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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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Contents

Foreword

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

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Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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

This document was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 290, *Dimensional and geometrical product specification and verification*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This fourth edition cancels and replaces the third edition (ISO 2692:2014), which has been technically revised.

The main changes to the previous edition are as follows:

— direct indication of maximum material or least material virtual size has been added (see 4.1.3);

— the use of SZ or CZ symbols has been added (see 4.1.4);

— the use of SIM symbol has been added (see 4.1.5).

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

0.1 General

This document is a geometrical product specification (GPS) standard and is to be regarded as a general GPS standard (see ISO 14638). It influences the chain links A, B and C of the chain of standards on size, form, orientation and location.

The ISO/GPS matrix model given in ISO 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 document to the GPS matrix model, see Annex E.

This document deals with some frequently occurring workpiece functional cases in design and tolerancing. The “maximum material requirement” (MMR) can cover, for example, “assemblability” and the “least material requirement” (LMR) can cover, for example, “minimum wall thickness” of a part. MMR and LMR requirements can accurately simulate the intended function of the workpiece by allowing the combination of two independent requirements into one collective requirement or to directly define maximum material virtual condition (MMVC) or least material virtual condition (LMVC) (see Annex C). In some cases of both MMR and LMR, the “reciprocity requirement” (RPR) can be added.

NOTE 1 In GPS standards, threaded features are often considered as a type of cylindrical feature of size. However, no rules are defined in this document for how to apply MMR, LMR and RPR to threaded features. Consequently, application of the tools defined in this document for threaded features is risky.

NOTE 2 A geometrical tolerance value of 0 (0Ⓜ or 0Ⓛ) can be used to avoid non-conformity of parts that can be assembled, in the case of MMR, or have minimum wall thickness, in the case of LMR.

0.2 Information about MMR

The assembly of parts depends on the combined effect of:

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

b) the geometrical deviation of the 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 (MMS) (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 fully consuming their tolerances. Assembly clearance increases to a maximum when the sizes of the assembled features of size are furthest from their MMSs (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 to manage the assemblability, the effect of the dimensional and geometrical variation can be dealt with by a specification using the maximum material concept. This requirement is indicated on the drawing by the symbol Ⓜ.

Furthermore, it can be useful to add Ⓜ to the datum indicator in the datum section when the datum is a feature of linear size and the clearance between the datum and the counterpart is favourable to the assembly of the part.

0.3 Information about LMR

The LMR is designed to control, for example, the minimum wall thickness, thereby preventing burst (due to pressure in a tube), or the maximum width of a series of slots. To manage the material strength function, the effect of the dimensional and geometrical variation can be dealt with by a specification using the minimum material concept. This requirement is indicated on drawings by the symbol Ⓛ.

0.4 Information about RPR

The RPR is an additional modifier, which may be used together with the MMR or with the LMR 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 MMVC or the LMVC.

The RPR is indicated on drawings by the symbol Ⓡ.

0.5 General information about terminology and figures

The terminology and tolerancing concepts in this document have been updated to conform to GPS terminology, notably that in ISO 286-1, ISO 14405-1, ISO 17450-1 and ISO 17450-3.

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

1 Scope

This document defines the maximum material requirement (MMR), the least material requirement (LMR) and the reciprocity requirement (RPR). These requirements can only be applied to linear features of size of cylindrical type or two parallel opposite planes type.

These requirements are often used to control specific functions of workpieces where size and geometry are interdependent, for example to fulfil the functions “assembly of parts” (for MMR) or “minimum wall thickness” (for LMR). However, the MMR and LMR can also be used to fulfil other functional design requirements.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 1101:2017, *Geometrical product specifications (GPS) — Geometrical tolerancing — Tolerances of form, orientation, location and run-out*

ISO 5458, *Geometrical product specifications (GPS) — Geometrical tolerancing — Pattern and combined geometrical specification*

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

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

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

ISO 17450-3, *Geometrical product specifications (GPS) — General concepts — Part 3: Toleranced features*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 5459, ISO 14405-1, ISO 17450-1 and ISO 17450-3 and the following apply.

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

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

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

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, for example skin of the workpiece.

[SOURCE: ISO 17450-1:2011, 3.3.5, modified — Notes 2 and 3 to entry removed.]

3.2
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

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

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

[SOURCE: ISO 17450-1:2011, 3.3.1.5.1, modified — Notes to entry removed; EXAMPLE 2 replaced.]

