. The location of the two MMVCs is theoretically exact— at a distance 25 mm relative to each other and perpendicular to the datum A [see Rule D and 3.9 NOTE 2].

a) Example of MMR without RPR for two external cylindrical features based on size and position (location) requirements

Figure A.1 *(to be continued)*

Dimensions in millimetres



The intended function of the part illustrated in Figure A.1 b) is an assembly with a plate with two holes 25 mm apart. The holes are required to be perpendicular to the contact surface of the plate.

The interpretation is based on the following rules and definitions given in this International Standard.

i. The extracted feature of the toleranced pins shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 10,3 mm [see Rule C and 3.8 and 3.9].

ii. The extracted feature of the toleranced pins shall have everywhere a local diameter larger than LMS = 9,8 mm [see Rule B 1) and 3.7]. There is no requirement concerning the upper limit of local diameters (see 5.2). The RPR requirement allows the size tolerance to increase.

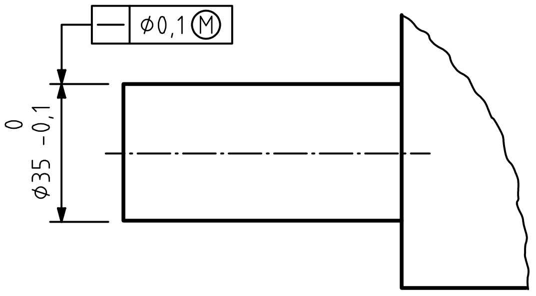
iii. The location of the two MMVCs is theoretically exact— at a distance 25 mm relative to each other and perpendicular to the datum A [see Rule D and 3.9 NOTE 2].

b) Example of MMR with RPR for two external cylindrical features based on size and position (location) requirements

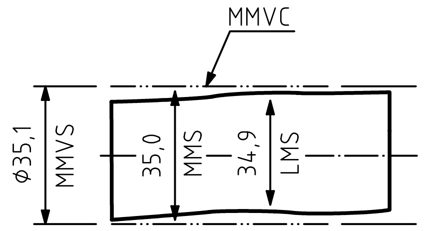
Figure A.1 — Examples of MMR for two external cylindrical features based on size and position (location) requirements

Dimensions in millimetres

Drawing indication



Interpretation



The intended function of the part toleranced in Figure A.2 a) could be a clearance fit with a hole of the same length as the toleranced cylindrical feature.

The interpretation is based on the following rules and definitions given in this International Standard.

i. The extracted feature shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 35,1 mm [see Rule C, 3.8 and 3.9.]

ii. The extracted feature shall have everywhere a local diameter larger than LMS = 34,9 mm [see Rule B 1) and 3.7] and smaller than MMS = 35,0 mm [see Rule A 1) and 3.5].

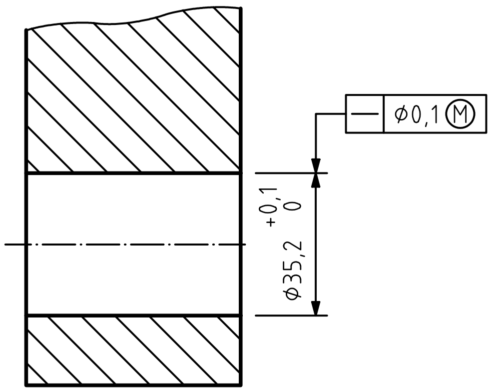
iii. The orientation and location of the MMVC are not controlled by any external constraints (see 3.9 NOTE 2).

a) Example of MMR for an external cylindrical feature based on size and form (straightness) requirements

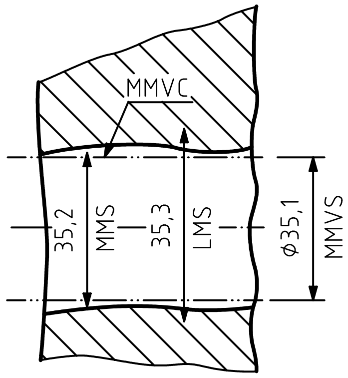
Figure A.2 *(to be continued)*

Dimensions in millimetres

Drawing indication



Interpretation



The intended function of the part toleranced in Figure A.2 b) could be a clearance fit with a shaft of the same length as the toleranced cylindrical feature.

The interpretation is based on the following rules and definitions given in this International Standard.

i. The extracted feature shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 35,1 mm [see Rule C, 3.8 and 3.9].

ii. The extracted feature shall have everywhere a local diameter smaller than LMS = 35,3 mm [see Rule B 2) and 3.7] and larger than MMS = 35,2 mm [see Rule A 2) and 3.5].

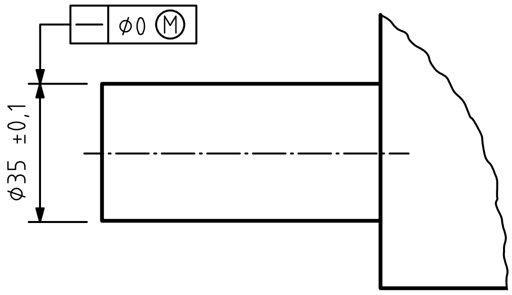
iii. The orientation and location of the MMVC are not controlled by any external constraints (see 3.9 NOTE 2).

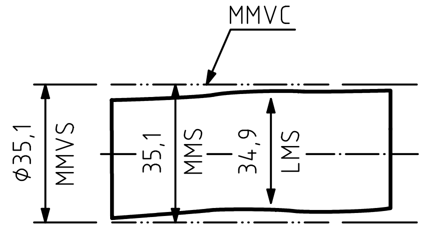
b) Example of MMR for an internal cylindrical feature based on size and form (straightness) requirements

Figure A.2 *(to be continued)*

Dimensions in millimetres

Drawing indication **Interpretation**





The intended function of the part toleranced in Figure A.2 c) could be a clearance fit with a hole of the same length as the toleranced cylindrical feature.

The interpretation is based on the following rules and definitions given in this International Standard.

i. The extracted feature shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 35,1 mm [see Rule C, 3.8 and 3.9].

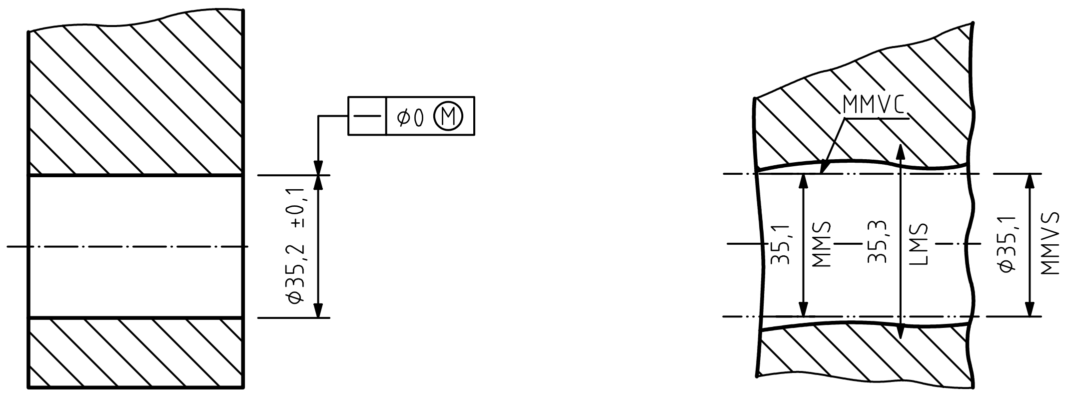
ii. The extracted feature shall have everywhere a local diameter larger than LMS = 34,9 mm [see Rule B 1) and 3.7] and smaller than MMS = 35,1 mm [see Rule A 1) and 3.5]. The difference between Figures A.2 c) and A.2 a) is in the specification of the local diameter, in this case MMS.

iii. The orientation and location of the MMVC are not controlled by any external constraints (see 3.9 NOTE 2).

c) Example of MMR [with 0 Ⓜ] for an external cylindrical feature based on size and form (straightness) requirements

Figure A.2 *(to be continued)*

Dimensions in millimetres



The intended function of the part toleranced on Figure A.2 d) could be a clearance fit with a shaft of the same length as the toleranced cylindrical feature.

The interpretation is based on the following rules and definitions given in this International Standard.

i. The extracted feature shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 35,1 mm [see Rule C, 3.8 and 3.9].

ii. The extracted feature shall have everywhere a local diameter smaller than LMS = 35,3 mm [see Rule B 2) and 3.7] and larger than MMS = 35,1 mm [see Rule A 2) and 3.5]. The difference between Figures A.2 d) and A.2 b) is in the specification of the local diameter, in this case MMS.

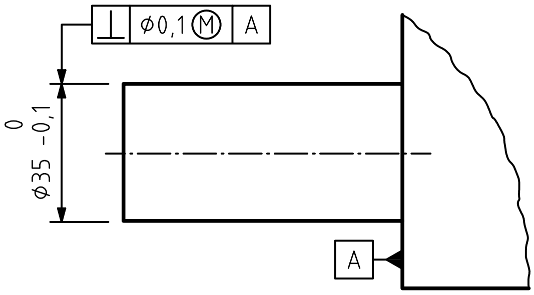
iii. The orientation and location of the MMVC are not controlled by any external constraints (see 3.9 NOTE 2).

d) Example of MMR [with 0 Ⓜ] for an internal cylindrical feature based on size and form (straightness) requirements

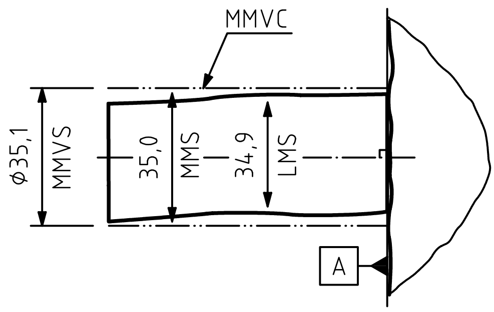
Figure A.2 — Examples of MMR for a cylindrical feature based on size and form (straightness) requirements

Dimensions in millimetres

Drawing indication



Interpretation



The intended function of the part toleranced in Figure A.3 a) could be an assembly with a part as shown in Figure A.3 b), where the functional requirement is that the two planar faces shall be in contact and the pin shall fit into the hole at the same time.

The interpretation is based on the following rules and definitions given in this International Standard.

i. The extracted feature shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 35,1 mm [see Rule C, 3.8 and 3.9].

