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Statistical methods in process management — Capability and performance —

Part 9: Process capability statistics for characteristics defined by geometrical specifications

Méthodes statistiques dans la gestion de processus — Aptitude et performance —

Partie 9: Méthodes statistiques pour l'aptitude des processus dont les caractéristiques sont définies par des spécifications géométriques

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Foreword

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This document was prepared by Technical Committee ISO/TC 69, *Applications of statistical methods*, Subcommittee SC 4, *Applications of statistical methods in process management*.

This document is a second draft for approval and only editorial changes will be made before publication.

A list of all parts in the ISO 22514 series can be found on the ISO website.

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

Many organizations will need to evaluate the capability and performance of their key processes when the specifications are defined by requirements other than linear size. The methods described in this document are intended to assist the organization in this respect.

During the last couple of years, it has more common in the design and development departments in companies to not only use linear tolerances alone, but also including modifiers as well as geometrical tolerances with or without use of the maximum material requirements.

This situation has been supported by new measurement methods used in production, where it is common to use measurement equipment, where the results are given in form of point clouds instead of one single value.

It is a challenge in such cases to calculate capability and performance, but organizations and customers still require the capability indices in acceptance of produced or delivered batches of parts.

This document describes how to calculate capability or performance where functional requirements on parts are given.

As an example, the “maximum material requirement”, MMR, covers “assemble ability” 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 simulates the intended function of the workpiece. In some cases of both MMR and LMR, the “reciprocity requirement”, RPR, can be added.

In Annex D, a case study of process analysis, where the characteristic to be improved is perpendicularity, is introduced.

Statistical methods in process management — Capability and performance —

Part 9:
Process capability statistics for characteristics defined by geometrical specifications

1 Scope

This document describes process capability and performance measures when the specifications are given by geometrical product specifications e.g. maximum material requirements or linear size with a modifier.

The purpose of this document of the international series of standards on capability calculation is to assist the organizations to calculate the PCIs when geometrical product specifications are used on drawings.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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 https://www.electropedia.org/

3.1 Terms

3.1.1
feature of size
feature of linear size
geometrical feature, having one or more intrinsic characteristics, only one of which can 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 opposite parallel plane surfaces are a feature of linear size. Its linear size is the distance between the two parallel planes.

[SOURCE: ISO 17450-1:2011, 3.3.1.5.1., modified: deleted Note 1 to Note 4, deleted reference to Figure 5 (ISO 17450-1:2011), deleted EXAMPLE 2, added new EXAMPLE 2]

3.1.2
local size
local linear size
local size characteristic
local linear size characteristic
size characteristic having by definition a non-unique result of evaluation along and/or around the feature of size

Note 1 to entry: For a given feature, an infinity of local sizes exists.

[SOURCE: ISO 14405-1:2016, 3.6]

3.1.3
two-point size
<local size> distance between two opposite points on an extracted integral linear feature of size

Note 1 to entry: A two-point size taken on a cylinder can be called a "two-point diameter". In ISO 17450-3, this is defined as a local diameter of an extracted cylinder.

Note 2 to entry: A two-point size taken on two opposite planes can be called "two-point distance". In ISO 17450-3, this is defined as a local size of two parallel extracted surfaces.

[SOURCE: ISO 14405-1:2016, 3.6.1, modified: deleted Note 1 to entry to Note 3 to entry, added two new notes]

3.1.4
envelope requirement
combination of the two-point size applied for the least material limit of the size and either the minimum circumscribed size or the maximum inscribed size for the maximum material limit of the size

Note 1 to entry: The "envelope requirement" was previously referred to as the "Taylor principle".

Note 2 to entry: According to ISO 8015, the surface of a single feature of size (e.g. cylindrical surface or a feature based on two parallel plane surfaces) cannot violate the envelope of a geometrical ideal form at a maximum material limit of size

[SOURCE: ISO 14405-1:2016, 3.8, modified: Note 2 to entry added]

3.1.5
maximum material virtual size
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 the following formula:

$$l_{\mathrm{MMVS,e}} = l_{\mathrm{MMS}} + \delta$$

and the MMVS for internal features of size, $l_{\mathrm{MMVS,i}}$, is given by the following one:

$$l_{\mathrm{MMVS,i}} = l_{\mathrm{MMS}} - \delta$$

where

l_{MMS} is the maximum material size;

δ is the geometrical tolerance.

3.1.6
least material virtual size
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 the following formula:

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

and the LMVS for internal features of size, $l_{LMVS,i}$, is given by the following one:

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

where

l_{LMS} is the least material size;

δ is the geometrical tolerance.

3.1.7
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 the maximum material virtual size, 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 assembly ability of a workpiece.