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* (3.1)

Note 1 to entry: A derived feature can be established from a nominal integral surface, an associated integral surface or an extracted integral surface. 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* (3.1) are types of derived features.

EXAMPLE 1 The median line of a cylinder is a derived feature obtained from the cylindrical surface, which is an *integral feature* (3.1). The axis of the nominal cylinder is a nominal derived feature.

EXAMPLE 2 The median surface of two parallel opposite planes is a derived feature obtained from the two parallel opposite planes, which constitute an *integral feature* (3.1). The median plane of the nominal two parallel opposite planes is a nominal derived feature.

[SOURCE: ISO 17450-1:2011, 3.3.6, modified.]

3.4
maximum material size
MMS
<external feature of linear size> value equal to the upper limit of size (ULS) or to the largest ULS in case of multiple size specifications

Note 1 to entry: An MMS can be defined for any of the size characteristics in ISO 14405-1.

Note 2 to entry: ULS is defined in ISO 14405-1.

3.5
maximum material size
MMS
<internal feature of linear size> value equal to the lower limit of size (LLS) or to the smallest LLS in case of multiple size specifications

Note 1 to entry: An MMS can be defined for any of the size characteristics in ISO 14405-1.

Note 2 to entry: LLS is defined in ISO 14405-1.

3.6
least material size
LMS
<external feature of linear size> value equal to LLS or to the smallest LLS in case of multiple size specifications

Note 1 to entry: An LMS can be defined for any of the size characteristics in ISO 14405-1.

Note 2 to entry: LLS is defined in ISO 14405-1.

3.7
least material size
LMS
<internal feature of linear size> value equal to ULS or to the largest ULS in case of multiple size specifications

Note 1 to entry: An LMS can be defined for any of the size characteristics in ISO 14405-1.

Note 2 to entry: ULS is defined in ISO 14405-1.

3.8
maximum material virtual size
MMVS
value equal to the size of the *maximum material virtual condition* (3.9)

Note 1 to entry: MMVS can be directly indicated (see 4.1.3) or calculated from the *maximum material size* (3.4, 3.5) and the geometrical tolerance (see 4.1.2)

3.9
maximum material virtual condition
MMVC
state of associated feature with size equal to *maximum material virtual size* (3.8)

Note 1 to entry: MMVC is a perfect form condition of the *feature of linear size* (3.2).

Note 2 to entry: 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). 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 examples in Annex A.

3.10
least material virtual size
LMVS
value equal to the size of the *least material virtual condition* (3.11)

Note 1 to entry: LMVS can be directly indicated (see 4.1.3) or calculated from the *least material size* (3.6, 3.7) and the geometrical tolerance (see 4.1.2)

3.11
least material virtual condition
LMVC
state of associated feature of *least material virtual size* (3.10)

Note 1 to entry: LMVC is a perfect form condition of the *feature of linear size* (3.2).

Note 2 to entry: 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. 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, A.9, A.14, A.15.

3.12
maximum material requirement
MMR
requirement for a *feature of linear size* (3.2), defining a geometrical feature of the same type and of perfect form, with a given value for the intrinsic characteristic (dimension) equal to the *maximum material virtual size* (3.8), which limits the non-ideal feature on the outside of the material

Note 1 to entry: 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 linear size* (3.2), defining a geometrical feature of the same type and of perfect form, with a given value for the intrinsic characteristic (dimension) equal to the *least material virtual size* (3.10), which limits the non-ideal feature on the inside of the material

Note 1 to entry: LMR is used, for example, to control the minimum wall thickness between two symmetrical or coaxially located similar features of size.

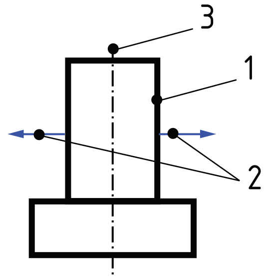
Note 2 to entry: See also 4.3.

3.14
reciprocity requirement
RPR
additional requirement for a *feature of linear size* (3.2) indicated in addition to the *maximum material requirement* (3.12) or the *least material requirement* (3.13) to indicate that the size tolerance is increased by the difference between the geometrical tolerance and the actual geometrical deviation

3.15
external feature of linear size
feature of linear size (3.2) where vectors normal to the surface are directed outward from the material in a direction opposite to the median feature

Note 1 to entry: The cylindrical surface of a shaft is considered to be an external feature of linear size.

Note 2 to entry: See Figure 1.