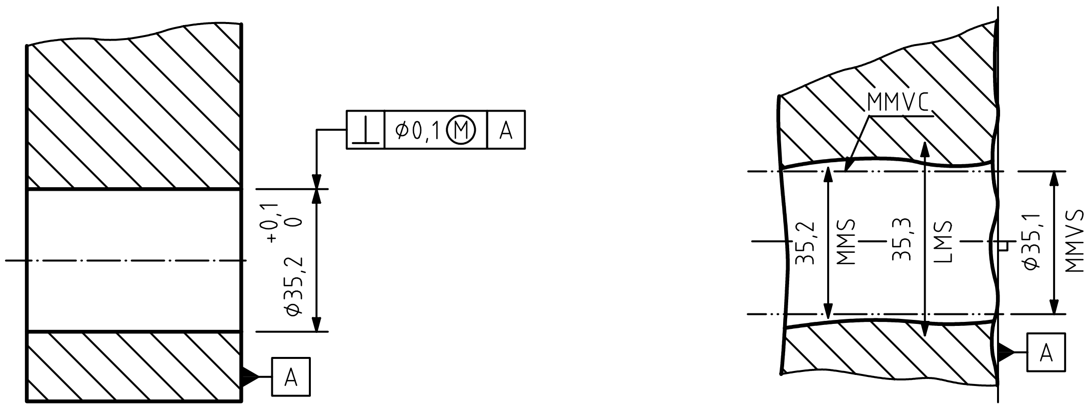
ii. The extracted feature shall have everywhere a local diameter larger than LMS = 34,9 mm [see Rule B 1) and 3.7] and smaller than MMS = 35,0 mm [see Rule A 1) and 3.5].

iii. The orientation of the MMVC is perpendicular to the datum and the location of the MMVC is not controlled by any external constraints [see Rule D and 3.9 NOTE 2].

a) Example of MMR for an external cylindrical feature based on size and orientation (perpendicularity) requirements

Figure A.3 *(to be continued)*

Dimensions in millimetres



The intended function of the part toleranced in Figure A.3 b) could be an assembly with a part as shown in Figure A.3 a), where the functional requirement is that the two planar faces shall be in contact and the pin shall fit into the hole at the same time.

The interpretation is based on the following rules and definitions given in this International Standard.

i. The extracted feature shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 35,1 mm [see Rule C, 3.8 and 3.9].

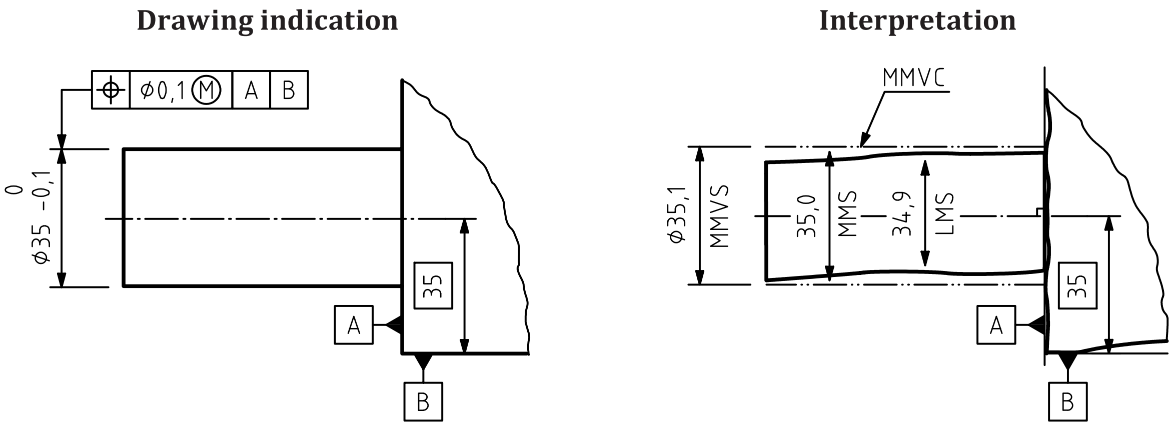
ii. The extracted feature shall have everywhere a local diameter smaller than LMS = 35,3 mm [see Rule B 2) and 3.7] and larger than MMS = 35,2 mm [see Rule A 2) and 3.5].

iii. The orientation of the MMVC is perpendicular to the datum and the location of the MMVC is not controlled by any external constraints [see Rule D and 3.9 NOTE 2].

b) Example of MMR for an internal cylindrical feature based on size and orientation (perpendicularity) requirements

Figure A.3 — Examples of MMR for a cylindrical feature based on size and orientation (perpendicularity) requirements

Dimensions in millimetres



The intended function of the part toleranced in Figure A.4 a) could be an assembly with a part as shown in Figure A.4 b), where the functional requirement is that the two planar faces A shall be in contact, the two planar faces B shall both simultaneously be in contact with a plane (on a part not shown).

The interpretation is based on the following rules and definitions given in this International Standard.

i. The extracted feature shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 35,1 mm [see Rule C, 3.8 and 3.9].

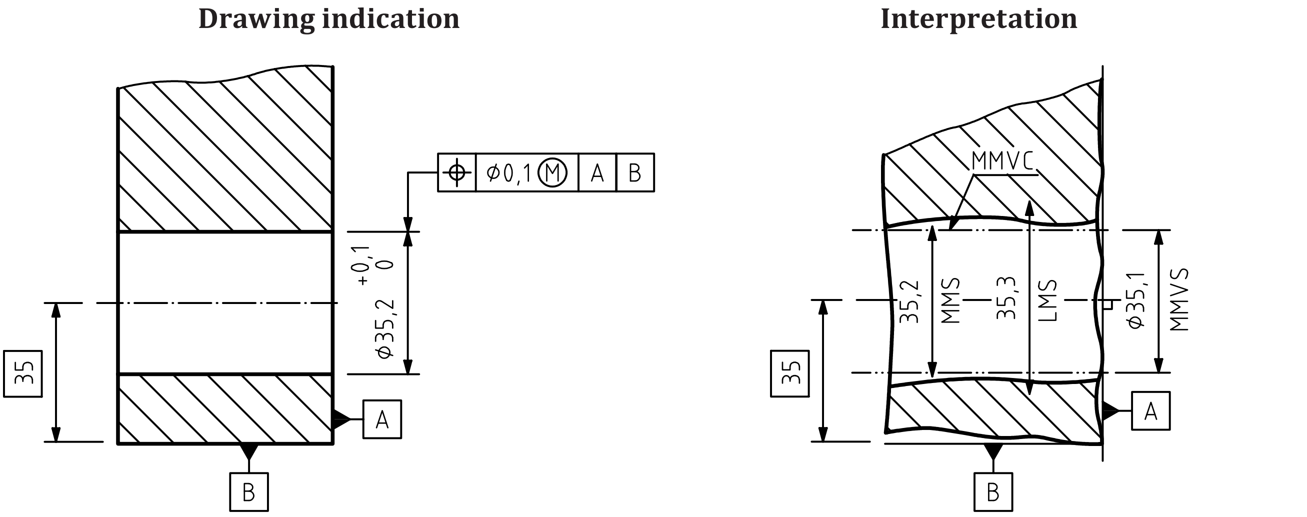
ii. The extracted feature shall have everywhere a local diameter larger than LMS = 34,9 mm [see Rule B 1) and 3.7] and smaller than MMS = 35,0 mm [see Rule A 1) and 3.5].

iii. The orientation of the MMVC is perpendicular to datum A and the location of the MMVC is in a theoretically exact position 35 mm from datum B [see Rule D and 3.9 NOTE 2]

a) Example of MMR for an external cylindrical feature based on size and location (position) requirements

Figure A.4 *(to be continued)*

Dimensions in millimetres



The intended function of the part toleranced in Figure A. 4b) could be an assembly with a part as shown in Figure A.4 a), where the functional requirement is that the two planar faces A shall be in contact, the two planar faces B shall both simultaneously be in contact with a plane (on a part not shown).

The interpretation is based on the following rules and definitions given in this International Standard.

i. The extracted feature shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 35,1 mm [see Rule C, 3.8 and 3.9].

ii. The extracted feature shall have everywhere a local diameter smaller than LMS = 35,3 mm [see Rule B 2) and 3.7] and larger than MMS = 35,2 mm [see Rule A 2) and 3.5].

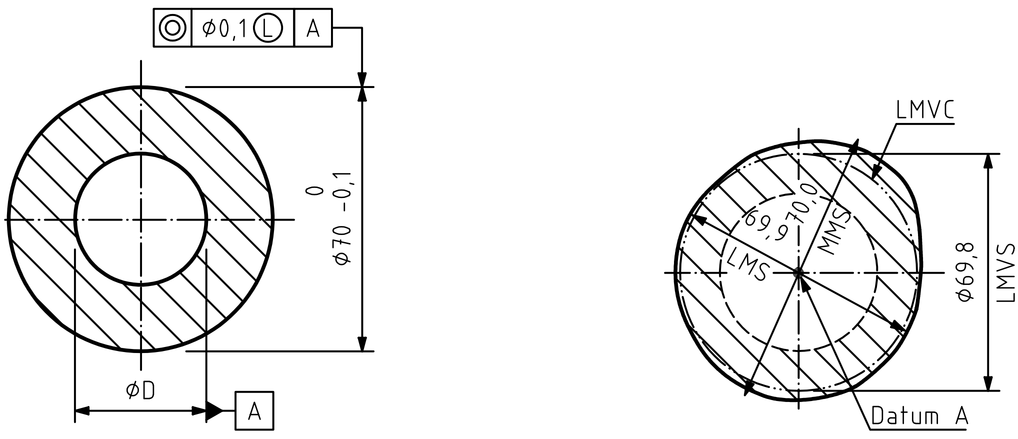
iii. The orientation of the MMVC is perpendicular to datum A and the location of the MMVC is in a theoretically exact position 35 mm from datum B [see Rule D and 3.9 NOTE 2].

b) Example of MMR for an internal cylindrical feature based on size and location (position) requirements

Figure A.4 — Examples of MMR for a cylindrical feature based on size and location (position) requirements

Dimensions in millimetres

Drawing indication **Interpretation**



Position and coaxiality/concentricity can be used with the same meaning in this case.

This figure only illustrates some rules for least material requirement. This drawing indication is incomplete and does not control the minimum wall thickness. The least material requirement is missing on the other feature. Therefore it is not possible to indicate a function.

The interpretation is based on the following rules and definitions given in this International Standard.

i. The least material virtual condition, LMVC, which has the diameter LMVS = 69,8 mm, shall be fully contained in the material [see Rule J, 3.10 and 3.11].

