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Machine tools — Short-term capability evaluation of machining processes on metal-cutting machine tools

Machines-outils — Évaluation de la capacité des procédés d'usinage des machines-outils travaillant par enlèvement de métal

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Contents

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ISO 26303:2022
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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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This document was prepared by Technical Committee ISO/TC 39, *Machine tools*, Subcommittee SC 2, *Test conditions for metal cutting machine tools*.

This second edition cancels and replaces the first edition (ISO 26303:2012), which has been technically revised. The main changes compared with the previous edition are as follows:

— additional explanations have been added in 6.6 "Measurement" and for Formula (23);

— the indices of variables in Formulae (3) and (18) have been corrected;

— agreement forms 2 to 4 of Annex B, analysis form 2 of Annex C, agreement forms 3 and 4 of Annex D and analysis forms 1 and 2 of Annex D have been corrected;

— the references in Figure 2 have been revised;

— Figure A.1 has been improved;

— the status of Annexes B and C has been changed to informative;

— the formulae in analysis form 4 of Annex C and in analysis form 4 of Annex D have been corrected;

— the Bibliography has been updated.

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.

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Introduction

The evaluation of the short-term capability of the machining process is a different approach in machine tool assessment compared with machine tool performance testing methods, which are covered by a number of International Standards, e.g. ISO 230 (all parts) and other machine tool type specific standards. The main differences are machining a sample batch of test pieces and definition of the relevant influencing factors as well as the statistical conditioning and analysis of the workpiece quality related data obtained during such tests.

This document is the result of a project guided closely by an international working group, and summarized in order to make the information available to as many interested parties as possible.

Especially for large batch production, short-term process capability estimates, as well as capacity measures, are very often applied in addition to testing of machine tool performances. In fact, machine tool users increasingly employ statistical process control (SPC) techniques in their activities and frequently ask the machine suppliers/manufacturers to become system suppliers as well, giving them responsibilities for the machining process too.

Statistical methods in process management are covered by ISO 22514 (all parts).

For the purposes of machine tool acceptance based on the test of its capability in machining a specified workpiece, both requirements and methods stated by individual users differ widely, due to the absence of a recognized International Standard. Long-winded discussions and adaptation processes during the acceptance tests are, therefore, often necessary, delaying delivery to the customer and causing great time- and cost-related expenditure. This document provides a unified procedure for the acceptance test of a machine tool based on its short-term process capability. It introduces:

— the short-term capability of a given process, which employs the machine tool under test, the machining process, tooling and clamping applied, as well as the workpiece properties;

— the estimate of relevant machine capability indexes.

This document adapts to and conforms to the specifications established in ISO 22514 (all parts). However, the term “process performance index” specified in ISO 3534-2:2006 and used in ISO 22514-3:2020 corresponds for normal distribution to the term “short-term capability” in this document. The term “short-term capability” has been widely used in the machine tool industry for many years; therefore, ISO/TC 39/SC 2 decided to maintain this term.

Combined with the statistical evaluation, many influencing factors significantly restrict the fraction of tolerance interval covered by machine tool variations. As a consequence, the machine capability indices are specified in conjunction with the test conditions and the required tolerance limits.

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Machine tools — Short-term capability evaluation of machining processes on metal-cutting machine tools

1 Scope

This document specifies procedures for acceptance of metal-cutting machine tools based on the tests of their capability in machining a specified workpiece (i.e. indirect testing). It gives recommendations for test conditions, applicable measurement systems and the requirements for machine tools.

This document is consistent with ISO 22514 (all parts) describing statistical methods for process management and deals with the specific application of those methods to machine tools and machining of a sample batch of test pieces. This document covers neither functional tests, which are generally carried out before testing the accuracy performance, nor the testing of the safety conditions of the machine tool.

Annex A gives additional information related to statistical evaluation, Annexes B and C provide agreement and evaluations forms for short-term capability tests, while Annex D gives an example.