[SOURCE: ISO 2692:2021, 3.12]

3.1.8
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.

[SOURCE: ISO 2692:2021, 3.13]

3.1.9
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

[SOURCE: ISO 2692:2021, 3.14]

3.2 Abbreviated terms

ASME	American Society of Mechanical Engineers
LMC	least material conditions
LMS	least material size
LMR	least material requirement
LMVC	least material virtual condition
LMVS	least material virtual size
MMC	maximum material condition
MMR	maximum material requirement
MMS	maximum material size
MMVS	maximum material virtual size
PCI	process capability indices
RPR	reciprocity requirement

3.3 Symbols

In addition to the symbols listed below, some symbols are defined where they are used within the text.

C_p	process capability index
C_{pk}	minimum process capability index
C_{pk_L}	lower process capability index
C_{pk_U}	upper process capability index
D	Diameter
Δ	geometrical tolerance
δ_A	measured geometrical tolerance
l_{LMS}	least material size
$l_{LMVS,e}$	LMVS for external features of size
$l_{LMVS,i}$	LMVS for internal features of size
l_{MMS}	maximum material size

l_{MMVS} maximum material virtual size

$l_{MMVS,e}$ MMVS for external features of size

$l_{MMVS,i}$ MMVS for internal features of size

L_{SL} lower specification limit

N total sample size

n subgroup sample size

μ location of the process; population mean value

P_p P_{po} process performance index

P_{pk} P_{pok} minimum process performance index

P_{pk_L} lower process performance index

P_{pk_U} upper process performance index

θ parameter required for the Rayleigh distribution

s standard deviation, sample statistic

$\bar{s}$ average sample standard deviation

σ standard deviation, population

U_{SL} upper specification limit

$\bar{X}$ arithmetic mean value, sample

$X_{99,865\ \%}$ upper 99,865 % quantile

$X_{0,135\ \%}$ lower 0,135 % quantile

4 Statistical measures used in the calculation of process capability or performance

4.1 General

The statistical analysis described in this document is designed to determine capability or performance indices when the characteristic of interest is a feature of linear size, and this size has a geometrical modifier added to the specification or a geometrical tolerance with or without maximum material condition.

4.2 Independency principle

4.2.1 General

A GPS specification for a feature or relation between features can be fulfilled independent of other specifications except when it is stated by special indication e.g. Ⓜ modifiers according to ISO 2692, CZ according to ISO 1101 or Ⓔ modifiers according to ISO 14405-1 as part of the specification. 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.

If those special indications are used as requirements, they need to be considered as a collective requirement and the capability indices can be calculated as one common value.

4.2.2 Maximum Material ISO versus ASME

In this standard the ISO definitions as defined in ISO 8015 are used. Geometrical product specifications in ASME are defined in Y 14.5 that often differs from the definitions in ISO. Tolerancing in ISO geometrical features are individual and independent of each other. In ASME tolerancing of the mating behaviour of the part in the assembly group used.

4.2.3 Measurement procedure

The measurement procedure is especially important when measuring properties with modifiers or geometric tolerances. The tolerance applies to the entire surface of the workpiece in 3 dimensions with an infinite number of points, therefore a sufficient number of measuring points defined in the procedure can be measured on every workpiece. You also have to consider the distribution of these points. More information can be found in Annex C.

4.3 Location

It is a precondition, that the size of the characteristic of interest can have only one value assigned and a characterisations of process location can be the mean, μ, or the median, $X_{50\ \%}$. If the variation of the characteristic can be described by a symmetric distribution the mean is the most natural selection, with non-symmetric distributions the median is the preferred selection.

4.4 Dispersion

It is important to differentiate between a standard deviation that measures only short-term variation and the standard deviation which measures longer-term variation. Methods for calculating standard deviations representing these two cases are given in Annex A. Very often, when data are gathered over a long period of time, the standard deviation is larger due to the effects of fluctuations in the process. It is important that the use and calculation of the standard deviation in the formulae's only make sense if the data is normally distributed.

In case of a characteristics with modifiers added or characteristics defined with geometrical tolerances the actual distribution in most cases cannot be described by a normal distribution therefore, the capability calculation formula based on reference limits can be used instead. The formulas for the distribution models can be found in Annex B.

4.5 Reference limits

The lower and upper reference limits are respectively defined as the 0,135 % and the 99,865 % quantiles of the distribution that describes the output of the process characteristic. They are described as $X_{0,135\ \%}$ and $X_{99,865\ \%}$.

4.6 Reference interval

The reference interval is the interval between the upper and the lower reference limits. The reference interval includes 99,73 % of the individual values in the population from a process.