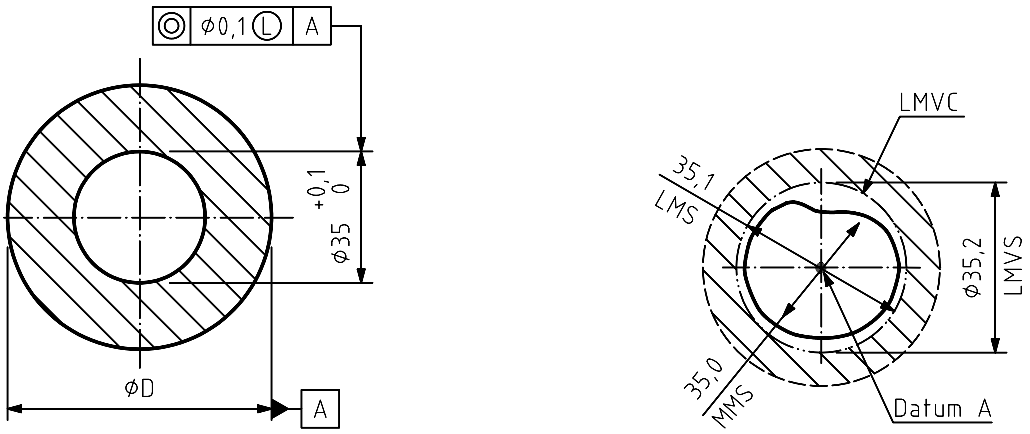
ii. The extracted feature shall have everywhere a local diameter smaller than MMS = 70,0 mm [see Rule I 1) and 3.5] and larger than LMS = 69,9 mm [see Rule H 1) and 3.7].

iii. The orientation of the LMVC is parallel to the datum and the location of the LMVC is in a theoretically exact position 0 mm from datum A [see Rule K and 3.11 NOTE 2].

a) Example 1 of LMR for one external feature of size with another concentric internal feature of size as the datum

Figure A.5 (*to be continued*)

Dimensions in millimetres



Position and coaxiality/concentricity can be used with the same meaning in this case.

This figure only illustrates some rules for least material requirement. This drawing indication is incomplete and does not control the minimum wall thickness. The least material requirement is missing on the other feature. Therefore it is not possible to indicate a function.

The interpretation is based on the following rules and definitions given in this International Standard.

i. The least material virtual condition, LMVC, which has the diameter LMVS = 35,2 mm, shall be fully contained in the material [see Rule J, 3.10 and 3.11].

ii. The extracted feature shall have everywhere a local diameter larger than MMS = 35,0 mm [see Rule I 2) and 3.5] and smaller than LMS = 35,1 mm [see Rule H 2) and 3.7].

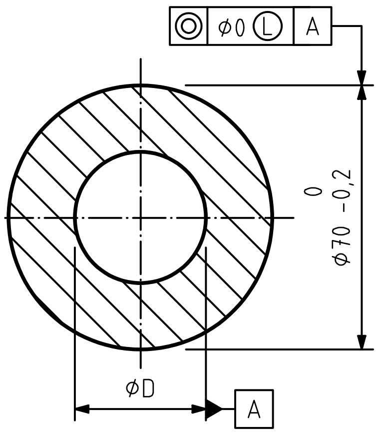
iii The orientation of the LMVC is parallel to the datum and the location of the LMVC is in a theoretically exact position 0 mm from datum A [see Rule K and 3.11 NOTE 2].

b) Example 1 of LMR for one internal feature of size with another concentric external feature of size as the datum

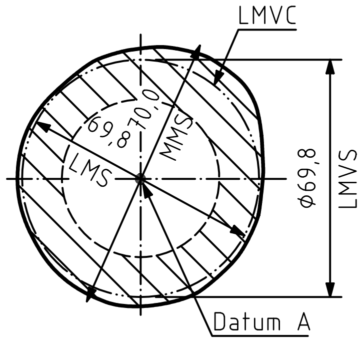
Figure A.5 (*to be continued*)

Dimensions in millimetres

Drawing indication



Interpretation



Position and coaxiality/concentricity can be used with the same meaning in this case.

This figure only illustrates some rules for least material requirement. This drawing indication is incomplete and does not control the minimum wall thickness. The least material requirement is missing on the other feature. Therefore it is not possible to indicate a function.

The interpretation is based on the following rules and definitions given in this International Standard.

i. The least material virtual condition, LMVC, which has the diameter LMVS = 69,8 mm, shall be fully contained in the material [see Rule J, 3.10 and 3.11].

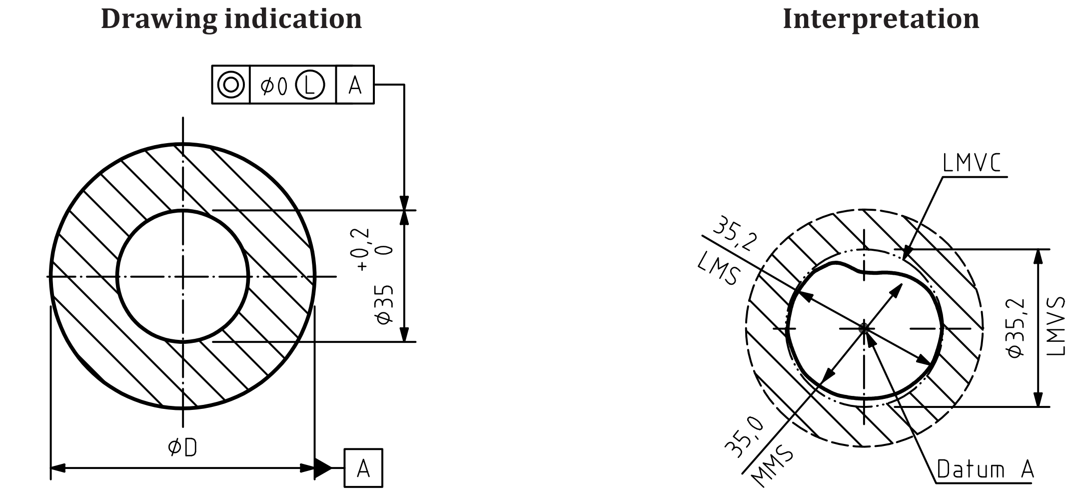
ii. The extracted feature shall have everywhere a local diameter smaller than MMS = 70,0 mm [see Rule I 1) and 3.5] and larger than LMS = 69,8 mm [see Rule H 1) and 3.7]. The difference between Figures A.5 c) and A.5 a) is in the specification of the local diameter, in this case to LMS.

iii. The orientation of the LMVC is parallel to the datum and the location of the LMVC is in a theoretically exact position 0 mm from datum A [see Rule K and 3.11 NOTE 2].

c) Example 2 of LMR for one external feature of size with another concentric internal feature of size as the datum

Figure A.5 *(to be continued)*

Dimensions in millimetres



Position and coaxiality/concentricity can be used with the same meaning in this case.

This figure only illustrates some rules for least material requirement. This drawing indication is incomplete and does not control the minimum wall thickness. The least material requirement is missing on the other feature. Therefore it is not possible to indicate a function.

The interpretation is based on the following rules and definitions given in this International Standard.

i. The least material virtual condition, LMVC, which has the diameter LMVS = 35,2 mm, shall be fully contained in the material [see Rule J, 3.10 and 3.11].

ii. The extracted feature shall have everywhere a local diameter larger than MMS = 35,0 mm [see Rule I 2) and 3.5] and smaller than LMS = 35,2 mm [see Rule H 2) and 3.7]. The difference between Figures A.5 d) and A.5 b) is in the specification of the local diameter, in this case to LMS.

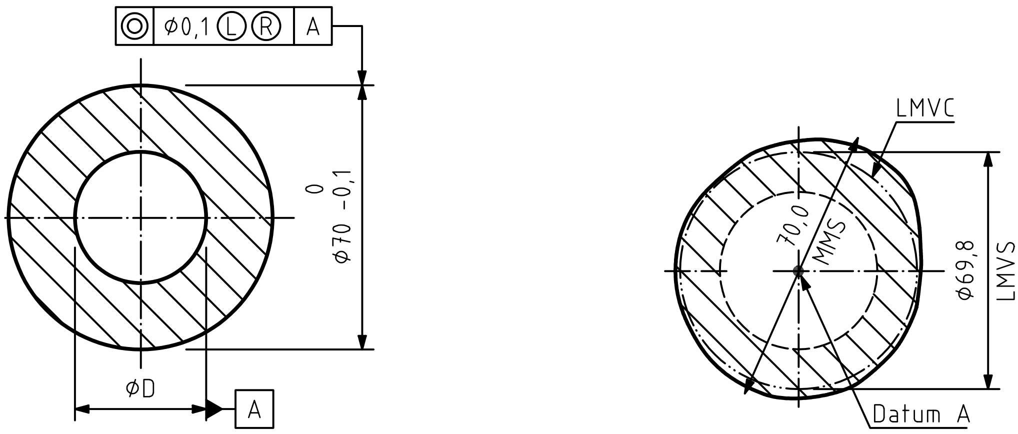
iii. The orientation of the LMVC is parallel to the datum and the location of the LMVC is in a theoretically exact position 0 mm from datum A [see Rule K and 3.11 NOTE 2].

d) Example 2 of LMR for one internal feature of size with another concentric external feature of size as the datum

Figure A.5 *(to be continued)*

Dimensions in millimetres

Drawing indication **Interpretation**



Position and coaxiality/concentricity can be used with the same meaning in this case.

This figure only illustrates some rules for least material requirement. This drawing indication is incomplete and does not control the minimum wall thickness. The least material requirement is missing on the other feature. Therefore it is not possible to indicate a function.

The interpretation is based on the following rules and definitions given in this International Standard.

i. The least material virtual condition, LMVC, which has the diameter LMVS = 69,8 mm, shall be fully contained in the material [see Rule J, 3.10 and 3.11].

ii. The extracted feature shall have everywhere a local diameter smaller than MMS = 70 mm [see Rule I 1) and 3.5]. The RPR allows the lower limit of size to decrease below LMS (local diameter may be smaller than 69,9 mm, down to LMVS) [see 5.3].

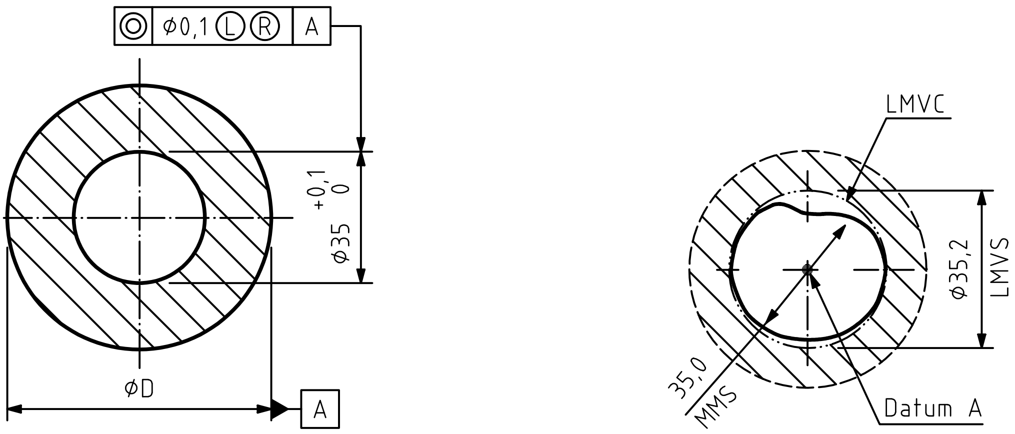
iii. The orientation of the LMVC is parallel to the datum and the location of the LMVC is in a theoretically exact position 0 mm from datum A [see Rule K and 3.11 NOTE 2].

e) Example of LMR and RPR for one external feature of size with another concentric internal feature of size as the datum

Figure A.5 (*to be continued*)

Dimensions in millimetres

Drawing indication **Interpretation**



Position and coaxiality/concentricity can be used with the same meaning in this case.

