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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 travaillant par enlèvement de métal*



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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.

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

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

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

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



# 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 International Standard 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 recognised 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 International Standard 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 under test, the machining process, tooling and clamping applied, as well as the workpiece properties, and

- the estimate of relevant machine capability indexes.

This International Standard adapts to and complies with the specifications established in ISO 22514 (all parts). However, the term “process performance” specified in ISO 22514-3 corresponds to the term “short-term capability” in this International Standard. 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.

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

## 1 Scope

This International Standard defines 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 International Standard 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 International Standard covers neither functional tests, which are generally carried out before testing the accuracy performance, nor the testing of the safety conditions of the machine.

Annex A gives additional information related to statistical evaluation, (normative) 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 properties, such as geometric or positioning accuracy. Short-term capability evaluation is meant to prove that a machine has the capability to fulfil a specific process task. It is, therefore, important to recognise 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 machines, such as machining centres used for large batch production if they meet the above-mentioned statistical requirements.



NOTE 2 The term “short-term capability”, which is a widely used term in machine tool industry, corresponds to the term “process performance” specified in ISO 22514-3.

## 2 Normative references

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

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

ISO 22514-3:2008, *Statistical methods in process management — Capability and performance — Part 3: Machine performance studies for measured data on discrete parts*

ISO/TR 22514-4:2007, *Statistical methods in process management — Capability and performance — Part 4: Process capability estimates and performance measures*

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

**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 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 Process capability is defined in ISO/TR 22514-4:2007, 2.2.1, as: statistical estimate of the outcome of a characteristic from a process which has been demonstrated to be in a state of statistical control and which describes that process's ability to realize a characteristic that will fulfil the requirements for that characteristic.

NOTE 3 In this International Standard, short-term capability indices, $C_{\mathrm{s}}$ and $C_{\mathrm{sk}}$, are estimated under the assumption of normal distribution of the characteristic value considered. If this assumption is not fulfilled, short-term range values, $R_{\mathrm{V,s}}$ and $R_{\mathrm{V,sk}}$, are evaluated instead of capability indices.

NOTE 4 This International Standard adapts to and complies with the specifications established in ISO 22514 (all parts). However, the term "process performance" specified in ISO 22514-3 corresponds to the term "short-term capability" in this International Standard. 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**
$C_{\mathrm{s}}$
ratio of the specified tolerance itself to the standard deviation of the measured values quantifying the scatter



NOTE Measured values are also known as characteristic values.

**3.3**
**critical short-term capability index**
$C_{\mathrm{sk}}$
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 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 Measured values are also known as characteristic values.

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

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

**3.6**
**control chart**
chart, with upper and lower control limits, on which values of some statistical measure for a series of samples, spiked samples and blanks, are plotted, usually in date or sample number order

[ISO 5667-14:1998, 3.10]

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

[ISO 3534-2:2006, 2.3.15]

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

[ISO 3534-2:2006, 2.4.2]

**3.9**
**lower specification limit**
specification limit that defines the lowest value a quality characteristic may have and still be considered conforming

[ISO 22514-1:2009, 2.1.13]



**3.10**
**upper specification limit**
specification limit that defines the highest value a quality characteristic may have and still be considered conforming



[ISO 22514-1:2009, 2.1.12]

## 4 Symbols

### 4.1 Upper case letters

| | |
|---|---|
| $C$ | Capability index |
| $C_{\mathrm{k}}$ | Critical capability index |
| $C_{\mathrm{s}}$ | Short-term capability index (corresponds to machine performance index $P_{\mathrm{m}}$ in ISO 22514-3:2008); |
| $C_{\mathrm{s,nom}}$ | nominal short-term capability index |
| $C_{\mathrm{sk}}$ | Critical short-term capability index |
| $C_{\mathrm{sk,nom}}$ | Nominal critical short-term capability index |
| $C_{\mathrm{act}}$ | Actual capability index |
| $K_i$ | $i^{\mathrm{th}}$ class (histogram) |
| $U$ | Uncertainty (of measurement or capability index) |
| $U_{\mathrm{CL},si}$ | Upper control limit for the standard deviation $s_i$ |
| $U_{\mathrm{CL},\bar{x}j}$ | Upper control limit for the average values $\bar{x}_j$ |
| $U_{\mathrm{SL}}$ | 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 |

## 4.2 Lower case letters

| | |
|---|---|
| $e$ | Shift of the average value |
| $f$ | Feed speed |
| $i$ | 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 |
| $n$ | 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 |
| $\bar{s}$ | Average standard deviation of the samples (groups) |
| $\bar{s}'$ | Sample standard deviation of shifted distribution |
| $s_g$ | Standard deviation of the measurement (gauging) system |
| $s_{g,act}$ | Actual standard deviation of the measurement system |
| $s_j$ | Standard deviation of the $j$th sample (group) |
| $t_m$ | Manufacturing time |
| $t_{tot}$ | Total manufacturing time |
| $\bar{x}$ | Mean value of population (of 50 measurements) |
| $\bar{x}'$ | Mean value of population with shifted distribution |
| $\bar{\bar{x}}$ | Mean value of group means $x_j$ |
| $x_i$ | $i$th measurement value |
| $x_{i,T}$ | $i$th measurement value (trend corrected) |
| $x_{u,k}$ | Upper class limit of the $k$th class (histogram) |
| $\bar{x}_j$ | Mean of the $j$th sample (group) |