NOTE 1 Direct testing aims to investigate individual machine tool properties, such as geometric or positioning accuracy. Short-term capability evaluation is meant to prove that a machine tool has the capability to fulfil a specific process task. It is, therefore, important to recognize that the short-term capability test is focused only on the manufactured product. This means that direct testing methods are more suited for the determination of error sources on the machine tool and for deriving constructive improvements of a machine tool that is used in a wide production spectrum; a short-term capability test is less suited for detection of error sources of the machine tool. Therefore, it is expected that short-term capability evaluation for the acceptance of metal-cutting machine tools in machining processes be primarily carried out on workpiece-dependent special-purpose machines, e.g. working stations of transfer lines, with a process-determined cycle time of less than 10 min, so that at least 50 workpieces are manufactured in one shift as the statistical uncertainty increases strongly for a smaller number. In principle, short-term capability evaluation can also be performed on universal machine tools, such as machining centres used for large batch production if they meet the above-mentioned statistical requirements.

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NOTE 2 The term “short-term capability”, which is a widely used term in machine tool industry, corresponds to the term “process performance index” specified in ISO 3534-2:2006 for normal distribution.

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 4288, *Geometrical Product Specifications (GPS) — Surface texture: Profile method — Rules and procedures for the assessment of surface texture*

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 http://www.electropedia.org/

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3.1
short-term capability
ability of a manufacturing unit to produce a given part within specified tolerances at a specified confidence level, a concept mainly applied to batch production

Note 1 to entry: A manufacturing unit may be a single machine tool, one spindle of a multi-spindle machine tool, one station of a transfer line, etc.

Note 2 to entry: In this document, short-term capability indices, C_S and C_{Sk}, are estimated under the assumption of normal distribution of the characteristic value considered. If this assumption is not fulfilled, *short-term range values*, $R_{V,S}$, (3.4) and *critical short-term range value*, $R_{V,sk}$, (3.5) are evaluated instead of capability indices.

Note 3 to entry: This document adapts to and conforms to the specifications established in ISO 22514 (all parts). However, the term "process performance index" specified in ISO 3534-2:2006 and used in ISO 22514-3 corresponds for normal distribution to the term "short-term capability" in this document. The term "short-term capability" is widely used in the machine tool industry; therefore, ISO/TC 39/SC 2 decided to maintain this term.

3.2
short-term capability index
C_S
ratio of the specified tolerance itself to the standard deviation of the measured values quantifying the scatter

Note 1 to entry: See Formula (14).

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Note 2 to entry: Measured values are also known as characteristic values.

3.3
critical short-term capability index
C_{Sk}

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ratio of the specified tolerance itself to the standard deviation of the measured values quantifying the scatter under consideration of the location of the mean value

Note 1 to entry: If the mean value of the measured values is in the centre of the tolerance zone, this is called a centred distribution; if the mean value is not in the centre of the tolerance zone, this is called a shifted distribution. For the relationship between centred and shifted distributions, see A.1.

Note 2 to entry: Measured values are also known as characteristic values.

3.4
short-term range value
$R_{V,s}$
ratio of the range of the measured values to the specified tolerance itself

3.5
critical short-term range value
$R_{V,sk}$
ratio of the range of the measured values to the specified tolerance itself under consideration of the location of the mean value

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3.6
control chart
chart on which some statistical measure of a series of samples is plotted in a particular order to steer the process with respect to that measure and to control and reduce variation

Note 1 to entry: The particular order is usually based on time or sample number order.

[SOURCE: ISO 3534-2:2006, 2.3.1, modified — Note 2 to entry has been deleted.]

3.7
control chart for individuals
individuals control chart
variables *control chart* (3.6) for evaluating the process level in terms of the individual observations in the sample

[SOURCE: ISO 3534-2:2006, 2.3.15, modified — The preferred term has been added and the notes to entry have been deleted.]

3.8
control limit
line on a *control chart* (3.6) used for judging the stability of a process

[SOURCE: ISO 3534-2:2006, 2.4.2, modified — The notes to entry have been deleted.]