This figure only illustrates some rules for least material requirement. This drawing indication is incomplete and does not control the minimum wall thickness. The least material requirement is missing on the other feature. Therefore it is not possible to indicate a function.

The interpretation is based on the following rules and definitions given in this International Standard.

i. The least material virtual condition, LMVC, which has the diameter LMVS = 35,2 mm, shall be fully contained in the material [see Rule J, 3.10 and 3.11].

ii. The extracted feature shall have everywhere a local diameter larger than MMS = 35 mm [see Rule I 2) and 3.5]. The RPR allows the upper limit of size to increase beyond LMS (local diameter may be larger than 35,1 mm, up to LMVS) [see 5.3].

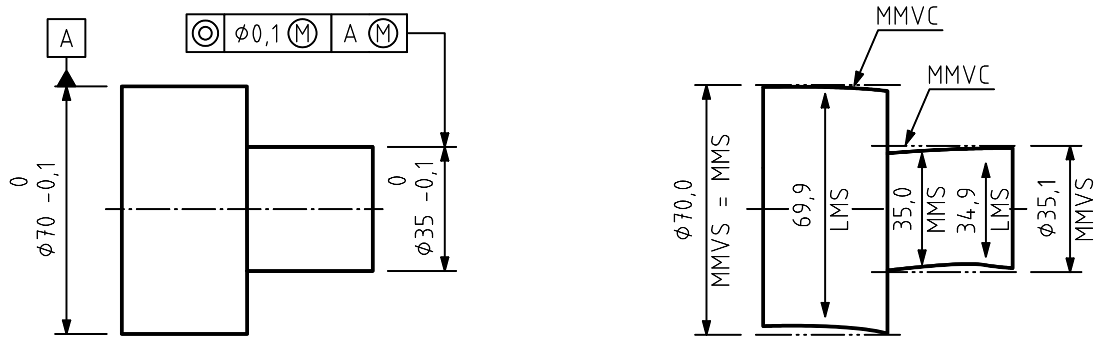
iii. The orientation of the LMVC is parallel to the datum and the location of the LMVC is in a theoretically exact position 0 mm from datum A [see Rule K and 3.11 NOTE 2].

f) Example of LMR and RPR for one internal feature of size with another concentric external feature of size as the datum

Figure A.5 — Examples of use of LMR for one feature of size with another concentric feature of size as the datum

Dimensions in millimetres

Drawing indication **Interpretation**



The intended function of the part toleranced in Figure A.6 a) could be an assembly with a part similar to that of Figure A.6 b).

The interpretation is based on the following rules and definitions given in this International Standard.

i. The extracted feature of the toleranced feature shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 35,1 mm [see Rule C, 3.8 and 3.9].

ii. The extracted feature of the toleranced feature shall have everywhere a local diameter larger than LMS = 34,9 mm [see Rule B 1) and 3.7] and smaller than MMS = 35,0 mm [see Rule A 1) and 3.5].

iii. The location of the MMVC at 0 mm from the axis of the MMVC of the datum feature [see Rule D and 3.9 NOTE 2].

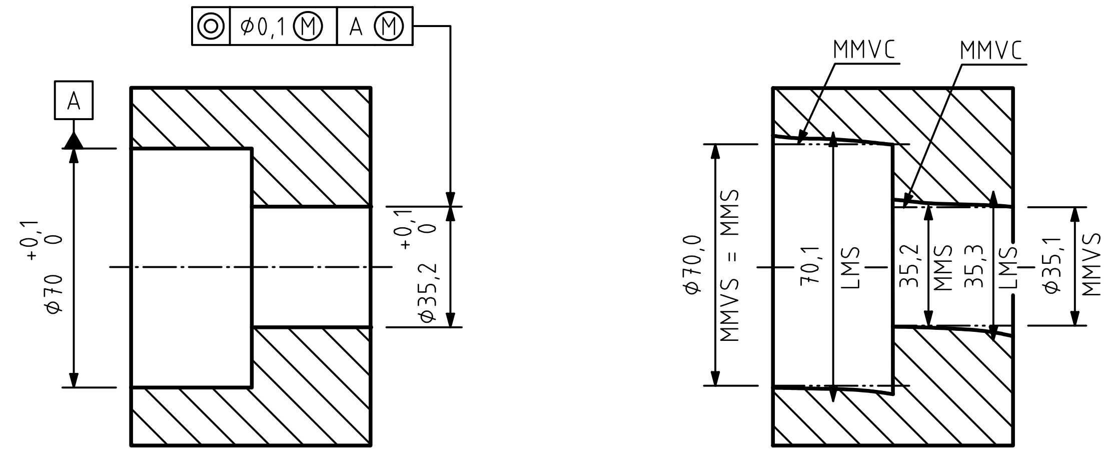
iv. The extracted feature of the datum feature shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = MMS = 70,0 mm [see Rule E, Rule F, 3.8 and 3.9].

v. The extracted feature of the datum feature shall have everywhere a local diameter larger than LMS = 69,9 mm [see Rule B 1), 3.7].

a) Example of MMR for an external cylindrical feature based on size and location (coaxiality) requirements with the axis of a cylindrical feature — with a size requirement — as the datum and also with MMR

Figure A.6 (*to be continued*)

Dimensions in millimetres



The intended function of the part toleranced in Figure A.6 b) could be an assembly with a part similar to that of Figure A.6 a).

The interpretation is based on the following rules and definitions given in this International Standard.

i. The extracted feature of the toleranced feature shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 35,1 mm [see Rule C, 3.8 and 3.9].

ii. The extracted feature of the toleranced feature shall have everywhere a local diameter smaller than LMS = 35,3 mm [see Rule B 2) and 3.7] and larger than MMS = 35,2 mm [see Rule A 2) and 3.5].

iii. The location of the MMVC is at 0 mm from the axis of the MMVC of the datum feature [see Rule D and 3.9 NOTE 2].

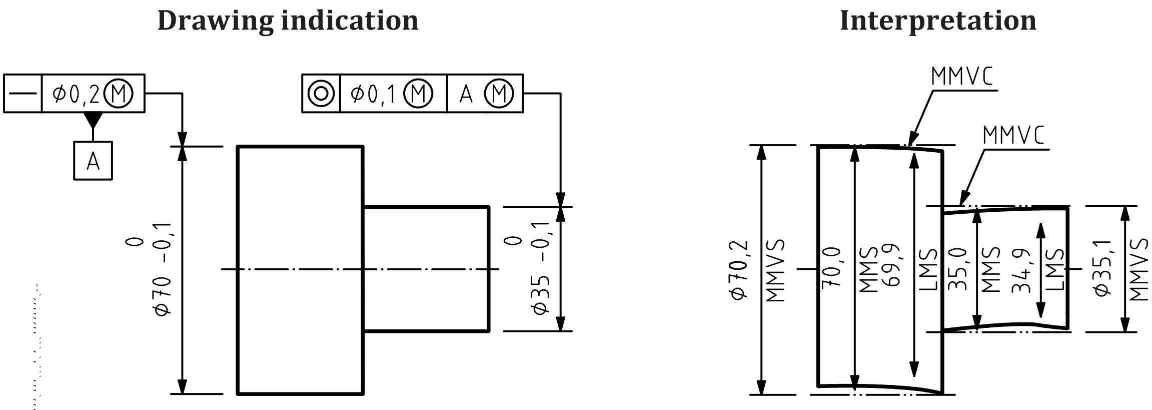
iv The extracted feature of the datum feature shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = MMS = 70,0 mm [see Rule E, Rule F, 3.8 and 3.9].

v. The extracted feature of the datum feature shall have everywhere a local diameter smaller than LMS = 70,1 mm [see Rule B 2) and 3.7].

b) Example of MMR for an internal cylindrical feature based on size and location (coaxiality) requirements with the axis of a cylindrical feature — with a size requirement — as the datum and also with MMR

Figure A.6 — Examples of MMR for a cylindrical feature based on size and location (coaxiality) requirements with the axis of a cylindrical feature — with a size requirement — as the datum and also with MMR

Dimensions in millimetres



The intended function of the part toleranced in Figure A.7 a) could be an assembly with a part similar to that of Figure A.7 b).

The interpretation is based on the following rules and definitions given in this International Standard.

i. The extracted feature of the toleranced feature shall not violate the MMVC, which has the diameter MMVS = 35,1 mm [see Rule C, 3.8 and 3.9].

ii. The extracted feature of the toleranced feature shall have everywhere a local diameter larger than LMS = 34,9 mm [see Rule B 1) and 3.7] and smaller than MMS = 35,0 mm [see Rule A 1) and 3.5].

iii. The location of the MMVC is at 0 mm from the axis of the MMVC of the datum feature [see Rule D and 3.9 NOTE 2].