$x_{max}$ Maximum value

$x_{min}$ Minimum value

### 4.3 Greek letters

$\delta X_{tot,T}$ Total trend (in relation to all values)

$\delta X_{tot,w}$ Total trend per workpiece

$\delta X_{td}$ Trend due to thermal drifting

$\delta X_{td,w}$ Trend due to thermal drifting per workpiece

$\delta X_{td,perm}$ Permissible trend due to thermal drift per workpiece

$\delta X_{a}$ Trend due to tool wear

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

$\Delta d_{u}$ Distance between the maximum value and the upper tolerance limit

$\Delta d_{l}$ Distance between the minimum value and the lower tolerance limit

$\Delta d_{c}$ Critical distance between the extreme values and the tolerance limits

$\Delta X_{k}$ Class width (histogram)

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

$\Delta X_{c}$ Critical distance of the average value to the tolerance limits

$\Delta X_{u}$ Distance between the average value and the upper tolerance limit

$\Delta X_{l}$ Distance between the average value and the lower tolerance limit

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

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

$\mu_{P}$ Mean value for population

$\vartheta$ Temperature

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

$\vartheta_{max}$ Maximum temperature

$\vartheta_{min}$ Minimum temperature

$\sigma$ Standard deviation of the population

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

$\tau$ Thermal time constant

$\Psi$ Shift ratio for shifted distribution



## 5 Preliminary remarks

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

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.

# 6 Procedure for short-term capability evaluation

## 6.1 General

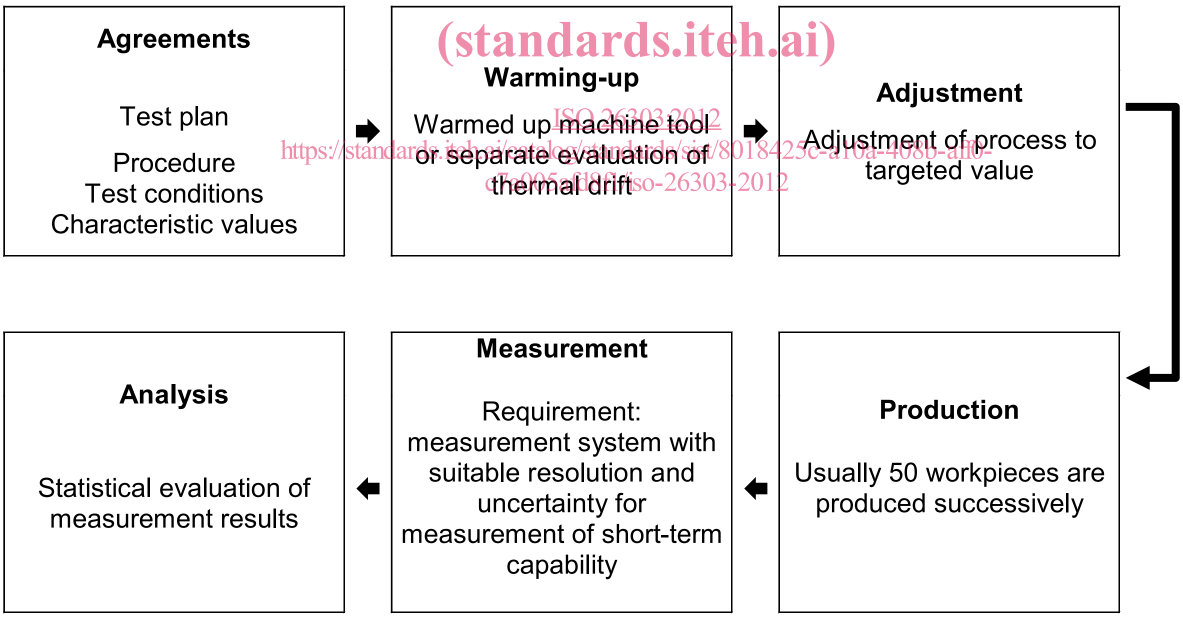
The basic procedure during a short-term capability evaluation is shown in Figure 1. Acceptance according to a short-term capability evaluation is only recommended for machine tools used in large batch production with a process cycle time of less than 10 min. In addition, the adequate short-term capability (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 [31].

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. 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 range values and, if applicable, thermal drift are beyond specified tolerances, the reasons shall be investigated. These can be, for example, faults which can be recognised as outlier values in the control chart for individuals (see 6.7.3). If improvements are possible, these shall be carried out and the tests shall be repeated in part or whole.