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3.9
lower specification limit
LSL
L_{SL}
specification limit that defines the lowest value a quality characteristic might have and still be considered conforming

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[SOURCE: ISO 22514-1:2014, 3.1.13, modified — The symbol has been changed from *L* and Note 1 to entry has been deleted.]

3.10
upper specification limit
USL
U_{SL}
specification limit that defines the highest value a quality characteristic can have and still be considered conforming

[SOURCE: ISO 22514-1:2014, 3.1.12, modified — The symbol has been changed from *U* and Note 1 to entry has been deleted.]

3.11
upper control limit
UCL
U_{CL}
control limit (3.9) that defines the upper control boundary

[SOURCE: ISO 3534-2:2006, 2.4.8]

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3.12
lower control limit
LCL
L_{CL}
control limit (3.9) that defines the lower control boundary

[SOURCE: ISO 3534-2:2006, 2.4.9]

4 Symbols

4.1 Uppercase letters

C	capability index
C_k	critical capability index
C_s	short-term capability index (corresponds to process performance index P_P in ISO 3534-2:2006 for normal distribution);
$C_{s,nom}$	nominal short-term capability index
C_{sk}	critical short-term capability index
$C_{sk,nom}$	nominal critical short-term capability index
C_{act}	actual capability index
K_i	i^{th} class (histogram)
U	uncertainty (of measurement or capability index)
U_{CL,s_i}	upper control limit for the standard deviation s_i
$U_{CL,\bar{x}j}$	upper control limit for the average values $\bar{x}_j$
U_{SL}	upper specification limit
R	range
$R_{V,s}$	short-term range value
$R_{V,s,nom}$	nominal short-term range value
$R_{V,sk}$	short-term critical range value
$R_{V,sk,nom}$	nominal short-term critical range value
T	tolerance
T_{min}	minimum usable tolerance for capability evaluation
$L_{CL,sj}$	lower control limit for the standard deviation s_j
$L_{CL,\bar{x}j}$	lower control limit for the average values $\bar{x}_j$
L_{SL}	lower specification limit

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4.2 Lowercase letters

e	shift of the average value
f	feed in mm/min or in mm/rev
i	running index for measurements
j	running index for groups of measurements
k	running index for measurements within one group
m	number of groups of parts for control charts
n	sample size (number of evaluated parts)
n_{mp}	number of manufactured parts
n_{K}	number of classes (histogram)
$n_{\min}$	minimum value of necessary parts
r	resolution of the measuring device
s	estimator of the standard deviation
$\overline{s}$	average standard deviation of the samples (groups)
s_{act}	actual standard deviation of process
s_{g}	standard deviation of the measurement (gauging) system
s_j	standard deviation of the j^{th} sample (group)
t	time
t_{m}	manufacturing time
t_{tot}	total manufacturing time
$\overline{x}$	mean value of population (of 50 measurements)
$\overline{x}'$	mean value of population with shifted distribution
$\overline{\overline{x}}$	mean value of group means $\overline{x}_j$
x_i	i^{th} measurement value
$x_{i,\mathrm{T}}$	i^{th} measurement value (trend corrected)
$x_{\mathrm{u},k}$	upper class limit of the k^{th} class (histogram)
$\overline{x}_j$	mean of the j^{th} sample (group)
$x_{\max}$	maximum value
$x_{\min}$	minimum value

4.3 Greek letters

$\delta X_{\mathrm{tot,T}}$	total trend (in relation to all values)
$\delta X_{\mathrm{tot,w}}$	total trend per workpiece
δX_{td}	trend due to thermal distortion

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ISO 26303:2022
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$\delta X_{td,w}$ trend due to thermal distortion per workpiece

$\delta X_{td,perm}$ permissible trend due to thermal distortion per workpiece in X-direction

δX_{a} trend due to tool wear

$\delta X_{a,exp}$ expected trend due to tool wear

Δd_{u} distance between the maximum value and the upper tolerance limit

Δd_{l} distance between the minimum value and the lower tolerance limit

Δd_{c} critical distance between the extreme values and the tolerance limits

ΔX_{k} class width (histogram)