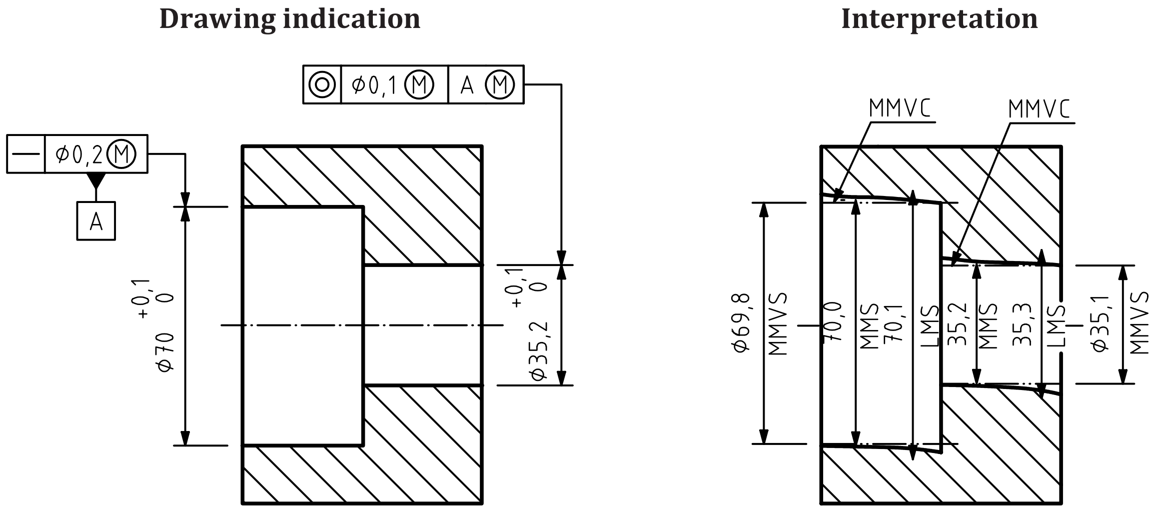
iv. The extracted feature of the datum feature shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 70,2 mm [see Rule E, Rule G, 3.8 and 3.9].

v. The extracted feature of the datum feature shall have everywhere a local diameter larger than LMS = 69,9 mm [see Rule B 1) and 3.7] and smaller than MMS = 70,0 mm [see Rule A 1) and 3.5].

a) Example of MMR for an external cylindrical feature based on size and location (coaxiality) requirements with the axis of a cylindrical feature — with a size requirement and a form tolerance — as the datum and also with MMR

Figure A.7 *(to be continued)*

Dimensions in millimetres



The intended function of the part toleranced in Figure A.7 b) could be an assembly with a part similar to that of Figure A.7 a).

The interpretation is based on the following rules and definitions given in this International Standard.

i. The extracted feature of the toleranced feature shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 35,1 mm [see Rule C, 3.8 and 3.9].

ii. The extracted feature of the toleranced feature shall have everywhere a local diameter smaller than LMS = 35,3 mm [see Rule B 2) and 3.7] and larger than MMS = 35,2 mm [see Rule A 2) and 3.5].

iii. The location of the MMVC is at 0 mm from the axis of the MMVC of the datum feature [see Rule D and 3.9 NOTE 2].

iv. The extracted feature of the datum feature shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 69,8 mm [see Rule E, Rule G, 3.8 and 3.9].

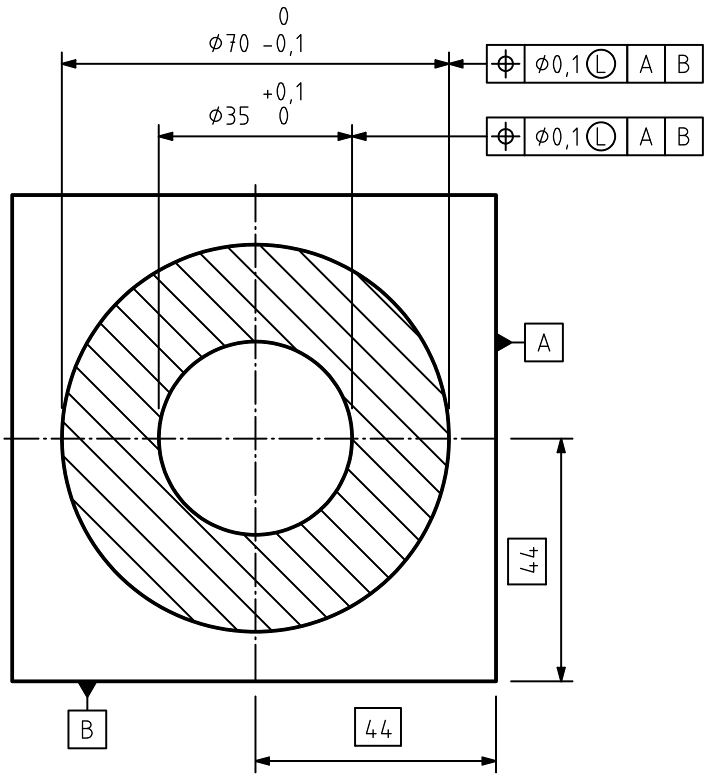
v. The extracted feature of the datum feature shall have everywhere a local diameter smaller than LMS = 70,1 mm [see Rule B 2) and 3.7] and larger than MMS = 70 mm [see Rule A 2) and 3.5].

b) Example of MMR for an internal cylindrical feature based on size and location (coaxiality) requirements with the axis of a cylindrical feature — with a size requirement and a form tolerance — as the datum and also with MMR

Figure A.7 — Examples of MMR for a cylindrical feature based on size and location (coaxiality) requirements with the axis of a cylindrical feature — with a size requirement and a form tolerance — as the datum and also with MMR

Dimensions in millimetres

Drawing indication



Interpretation

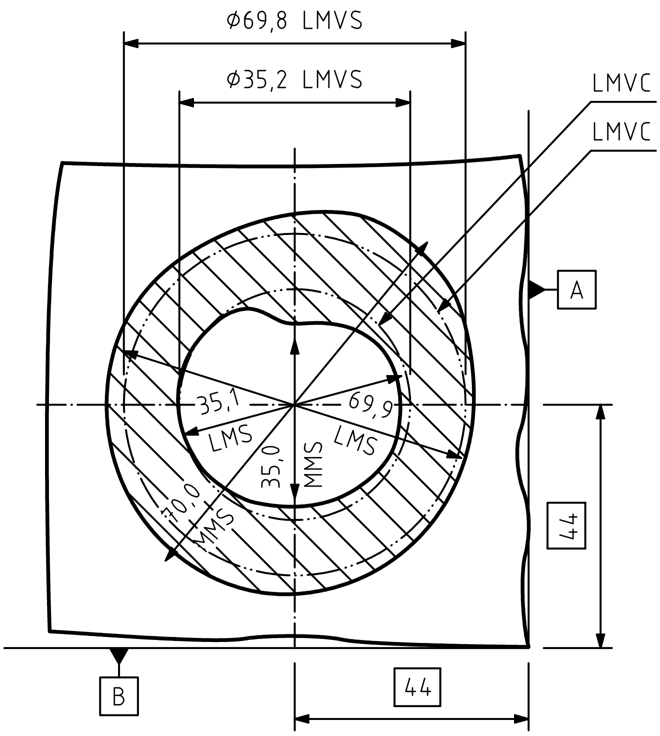


Figure A.8 *(to be continued)*

The intended function of the part illustrated in Figure A.8 is the ability to resist internal pressure and prevent breakout.

The interpretation is based on the following rules and definitions given in this International Standard.

i. The least material virtual condition, LMVC, of the external feature shall be fully contained in the material. The diameter LMVS = 69,8 mm [see Rule J, 3.10 and 3.11].

ii. The extracted feature of the external feature shall have everywhere a local size smaller than MMS = 70,0 mm (see Rule I 1) and 3.5) and larger than LMS = 69,9 mm [see Rule H 1) and 3.7].

iii. The least material virtual condition, LMVC of the internal feature shall be fully contained in the material. The diameter LMVS = 35,2 mm [see Rule J,3.10 and 3.11].

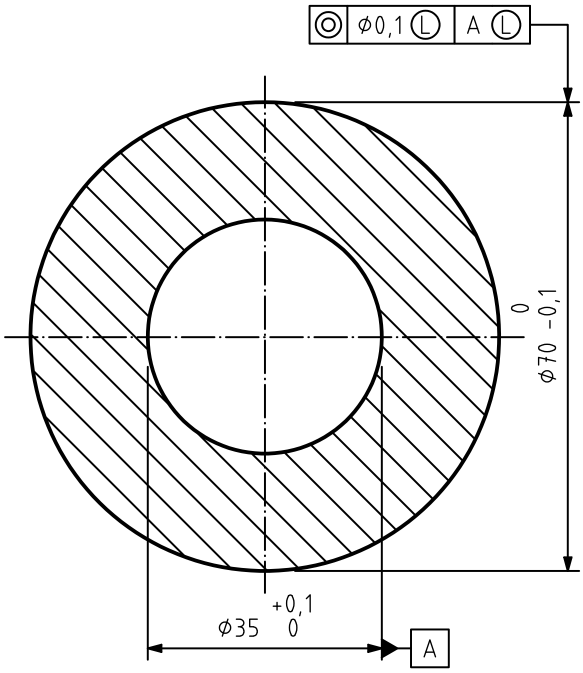
iv. The extracted feature of the internal feature shall have everywhere a local size larger than MMS = 35,0 mm (see Rule I 2 and 3.5) and smaller than LMS = 35,1 mm [see Rule H 2) and 3.7].

v. The least material virtual condition, LMVC, of both the external and the internal feature shall be in a theoretically exact orientation relative to the datum system and the location relative to the datum system shall be at a position 44 × 44 mm [see Rule K and 3.11 NOTE 2].

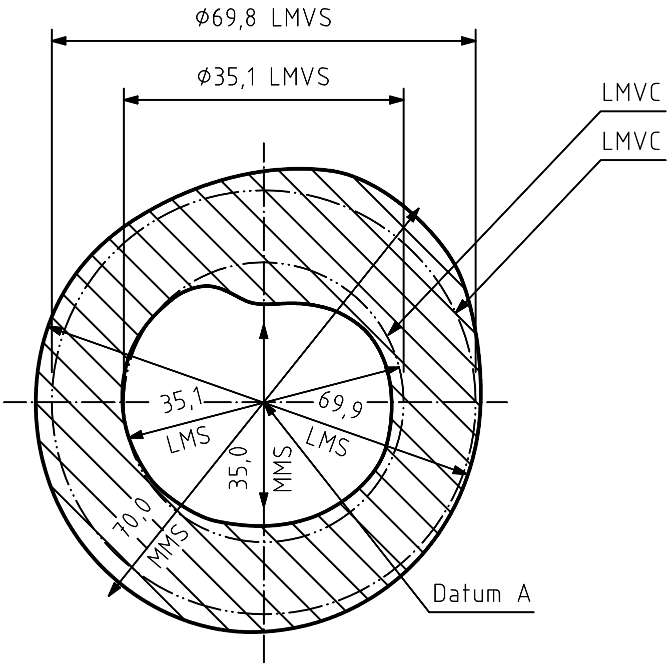
Figure A.8 — Example of LMR for two concentric cylindrical features (internal and external) both controlled by size and location (position) to the same datum system A and B

Dimensions in millimetres

Drawing indication



Interpretation



[Figure A.9](#) *(to be continued)*

The intended function of the part illustrated in Figure A.9 is the ability to resist internal pressure and prevent breakout.

