

Definition

The quality of a production process is subject to certain fluctuations. What are known as capability indexes are calculated so that these processes can be assessed, with a broad distinction being made between machine capability studies on the one hand and process capability studies on the other.

Both are designed to identify and evaluate random and also systematic influences.

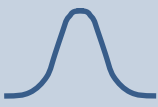
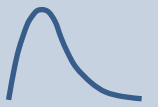
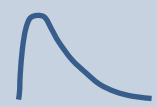
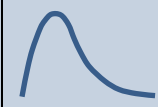
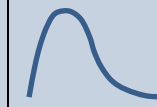

Procedure

The specialist department shall stipulate the properties definitive for the capability indexes. It is impractical to apply process capability to each individual part. Instead function-critical or quality-critical properties of the assembly should be considered.

Single parts that are not capable by themselves, can be classed and paired so as to achieve a capable functional dimension in the assembly, for example the bearing shell and crank pin. If re-adjustment takes place in final assembly, the process property of the finished product shall be assessed, e.g. body parts and their gap dimensions.

Fundamentals

The distributions to be used are:

	Normal distribution	Folded normal distr. B1	Folded normal distr. B2	Log-normal distribution	Weibull distribution	Mixed distribution
Form						
Exempl.	Geometric dimensions e.g. diameter, length, etc.	Properties limited on one side, e.g. roundness, parallelism	Properties limited on one side, e.g. imbalance, co-axiality	Properties limited on one side, e.g. true-running	Properties limited on one side, e.g. with time reference	Con-mingling of process fluctuations, e.g. machines, batches, etc.
Param.	2-parameter (Gaussian standard)	Negative proportions are mirrored at x=0	Corresponds to Weibull distribution with b=2	2-parameter	2- or 3-parameter	Only triple mixed distribution on basis of proportional normal distribution allowed
Calculation	Calculation analytic by $\mu + \sigma$	Calculation analytic with folding $\langle > 0$	Calculation by least-square Δy	Calculation analytic by median & scatter factor	Calculation by least-square Δy	Calculation analytic, percentile method
Formula	$C_p = \frac{USL - LSL}{6s}$	$C_{pk} = \text{Min} \left(\frac{X_{50\%} - LSL}{X_{50\%} - X_{0,135\%}} ; \frac{USL - X_{50\%}}{X_{99,865\%} - X_{50\%}} \right)$				

Process Capability Studies

Important notes:

- 1.) Invariably, distributions are assigned with the technical context taken duly into account. In the case of the roundness property, for example, the distribution to be used is the folded normal B1, even if the statistical test would accept a normal distribution.
- 2.) In a folded normal distribution, the mean value is determined from the data and not set to 0 (folding $\langle \rangle$ 0).
- 3.) A mixed distribution shall be used only if the normal distribution is rejected by the statistical test!

The folded normal distributions for standard properties are given as follows:













In addition to the normal distribution, e.g. for a unit of length, additional distribution types exist for the subsequent characteristics:

LN* Log-normal distribution

B1 Folded normal 1st type

B2 Folded normal 2nd type

* If LN is not offered in the evaluation strategy it can be mapped by using the 3-parameter Weibull distribution.

Characteristic	Symbol	Distribn.
Straightness	—	B1
Levelness		B1
Roundness		B1
Cylindrical shape		B1
Linear shape		B1
Surface shape		B1
Roughness		B1
Imbalance		B2
Parallelism	//	B1
Perpendicularity		B1
Slope/angularity		B1
Position		B2
Coaxiality, concentricity		B2
Symmetry		B1
Concentricity		B1/B2
Linear movement		B1, LN*

Machine capability study

A machine capability study reveals the short-term scatter and the production and repeat precision of the machine when, under near-series conditions, only machine-related influences apply. This is sometimes also referred to as a **short-term capability study**.

The purpose of the study is to ascertain a machine's capability with regard to the production process. In principle, a machine capability study has to be conducted for each new machine in the framework of acceptance testing. Reasons for deviations from this standard practice shall be given and the deviations documented.

Process Capability Studies

Calculation of the indexes for process capability

Evaluation is carried out entirely in accordance with the evaluation strategy described in the Appendix.

The relationships as stated below shall apply for properties with normal distribution (standard deviation ascertained by single-sample strategy, verification of normal distribution by the Anderson-Darling test).

$$C_m = \frac{USL - LSL}{6s} \quad C_{mk} = \text{Min} \left(\frac{USL - \bar{x}}{3s}, \frac{\bar{x} - LSL}{3s} \right)$$

where \bar{x} and s are calculated from the specified sample.

For all other properties with non-normal distribution, such as folded normal distribution, for example, calculation shall be by analogy with the descriptions for process capability.