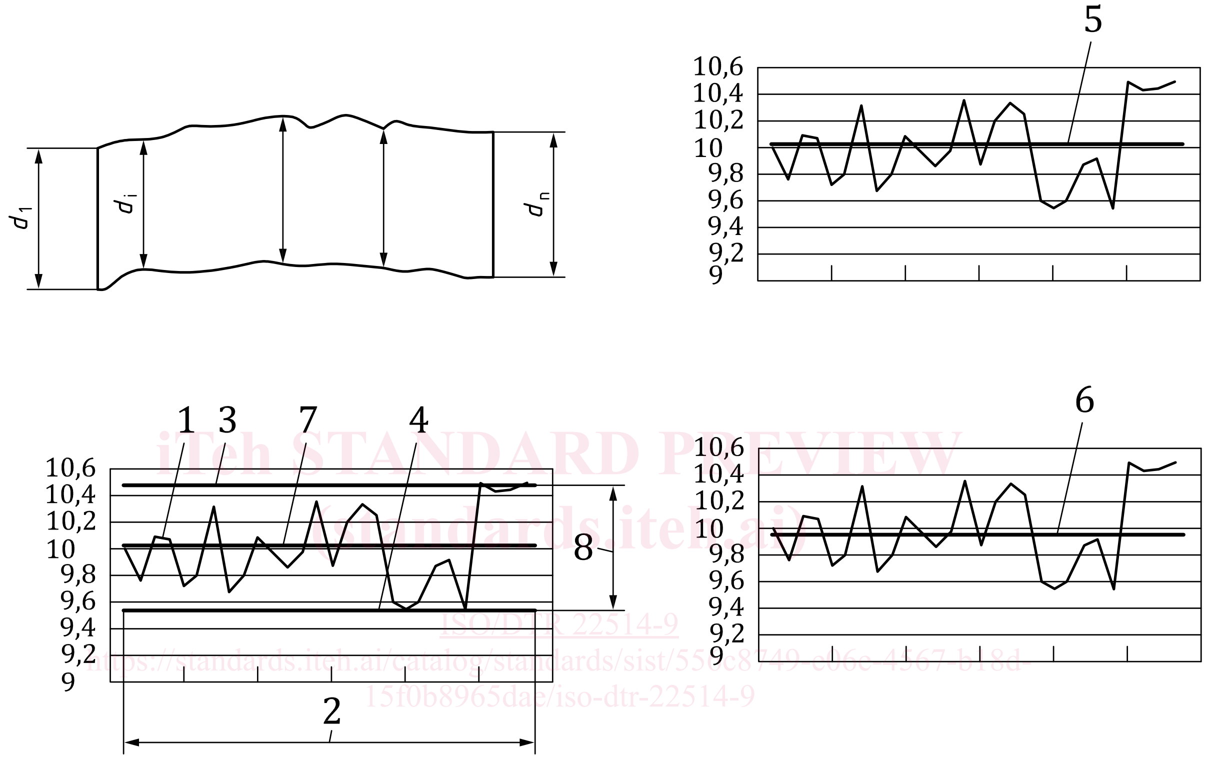
5 Geometrical product specifications

5.1 General

Produced workpieces exhibit deviations from the ideal geometric form shown on a drawing. The real value of the dimension of a feature of size is dependent on the form deviations and on the specific type of size applied.

The definition of an indication of a size tolerance by direct indication (plus and minus tolerancing), or indication by the limit values of the upper and the lower deviation limits, e.g. 25,65 ± 0,05 has not been defined before the first version of ISO 14405-1 was published, and therefore resulted in an ambiguous requirement when used on features of size of imperfect form.

The type of size to be applied to a feature of size depends on the function of the workpiece in the product. The type of size can be indicated on the drawing by a specification modifier for controlling the feature definition and evaluation method to be used. If no modifier has been added to the tolerance, the two-point size is the default requirement. In this case, there can be a lot of different values because a number of measurements has to be taken on the workpiece.



Key

1	set of values of local sizes	5	average size (= 10,011 69)
2	positions along the axis	6	median size (= 9,969 86)
3	maximum size (= 10,497 88)	7	mid-range size (= 10,020 345)
4	minimum size (= 9,542 81)	8	size range (= 0,955 07)
d_i, d_1, d_n	different values of local size		

Figure 1 — Different results for two-point requirement (adapted from ISO 14405-1:2016, Figure 8)

The calculation of capability in case of two-point size can be based on the average and the reference interval of the minimum two-point value found on the workpieces and the average and the reference interval of the maximum measured values on the workpieces. The two distribution models will very often be extreme value distributions.

5.2 Linear size with modifiers

Geometrical product specifications with different modifiers such as (GG) or (GX) are very often used in modern drawings to specify the function of the workpiece. The combination of such requirement when the calculation of capability indices is required will often be a subject to discussions between the