The interpretation is based on the following rules and definitions given in this International Standard.

i. The least material virtual condition, LMVC, of the external feature shall be fully contained in the material. The diameter LMVS = 69,8 mm [see Rule J, 3.10 and 3.11].

ii. The extracted feature of the external feature shall have everywhere a local size smaller than MMS = 70,0 mm [see Rule I 1) and 3.5] and larger than LMS = 69,9 mm [see Rule H 1) and 3.7].

iii. The least material virtual condition, LMVC, of the internal datum feature shall be fully contained in the material. The diameter LMVS = LMS = 35,1 mm [see Rule L, Rule M, 3.10 and 3.11].

iv. The extracted feature of the internal feature shall have everywhere a local size larger than MMS = 35,0 mm [see Rule I 2) and 3.3] and smaller than LMS = 35,1 mm [see Rule H 2) and 3.7].

v. The least material virtual condition, LMVC, of the external feature shall be in a theoretically exact location at 0 mm from the axis of the least material virtual condition, LMVC, of the internal datum feature [see Rule K and 3.11 NOTE 2].

Figure A.9 — Example of LMR for an external cylindrical feature controlled by size and location (coaxiality) relative to an internal cylindrical feature used as a datum controlled by size and LMR

Dimensions in millimetres

Drawing indication

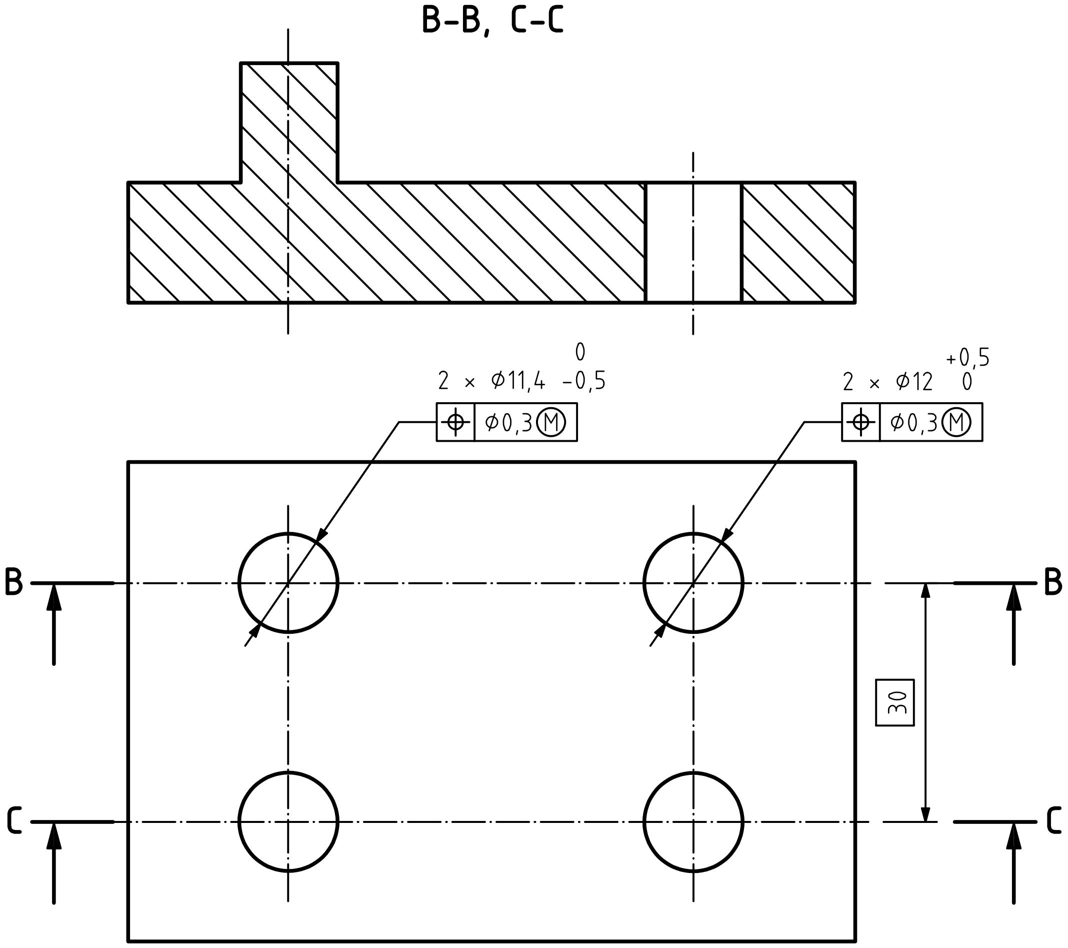
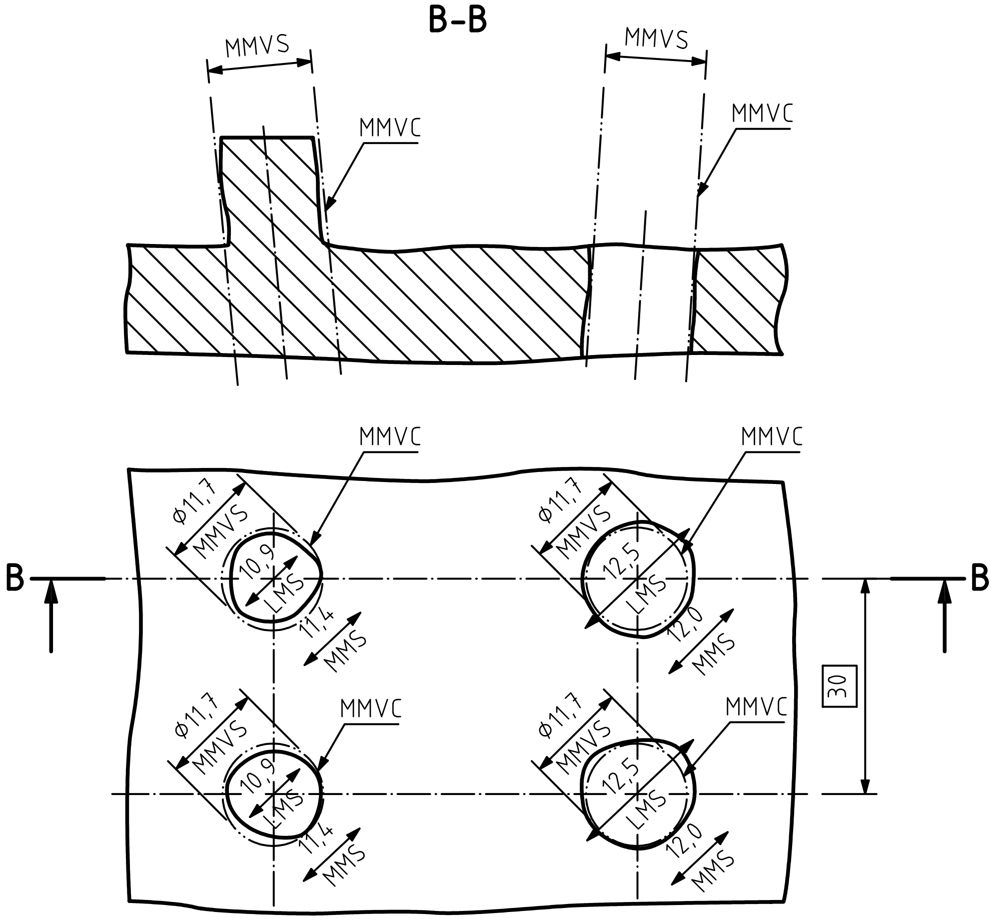


Figure A.10 (*to be continued*)

Dimensions in millimetres

Interpretation



The interpretation is based on the following rules and definitions given in this International Standard.

i. The extracted feature of the toleranced pins shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 11,7 mm [see Rule C, 3.8 and 3.9].

ii. The extracted feature of the toleranced pins shall have everywhere a local diameter larger than LMS = 10,9 mm [see Rule B 1) and 3.7] and smaller than MMS = 11,4 mm [see Rule A 1) and 3.5].

iii. The extracted feature of the toleranced holes shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 11,7 mm [see Rule C, 3.8 and 3.9].

iv. The extracted feature of the toleranced holes shall have everywhere a local diameter smaller than LMS = 12,5 mm [see Rule B 2) and 3.7] and larger than MMS = 12,0 mm [see Rule A 2) and 3.5].

v. The two MMVCs of the toleranced pins are in theoretically exact orientation and location – parallel to each other and at a distance 30 mm relative to each other [see Rule D and 3.9 NOTE 2]. There is no orientation or location requirement relative to the rest of the part.

vi. The two MMVCs of the toleranced holes are in theoretically exact orientation and location – parallel to each other and at a distance 30 mm relative to each other [see Rule D and 3.9 NOTE 2]. There is no orientation or location requirement relative to the rest of the part, and more particularly between the holes and the pins.

Figure A.10 — Example of MMR separately applied on a pattern of holes and on a pattern of pins, without using a datum