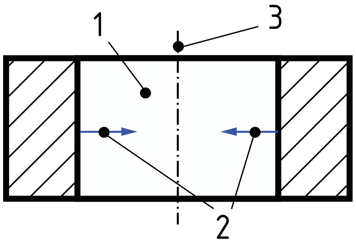
Key
1 external feature of linear size
2 normal vectors directed outward from the material
3 median feature (cylinder axis)

Figure 1 — Example of external feature of linear size

3.16
internal feature of linear size
feature of linear size (3.2) where vectors normal to the surface are directed outward from the material in a direction toward the median feature

Note 1 to entry: The cylindrical surface of a hole is considered to be an internal feature of linear size.

Note 2 to entry: See Figure 2.



Key

1 internal feature of linear size

2 normal vectors directed outward from the material

3 median feature (cylinder axis)

Figure 2 — Example of internal feature of linear size

4 Maximum material requirement (MMR) and least material requirement (LMR)

4.1 General

4.1.1 MMVS or LMVS specification

The MMR and the LMR can be applied to a set of one or more feature(s) of size as toleranced feature(s), datum(s) or both. The MMVS or the LMVS shall be specified by one of the two following options:

a) An MMR without direct indication of MMVS or an LMR without direct indication of LMVS but with a size specification for the considered feature. This option is referred to as indirect determination of virtual size in this document.

b) An MMR with direct indication of MMVS between square brackets in the tolerance indicator or an LMR with direct indication of LMVS between square brackets in the tolerance indicator as explained in this document. This option is referred to as direct indication of virtual size.

A geometrical specification with MMR or LMR shall be indicated as applying to a derived feature. However, the toleranced feature considered in the rules of this document is the corresponding integral feature.

The rules in this document shall not be applied to threaded features, even if threaded features are often considered as cylindrical features in GPS standards.

The possible combinations of geometrical characteristic symbols and MMR or LMR are illustrated in Annex D.

4.1.2 Indirect determination of MMVS or LMVS

When indirect determination of virtual size is selected [4.1.1 a)], the virtual size(s) introduced by the use of maximum or least material modifier in geometrical specification shall be calculated by considering the combination(s) of the geometrical tolerance(s) (applied to the derived feature of the feature of size) and the upper or lower tolerance limit of the dimensional specification(s) (of the feature(s) of size).

NOTE As limited by the scope, the only derived features considered in this document are median lines and median surfaces.

When indirect determination of virtual size is used, then the MMVS or the LMVS shall be the result of the computations described hereafter.

For external features of linear size except for a datum feature with MMR when rule F is fulfilled [see 4.2.2 b)], the MMVS is given by Formula (1):

$$\sigma_{MMVS} = \sigma_{MMS} + \delta \tag{1}$$

For internal features of linear size except for a datum feature with MMR when rule F is fulfilled [see 4.2.2 b)], the MMVS is given by Formula (2):

$$\sigma_{MMVS} = \sigma_{MMS} - \delta \tag{2}$$

For external features of linear size except for a datum feature with LMR when rule M is fulfilled [see 4.3.2 b)], the LMVS is given by Formula (3):

$$\sigma_{LMVS} = \sigma_{LMS} - \delta \tag{3}$$

For internal features of linear size except for a datum feature with LMR when rule M is fulfilled [see 4.3.2 b)], the LMVS is given by Formula (4):

$$\sigma_{LMVS} = \sigma_{LMS} + \delta \tag{4}$$

For a datum feature with MMR when rule F is fulfilled [see 4.2.2 b)], the MMVS for external and internal features of size is given by Formula (5):

$$\sigma_{MMVS} = \sigma_{MMS} \tag{5}$$

For a datum feature with LMR when rule M is fulfilled (see 4.3.2 b)], the LMVS for external and internal features of size is given by Formula (6):

$$\sigma_{LMVS} = \sigma_{LMS} \tag{6}$$

where

σ_{MMVS} is the MMVS;

σ_{MMS} is the MMS;

σ_{LMVS} is the LMVS;

σ_{LMS} is the LMS;

δ is the geometrical tolerance.

4.1.3 Direct indication of MMVS or LMVS

When direct indication of virtual size is selected [4.1.1 b)], then the MMVS or the LMVS shall be indicated between square brackets in the tolerance indicator and the virtual size is equal to this value as stated in the rules of this document. If a size is also specified for the considered feature, it shall be considered as an independent specification according to ISO 14405-1. No collective requirement is created between the two specifications (size specification and geometrical specification) in the case of direct indication of MMVS or LMVS.