$\Delta X_{K,k}$ border line of class (histogram)

ΔX_{c} critical distance of the average value to the tolerance limits

ΔX_{u} distance between the average value and the upper tolerance limit

ΔX_{l} distance between the average value and the lower tolerance limit

$\Delta x(t)$ thermal displacement as a function of time t

Δx_{max} maximum displacement

$\Delta \upsilon_{amb}$ ambient temperature gradient

$\Delta \upsilon_{amb,max}$ maximum ambient temperature gradient

ϑ temperature

$\vartheta_{amb,0}$ ambient temperature at beginning of test

ϑ_{max} maximum temperature

ϑ_{min} minimum temperature

$\delta Y_{td,perm}$ permissible trend due to thermal distortion per workpiece in Y-direction

$\delta Z_{td,perm}$ permissible trend due to thermal distortion per workpiece in Z-direction

$\hat{\sigma}$ estimation of the standard deviation of the population

τ thermal time constant

Ψ shift ratio for shifted distribution

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5 Preliminary remarks

Short-term capability evaluation belongs to the class of indirect testing methods and, hence, is a different approach to machine tool acceptance testing in comparison to the direct testing defined in several series of International Standards, e.g. ISO 230 (all parts).

The measured feature shall be machined on one machining unit only. If the same feature is machined on different, but similar, machining units, the statistical analysis shall be carried out separately for each machining unit.

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6 Procedure for short-term capability evaluation

6.1 General

The basic procedure during a short-term capability evaluation is shown in Figure 1. Acceptance according to a short-term capability evaluation is only recommended for machine tools used in large batch production with a process cycle time of less than 10 min. In addition, the adequate short-term capability (see 6.6) of the measuring process is a necessary requirement for measuring the workpieces.

NOTE In some cases, preparatory studies are performed in order to demonstrate that the operator can successfully interact with the machining process and that the subsequent process capability study will be successful (see ASME B89.7.3.1).

Before initiating the test and evaluation process, the supplier/manufacturer and the user shall reach necessary agreements concerning the test plan, including the workpiece features to be measured and analysed, the procedure, the test conditions and the characteristic values. Hereinafter, all agreements which are referred to are between the supplier/manufacturer and the user. The evaluations process is started by warming-up the machine tool. The subsequent adjustment is for the setting of the manufacturing process to the required tolerances (e.g. the middle of the tolerance zone in the case of characteristic with two-sided tolerances or zero for a zero-limited characteristic). The 50 workpieces are then manufactured in series and measured with a suitable measuring device. The measurements attained are then statistically evaluated in the final step.

If the short-term capability indices or the short-term range values and, if applicable, thermal distortion are beyond specified tolerances, the reasons shall be investigated. These can be, for example, faults which can be recognized as outlier values in the outlier management (see 6.7.3). If improvements are possible, these shall be carried out and the tests shall be repeated in part or whole.