Dimensions in millimetres

Drawing indication

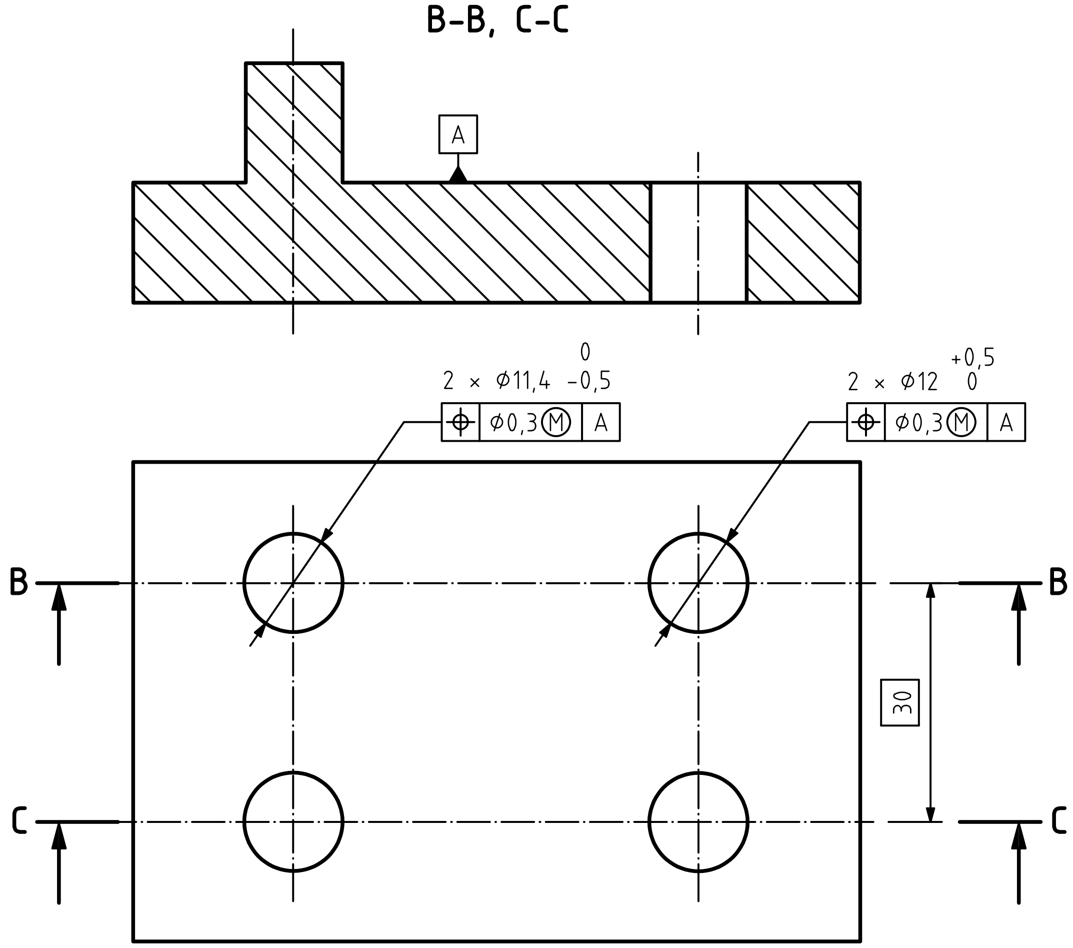
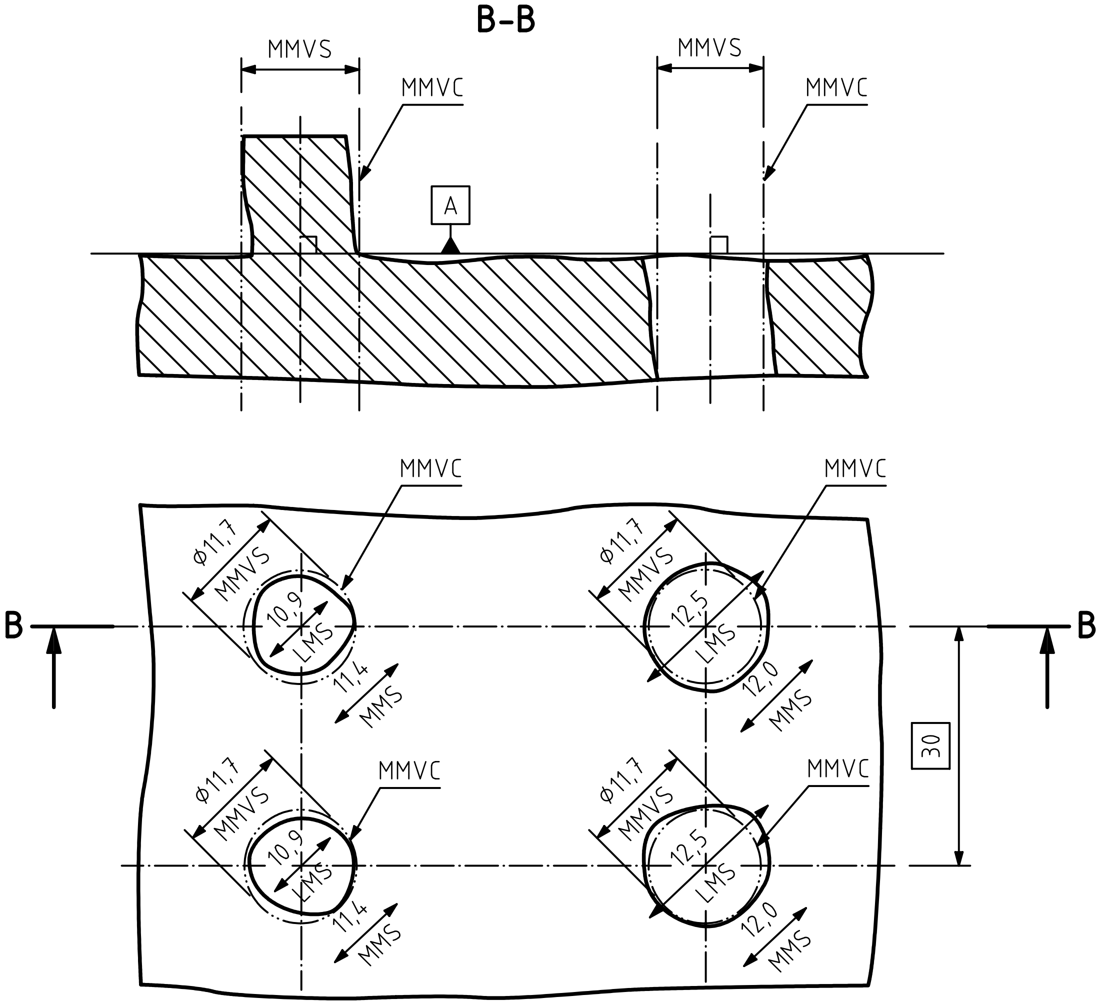


Figure A.11 (*to be continued*)

Dimensions in millimetres

Interpretation



The interpretation is based on the following rules and definitions given in this International Standard.

i. The extracted feature of the toleranced pins shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 11,7 mm [see Rule C, 3.8 and 3.9].

ii. The extracted feature of the toleranced pins shall have everywhere a local diameter larger than LMS = 10,9 mm [see Rule B 1) and 3.7] and smaller than MMS = 11,4 mm [see Rule A 1) and 3.5].

iii. The extracted feature of the toleranced holes shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 11,7 mm [see Rule C, 3.8 and 3.9].

iv. The extracted feature of the toleranced holes shall have everywhere a local diameter smaller than LMS = 12,5 mm [see Rule B 2) and 3.7] and larger than MMS = 12,0 mm [see Rule A 2) and 3.5].

v. The two MMVCs of the toleranced pins are in theoretically exact orientation and location – perpendicular to the datum A and at a distance 30 mm relative to each other [see Rule D and 3.9 NOTE 2].

vi. The two MMVCs of the toleranced holes are in theoretically exact orientation and location – perpendicular to the datum A and at a distance 30 mm relative to each other [see Rule D and 3.9 NOTE 2]. There is no orientation or location requirement relative to the pins.

Figure A.11 — Example of MMR separately applied on a pattern of holes and on a pattern of pins with using a datum

Dimensions in millimetres

Drawing indication

Interpretation

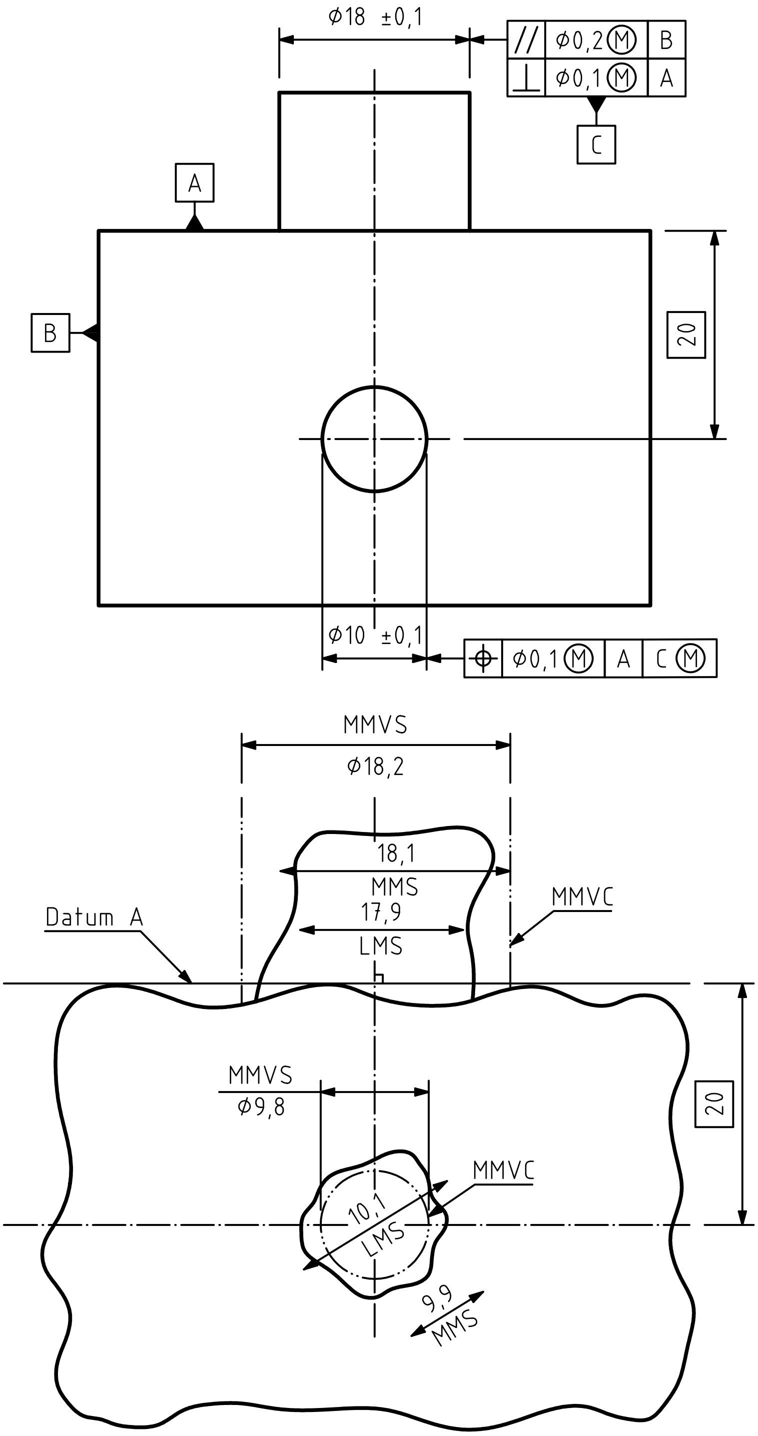


Figure A.12 *(to be continued)*

The interpretation is based on the following rules and definitions given in this International Standard.

i. The extracted feature of the toleranced hole shall not violate the MMVC, which has the diameter MMVS = 9,8 mm [see Rule C, 3.8 and 3.9].

ii. The extracted feature of the toleranced hole shall have everywhere a local diameter smaller than LMS = 10,1 mm [see Rule B 2) and 3.7] and larger than MMS = 9,9 mm [see Rule A 2) and 3.5].

iii. The location of the MMVC of the hole is at 20 mm from the datum plane A and at 0 mm from the axis of the MMVC of the datum feature C [see Rule D and 3.9 NOTE 2].

iv. The extracted feature of the datum feature C shall not violate the maximum material virtual condition, MMVC, which has the diameter MMVS = 18,2 mm [see Rule E, Rule G, 3.8 and 3.9].