Requirement for machine capability

The requirement is satisfied if:

$$C_m \geq 1.67 ; C_{mk} \geq 1.67$$

Sample size

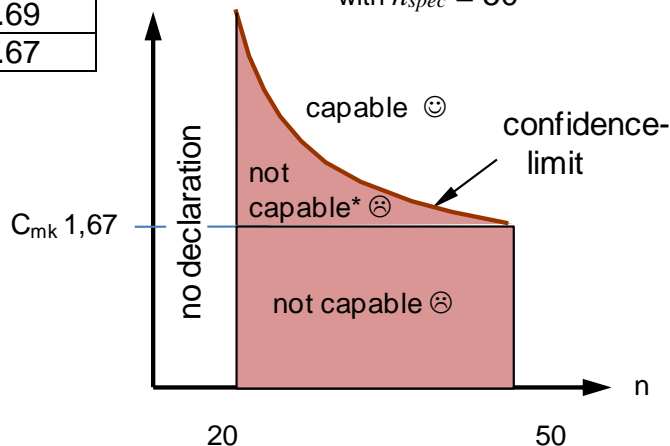
Sample size shall be 50. Parts manufactured in direct sequence shall be removed from the machine. The prerequisite is that production of these parts must be under series conditions.

In justified exceptions, for example short-run production, a smaller sample size is possible but shall be documented (evaluation is impractical with fewer than 20 parts). If the sample size is less than 50, the requirement applies with reference to the lower confidence limit (confidence interval 95%, table by analogy with VDI/VDE 2645):

n	C _{mk}
20	1.93
25	1.85
30	1.79
35	1.75
40	1.72
45	1.69
50	1.67

$$C_{mk} \geq 1,67 \frac{\left(1 + \frac{1}{2n}\right) \sqrt{\frac{n-1}{\chi_{n-1,\alpha}^2}}}{\left(1 + \frac{1}{2n_{\text{soll/spec}}}\right) \sqrt{\frac{n_{\text{soll/spec}}-1}{\chi_{n_{\text{soll/spec}}-1,\alpha}^2}}}$$

with $n_{\text{spec}} = 50$



Process Capability Studies

- * $C_{mk} \geq 1.67$ for existing plant, e.g. on repeat acceptance testing after repair or other modifications, also permissible for sample sizes $n < 50$ (no provision for confidence interval made)

Boundary conditions

The capability study shall also be conducted after repairs, on a change of production, after modification to the machine and/or relevant part properties and on production of new parts. Necessary interventions shall be documented (planned interventions can be routine adjustments to the process necessitated by a trend). If an unplanned intervention is necessary the study shall be restarted from the beginning. Data shall not be sorted out (see example in the Appendix, isolated outliers are the exception, proved by a statistical outlier test and with technical reason).

A machine capability study shall be conducted regularly for threaded fastener technology, with the concurrence of the specialist department. Other, agreed regulations shall be applied.

Process capability studies

Process capability studies, also known as **long-term capability studies**, establish the long-term quality capability of the entire process. A study of this nature aims at taking all the influencing variables listed below duly into account. A process capability study is the prerequisite for process monitoring/steering, particularly with control charts or statistical process control (SPC).

A process capability study is conducted for the first time when a new process is introduced. The process capability study has to be repeated at least when, for example, a relocation or a serious change in the production process has taken place. Information indicating which changes necessitate this is set out in the production-process and product-release process (see VDA Volume 2).

Calculation of the indexes for process capability

Evaluation is carried out entirely in accordance with the evaluation strategy described in the Appendix.

Properties with normal distribution

The relationships as stated below shall apply for properties with normal distribution (standard deviation ascertained by single-sample strategy, verification of normal distribution by the Epps-Pulley test ($n > 1000$ χ^2 test). Alternatively, the Anderson-Darling test can also be used.

$$C_p = \frac{USL - LSL}{6s} \quad C_{pk} = \text{Min} \left(\frac{USL - \bar{x}}{3s}, \frac{\bar{x} - LSL}{3s} \right)$$

Note: The sample sizes were grouped for calculation of s in the formula above.