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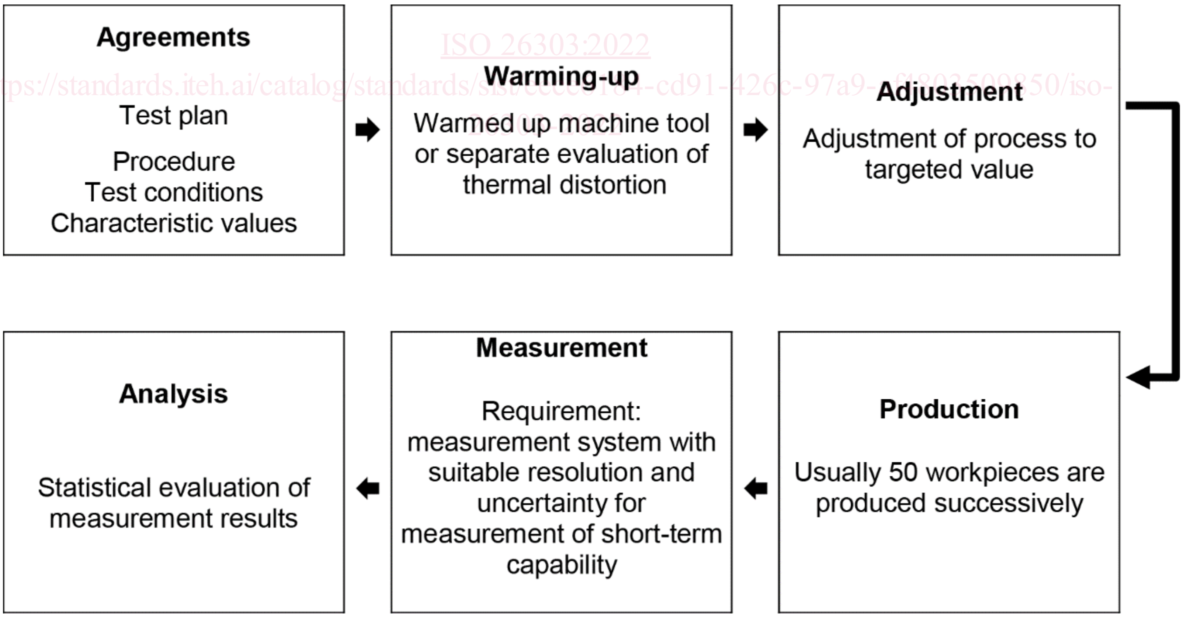

NOTE This is recommended only for large batch production machine tools with cycle time <10 min.

Figure 1 — Basic procedure for short-term capability evaluation

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6.2 Agreements

Before the actual acceptance test is carried out, agreements between the manufacturer/supplier and the user are necessary in order to ensure that:

a) the machine tool and the applied machining process are evaluated with as few interfering influences as possible;

b) requirements, which cannot be fulfilled due to the various influencing factors and the narrowing of the tolerance caused by the statistical analysis, are not set;

c) contractual agreements between the manufacturer/supplier and the user can be formulated, defining the scope, procedure and evaluation factors for the acceptance;

d) tolerances that are subject to a short-term capability evaluation are identified considering the associated costs.

The relevant agreements are listed in the forms provided in Annex B; Annex D provides an example. The test conditions under which the machine tool is evaluated shall be negotiated between the manufacturer/supplier and the user. These include, among others, the ambient temperature and its allowable variation during the test period. The limits depend on the manufacturing task, as does the location where the machine tool is installed in the machine shop or in an air-conditioned room. The following limits shall be used as default values for normal manufacturing tasks: ambient temperature, i.e. temperature change within ±3 °C during time of test; temperature gradient, i.e. within a maximum of +2 °C/h or −2 °C/h.

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Since the aim of the acceptance test is to prove the short-term capability and not the long-term capability, which is influenced by additional factors, a defined and uniform quality of the oversized blanks shall be ensured. The composition and characteristics of the material shall not be influenced by a change of batch. An oversize tolerance shall be agreed upon by the manufacturer/supplier and the user in order to limit the differences in static deformation due to back forces (component of the total cutting force perpendicular to the working plane) for varying oversizes.

Machining of blanks can have a direct influence (e.g. differences in machined dimension) and an indirect influence (e.g. differences in flatness of machined clamping faces) on the scattering of the measured features resulting from the process. Therefore, tolerances for machining of blanks shall be compatible with the required process short-term capability. In addition, it can be necessary to further limit the tolerances of the blanks depending on the machining process and sequence.

Fifty workpieces shall be manufactured in series. The total manufacturing time shall not exceed 8 h, resulting in a permissible manufacturing time of 10 min per workpiece. In special circumstances of longer manufacturing times per workpiece, a lower number of workpieces may be agreed upon by the manufacturer/supplier and the user; but in any case, the number of workpieces shall not be less than 30. If workpieces with small cycle times are being manufactured, a total manufacturing period of 6 h to 8 h and the production of more than 50 workpieces with the taking of samples from the larger set, which results in a total of 50 measurements (sample size of group multiplied by number of samples) may be negotiated.