NOTE It is the responsibility of the designer to select compatible values for the size of the feature and the MMVS or LMVS as they can conflict.

4.1.4 MMR or LMR applied to several toleranced features

When an MMR or LMR applies to several toleranced features, the symbols CZ or SZ shall always be indicated in the zone section of the tolerance indicator following the sequence order specified in ISO 1101.

NOTE See Annex B for former practice.

4.1.5 Simultaneous requirement

A simultaneous requirement can be useful for example for MMR or LMR with same datum indication containing MMR or LMR.

When a simultaneous requirement is needed, the SIM symbol possibly followed by an identification number (SIMi) without a space shall be indicated in the adjacent indication area of each related geometrical specification in accordance with ISO 5458.

The use of the SIM modifier transforms a set of more than one geometrical specification with MMR or LMR into a combined specification. The corresponding MMVC or LMVC are locked together with location and orientation constraints according to the rules of this document. The datum system is also constrained to be the same for each specification in the same SIM group.

Figure A.17 shows an example of simultaneous requirement.

4.1.6 MMR or LMR on a datum without MMR or LMR on the toleranced feature

When an MMR or LMR is applied to the datum only (see Figure A.19), then the rules for datum fully apply (see 4.2.2, 4.2.4 and 4.3.2, 4.3.4). In addition, the constraints on the MMVC(s) of the datum(s) and the MMVC(s) of the toleranced feature(s) stated in rule D [see 4.2.1 d)] or in rule K (see 4.3.1 d)] are replaced with the corresponding constraints applied on the MMVC(s) of the datum(s) and the tolerance zone as defined in ISO 1101 and ISO 5459.

4.2 Maximum material requirement (MMR)

4.2.1 MMR for toleranced features with indirect determination of virtual size

When the MMR applies to the toleranced feature and the indirect determination of virtual size is selected, it shall be indicated on drawings by the symbol Ⓜ placed after the geometrical tolerance of the derived feature of the feature of linear size (toleranced feature) in the tolerance indicator with no size indicated in square brackets.

The MMR for toleranced features with indirect determination of virtual size results in four independent requirements:

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

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

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

— a requirement for applying constraints on MMVCs (see rule D).

When the MMR is specified for the toleranced feature with indirect determination of virtual size, then the following rules shall be applied for the surface(s) (of the feature of linear size), and the MMVS shall be computed from the size specification and the geometric specification according to the rules of this document.

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

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

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

   NOTE 1 This rule can be altered by the indication of RPR, with symbol Ⓡ after the symbol Ⓜ [see 5.2 and Figure A.1 b)].

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

   1) equal to or larger than the LMS, for external features [see Figures A.2 a), A.3 a), A.4 a), A.6 a), A.7 a), A.10, A.11 and A.12];

   2) equal to or smaller than the LMS, for internal features [see Figures A.2 b), A.3 b), A.4 b), A.6 b), A.7 b), A.10 to A.13, A.16 to A.19].

c) **Rule C:** The 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 to A.19).

   NOTE 2 Use of the envelope requirement Ⓔ may lead to superfluous constraints, reducing the technical and economic advantage of MMR, if the functional requirement is purely assemblability.

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

d) **Rule D:** The rule applies as follows:

   — When the geometrical specification is an orientation or a location relative to a (primary) datum or a datum system, the 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 to entry, and Figures A.3, A.4, A.6 and A.7).

   — Moreover, if several toleranced features are controlled by the same tolerance indication with the CZ symbol, the MMVCs shall also be in theoretically exact orientation and location relative to each other (see Figures A.1, A.10, A.11 and A.13).

   — If several toleranced features are controlled by the same tolerance indicator with the SZ symbol, then the MMVCs are not constrained to be in theoretically exact orientation nor location relative to each other (see Figure A.18). In both cases (CZ or SZ indication) constraints relative to datums remain.

   — Additionally, if the symbol SIM possibly followed by an index number as required by ISO 5458 is indicated, then the MMVCs shall be constrained in orientation and location with the MMVCs of the SIM group.

4.2.2 MMR for related datum features with indirect determination of virtual size

When the MMR applies to the datum feature and the indirect determination of virtual size is selected, it shall be indicated on drawings by the symbol Ⓜ placed after the datum letter(s) in the tolerance indicator.

The datum letter(s) followed by the symbol Ⓜ result in an associated feature with a fixed size defined by the MMVC.

NOTE 1 Virtual conditions of toleranced feature and datum feature are constrained between them in orientation and location. The result is one combined virtual condition.