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

**Figure 1 — Basic procedure for short-term capability evaluation**

## 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 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, and

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 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 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.

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 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 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).

As an alternative to the short-term capability indices, $C_{\text{s}}$ or $C_{\text{sk}}$, the evaluation of the range values, $R_{\text{V,s}}$ or $R_{\text{V,sk}}$, may be agreed upon by the manufacturer/supplier and the user. Additional information on the relationship between standard deviation and range values is given in A.2. The 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 range values are used, the evaluation of the process using the control chart for individuals, the control chart and a histogram is of special importance (see 6.7).

NOTE The definition of the short-term capability indices or range values is of great economic importance. On the one hand, the conformance 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 range values. Such costs result from supplementing or equipping the machine 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[41]. 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.

Roughness values are usually not very scattered. Therefore, they result in a high confidence against exceeding a limit. In such cases, it is sufficient to keep a safety margin of 10 % of the tolerance towards the tolerance limit. Due to the strong influence of the position of the measuring area on the surface of the workpiece on the roughness value, it is advisable to perform repetitive measurements in different areas on some workpieces and, if necessary, calculate the average of the measured values.

Features with one-sided tolerance shall be evaluated only by their critical parameters. The question of whether $C_{sk}$ or $R_{V,sk}$ are relevant for acceptance shall be agreed between the manufacturer/supplier and the user.

For other special processes or features, the question of relevance of the characteristic values shall be agreed upon by the manufacturer/supplier and the user for each individual case. For example, in the case of multi-spindle machines which manufacture several workpieces simultaneously, or if using several identical clamping units, it is useful to use a $C_s$ value that is calculated using the standard deviation estimation value $\hat{\sigma}$ [see Equation (6)]. The number of values per spindle or device shall be an integer multiple of the number of values per group in order to avoid mixing the results of the individual spindles or clamping units. This procedure is similar to separately evaluating workpieces of each spindle or clamping unit. Additionally, the range value, $R_{V,s}$, calculated from all workpieces, shall be within limits in order to ensure that all parts are within the tolerance. If these two conditions are not met, each spindle or clamping unit shall be investigated individually for the respective causes and reasons. Depending on the number of clamping units investigated and the work load for the production of a workpiece, it can be useful to carry out an adjustment run with two to three workpieces per clamping unit in order to determine the scattering and setting of the workpiece contact surface. The sample workpieces destined for evaluation can then be taken from one clamping unit.

The maximum permissible trend due to thermal drift depends on the manufacturing method, the size of the machine and the production and ambient conditions. During the warm-up phase, a trend due to thermal drift of up to 40 µm/h can be expected[36]. As described in 6.3, this trend is often of lesser importance for machines undergoing short-term capability tests. It shall, therefore, only be agreed upon as relevant by the manufacturer/supplier and the user for acceptance in individual cases.

## 6.3 Warm-up procedure



A warm-up procedure should be planned for the short-term capability test to ensure that the machine is operating in thermal equilibrium. If, nevertheless, the trend due to thermal drift is of special importance to the user or the warm-up period cannot be extended until the machine is in thermal equilibrium, a permissible trend shall be agreed between the manufacturer/supplier and the user before running the test and also be considered during the analysis.



For small batches, the thermoelastic deformation due to mixed or interrupted production is of greater importance for the thermal behaviour of the machine. This behaviour may be evaluated using other test methods, such as direct thermal tests (e.g. according to ISO 230-3) or a suitable machining test.

## 6.4 Adjustment

The adjustment run serves the purpose of adjusting the process to the target value (or preferred or reference value) of a characteristic. A target value can be equal to the middle of the tolerance zone for features with a two-sided tolerance or to zero for zero-limited features. A.3 shows the effects of the setting on the remaining tolerance. If the mean value is not in the middle of the tolerance zone, the remaining area which can be used by production is limited. This means, for instance, that for a displacement of the mean value by a quarter of the tolerance and a $C_{sk}$ requirement of 1,67, the remaining $6s$ area (roughly the maximum permissible range) is only 30 % of the tolerance.

How exact the adjustment of the process should be in terms of the set value depends, among other factors, on how much work is involved and the importance of the mean value position varies for each individual case. For instance, one can expect that keeping the mean value in the middle of the tolerance zone is time-consuming, but in principle, possible without any problem. In such a case, it can be useful to set the process such that the mean value is only roughly in the middle of the tolerance zone, and only agree on the short-term capability index, $C_s$, or the range value, $R_{V,s}$, as acceptance criteria.

The blanks shall be supplied with the required quality and shall have acquired the ambient workshop temperature. Uncoated cutting tools shall not be used in mint condition as they are subject to high initial wear. Besides the consequence on workpiece dimensions, such high initial wear increases the cutting force significantly. For this reason, if an uncoated tool in mint condition is being used, some cutting runs shall be performed before the adjustment runs.