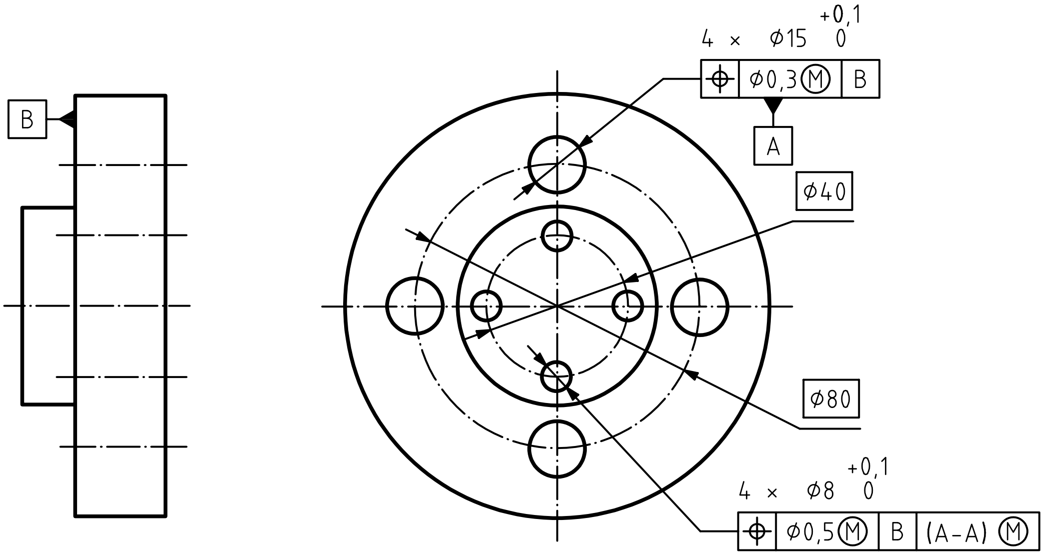
v. The extracted feature of the datum feature C shall have everywhere a local diameter larger than LMS = 17,9 mm [see Rule B 1) and 3.7] and smaller than MMS = 18,1 mm [see Rule A 1) and 3.5].

vi. The MMVC of the datum feature C is in theoretically exact orientation relative to the datum A, i.e. perpendicular to the datum plane A [see Rule D and 3.9 NOTE 2]. There is no other orientation or location requirement for the datum feature C. Parallelism relative to datum plane B is an another geometrical specification that shall be respected according to the Independency Principle, but does not concern the pin as datum feature C.

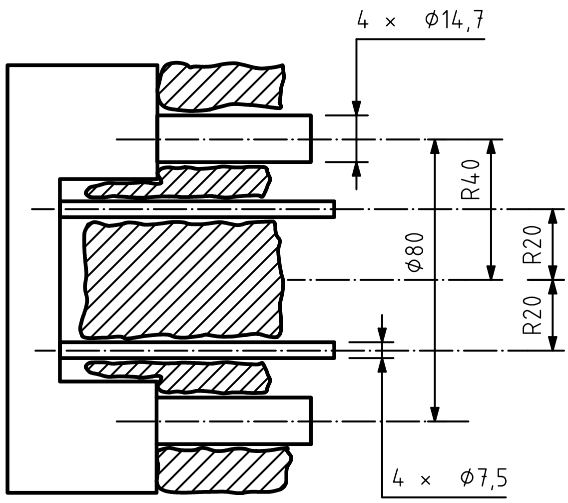
Figure A.12 — Example of use of MMR applied on a datum feature (followed by the symbol Ⓜ) controlled by an orientation specification whose tolerance value is followed by the symbol Ⓜ and whose datum corresponds exactly to the datum called before the related datum

Dimensions in millimetres

Drawing indication



Interpretation



The interpretation is based on the following rules and definitions given in this International Standard.

i. The extracted features of the four toleranced features shall not violate the maximum material virtual conditions, MMVCs, which have the diameters MMVS = 7,5 mm [see Rule C, 3.8 and 3.9].

ii. The extracted features of the four toleranced features shall have everywhere a local diameter smaller than LMS = 8,1 mm [see Rule B 2) and 3.7] and larger than MMS = 8 mm [see Rule A 2) and 3.5].

iii. The locations of the four MMVCs are positioned (and orientated) to the situation features of the collection of associated features (constrained at a fixed size equal to their MMVS) to the datum features [see Rule D and 3.9 NOTE 2]. The location and orientation of the MMVCs are theoretically exact.

iv. The extracted features of the datum features shall not violate their MMVCs, which are four cylinders with diameter MMVS = MMS − 0,3 = 14,7 mm [see Rule E, Rule G, 3.8 and 3.9].

v. The extracted features of the datum features shall have everywhere a local diameter smaller than LMS = 15,1 mm [see Rule B 2) and 3.7] and larger than MMS = 15 mm.

vi. MMVCs of the four datum features are in theoretically exact orientation relative to datum B, i.e. perpendicular to the datum plane B, and in theoretically exact location relative to each other, i.e. equally distributed on a cylinder of diameter 80 mm [see Rule D, 3.9 NOTE 2 and 4.2.2 NOTE 2].

Figure A.13 — Example of use of MMR applied on a common datum

Annex B
(informative)

Concept diagram

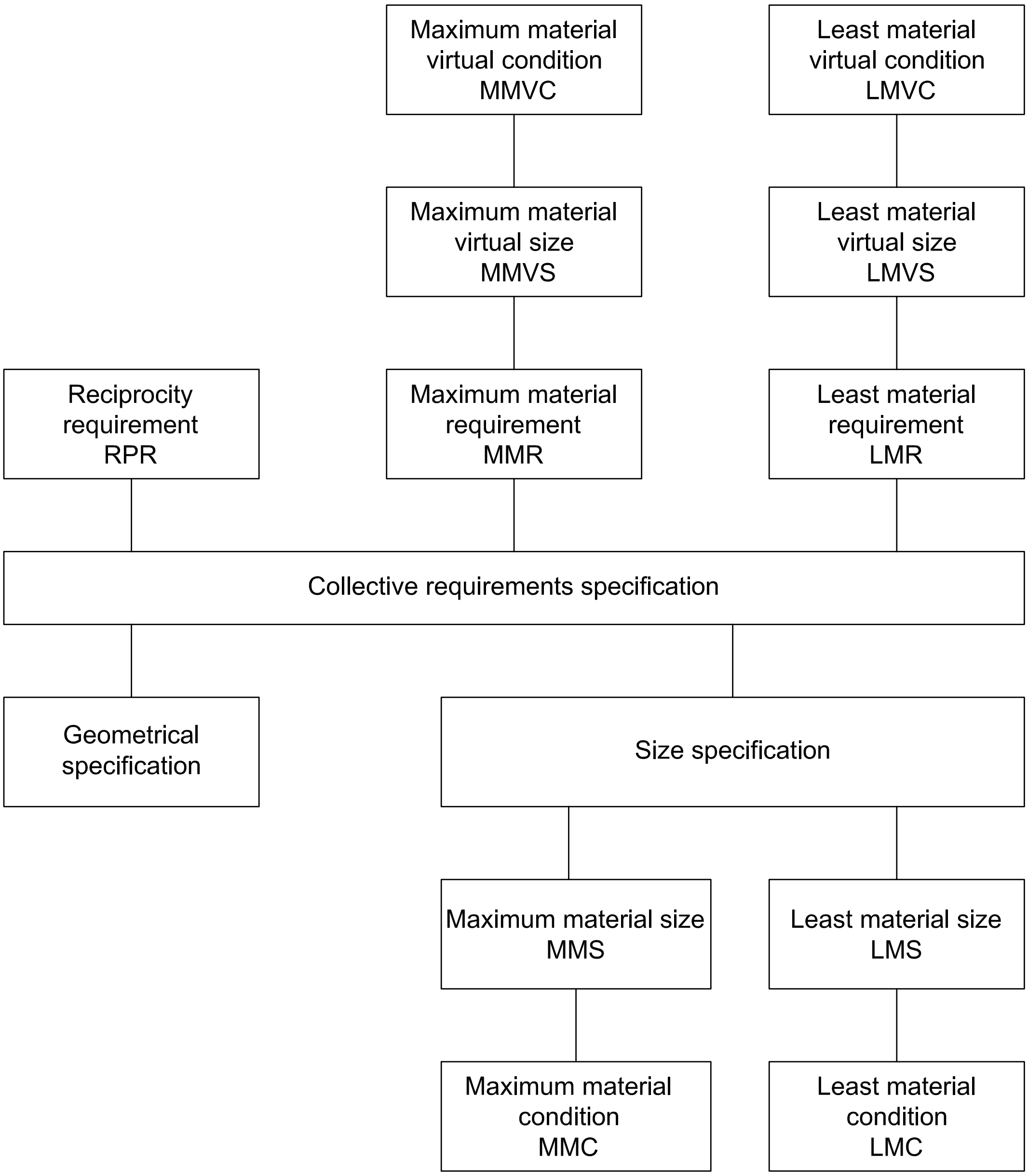


Figure B.1 — Concept diagram for terms and concepts related to maximum material requirement and least material requirement

Annex C
(informative)

Relation to the GPS matrix model

C.1 General

For full details about the GPS matrix model, see ISO/TR 14638.

The ISO GPS Masterplan given in ISO/TR 14638 gives an overview of the ISO GPS system of which this document is a part. The fundamental rules of ISO GPS given in ISO 8015 apply to this document and the default decision rules given in ISO 14253-1 apply to specifications made in accordance with this document, unless otherwise indicated.

C.2 Position in the GPS matrix model

This International Standard is a general GPS standard, which influences the chain links 1, 2 and 3 of the chain of standards on size, form of a line independent/dependent of a datum, form of a surface independent/dependent of a datum, orientation, location and datums in the general GPS matrix, as graphically illustrated in Table C.1.

Table C.1 — Position in the GPS matrix model

<table>
<tr><td rowspan="22">Fundamental GPS standards</td><td rowspan="22"></td><td colspan="7">Global GPS standards</td></tr>
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<tr><td>Form of line dependent on datum</td><td>•</td><td>•</td><td>•</td><td></td><td></td><td></td></tr>
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<tr><td>Edges</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

C.3 Related International Standards

The related International Standards are those of the chains of standards indicated in Table C.1.

Bibliography

[1] ISO 286-1:2010, *Geometrical product specifications (GPS) — ISO code system for tolerances on linear sizes — Part 1: Basis of tolerances, deviations and fits*

[2] ISO 5458:1998, *Geometrical Product Specifications (GPS) — Geometrical tolerancing — Positional tolerancing*

[3] ISO 7083:1983, *Technical drawings — Symbols for geometrical tolerancing — Proportions and dimensions*

[4] ISO 8015, *Geometrical product specifications (GPS) — Fundamentals — Concepts, principles and rules*

[5] ISO 14253-1, *Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 1: Decision rules for proving conformity or nonconformity with specifications*

[6] ISO/TR 14638:1995, *Geometrical product specification (GPS) — Masterplan*

[7] ISO 22432:2011, *Geometrical product specifications (GPS) — Features utilized in specification and verification*

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