Furthermore, the manufacturing technology and an adequate warm-up procedure shall be agreed upon by the manufacturer/supplier and the user before starting the acceptance test, in order to ensure that the machine tool is in thermal equilibrium (see 6.3 and 7.2).

The resolution and measuring uncertainty of the measuring device shall be taken into account. The short-term capability of the measuring device shall be verified. Generally, one needs a measurement equipment investigation, including the influence of the operator, at the time of evaluating the short-term capability (see 6.6).

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As an alternative to the short-term capability indices, C_s or C_{sk}, the evaluation of the short-term range values, $R_{V,s}$ or $R_{V,sk}$, may be agreed upon by the manufacturer/supplier and the user. Additional information on the relationship between standard deviation and short-term range values is given in A.2. The short-term range values only take account of the greatest and least values and are very susceptible to outliers in the set. Therefore, they do not provide enough information about the process behaviour within the extreme values. Consequently, if short-term range values are used, the evaluation of the process using the control chart for individuals, the $\bar{x}-s$ control chart and a histogram is of special importance (see 6.7).

NOTE The definition of the short-term capability indices or short-term range values is of great economic importance. On the one hand, conformity to stringent requirements can guarantee reliable production. On the other hand, this does not necessarily mean that the manufacturing costs can be reduced. Generally, much higher expenditure is needed for achieving greater short-term capability indices or lesser short-term range values. Such costs result from supplementing or equipping the machine tool with additional components (e.g. direct measuring systems, probing devices) and additional control circuits (e.g. measurement control, thermal compensation) or changing to a more expensive manufacturing method (e.g. from turning to grinding).

The required values shall be specified with considerations of the technical possibility and economical feasibility. In this sense, it is not suitable to set uniform boundaries for all processes. The direct relationship between the short-term capability indices and the required tolerances shall be taken into special consideration. As proof of short-term capability naturally guarantees a statistical confidence regarding the manufacturing process, current tolerances set by the designer for safety reasons should be re-thought. According to current short-term capability indices, the thresholds given in Table 1 are recommended for evaluating short-term capability. In individual cases, it can be of advantage to make other agreements.

The basis for the recommendation of the limits is the fact that, for long-term capability with increased influencing factors, a C_s value of at least 1,33 should be attained (see reference [10]). The calculation of the characteristic values is described in 6.7.

For certain processes or features, it can be appropriate for manufacturer/supplier and the user to disregard the C_{sk} value and only agree on a C_s value. For example, this can be the case if the setting of the process is very complicated, but principally unproblematic (see 6.4) or if features which depend largely on the cutting tools are investigated, e.g. the diameter during drilling, countersinking and reaming.

Table 1 — Recommended values for short-term process capability parameters

Process/feature	C_s	C_{sk}	$R_{V,s}$	$R_{V,sk}$	Notes
Normal processes or features	≥1,67	≥1,67	—	—	For example diameter or length in uncontrolled processes
In-process measurement control	—	—	≤100 %	≤100 %	The full tolerance may be used.
Roughness values	—	—	if necessary ≤ 80 %	≤80 %	In many cases, there is only an upper limit; therefore, only $R_{V,sk}$ is specified.
One-sided limited tolerance	—	≥1,67	—	≤60 %	The manufacturer/supplier and the user shall agree on which of the two characteristic values is used for acceptance.
Other special processes or features (e.g. meas. control)	≥1,67	≥1,67	≤60 %	≤60 %	The manufacturer/supplier and the user shall agree which values, i.e. C_s and C_{sk} or $R_{V,s}$ and $R_{V,sk}$ are relevant for acceptance.

Whenever applying an in-process measurement control, agreed action limits for the control algorithm shall be defined. These have, for instance, a safety margin of 10 % to 20 % towards the tolerance limits. In this case, short-term capability is proven if all values are within the tolerance limits.

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