Process Capability Studies

$$s = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2}$$

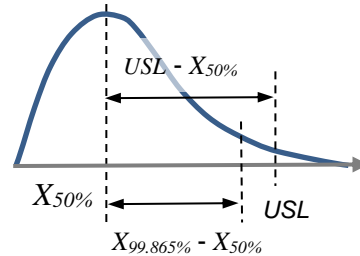
n : scope of complete data

Properties with non-normal distribution

For all other properties with non-normal distribution and upper specification limit only (natural lower limit at 0):

$$C_{pk} = C_{pkU} = \frac{USL - X_{50\%}}{X_{99,865\%} - X_{50\%}}$$

$X_{50\%}$ = median

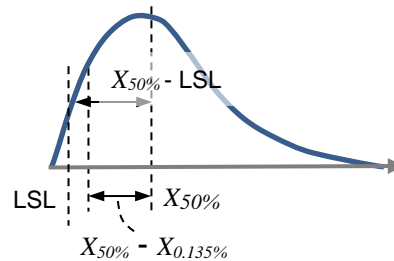


If there is a lower specification limit as well, for example for minimum surface roughness, C_{pu} has to be calculated as well:

$$C_{pkL} = \frac{X_{50\%} - LSL}{X_{50\%} - X_{0,135\%}}$$

Process capability is then expressed as:

$$C_{pk} = \text{Min} \left(\frac{X_{50\%} - LSL}{X_{50\%} - X_{0,135\%}} ; \frac{USL - X_{50\%}}{X_{99,865\%} - X_{50\%}} \right)$$



Requirement for process capability

The requirement is satisfied if:

$$C_p \geq 1.33 ; C_{pk} \geq 1.33$$

Process capability shall be verified no later than three months after the start of standard production.

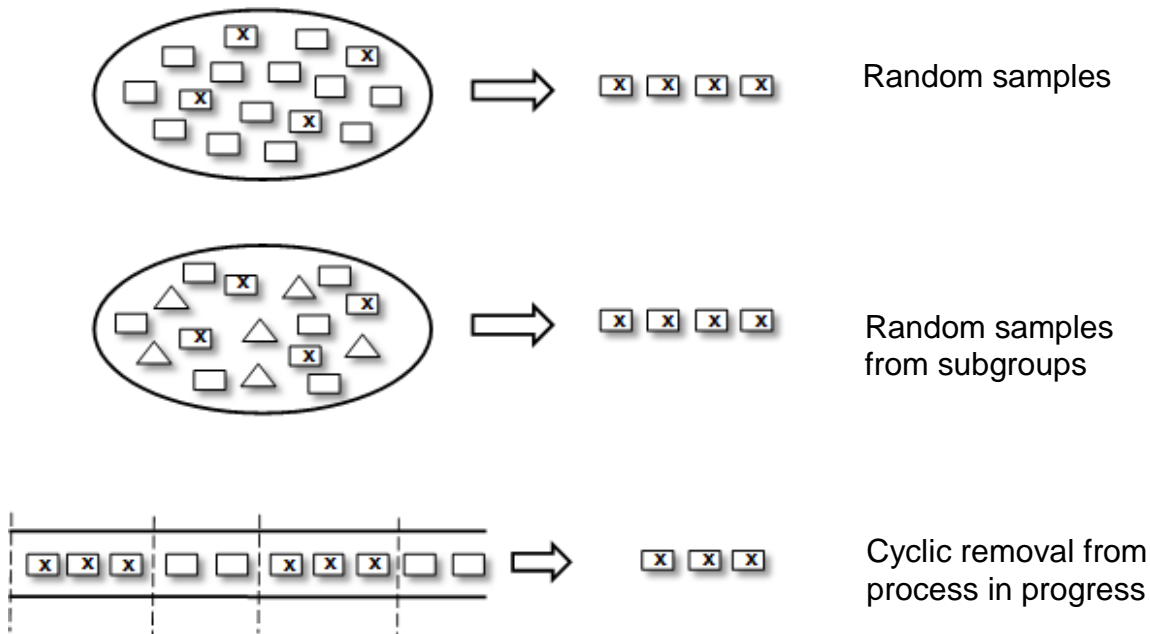
The measured data of the machine capability study cannot also be incorporated into the process capability study, because long-term influences are not taken into account in the machine capability study.

Sample size

In this instance 'sample size' means the total number of measurements taken to calculate the C_p and C_{pk} indexes. Split, usually cyclic single samples n_i are needed for the purpose of ascertaining whether a process is stable.

Process Capability Studies

The total size of the sample is defined as 125, individual samples to be taken uniformly from production over a period of 10 to 20 weeks, or over 4 weeks at least. Ensure that the process proceeds under series conditions when sampling is in progress and is not disrupted or changed. An intervention is permissible only between samples and shall be documented. If parts are removed only in samples, the possibilities include the following:



Ensure that process-changing influences are taken into account, for example tooling and set-up processes, shift changes, batch changes (raw material), etc. The single samples n_i mentioned above shall be defined accordingly and should be at least 5 in number.

In justified exceptions, for example short-run production, a smaller sample size is possible but shall be documented (min $n \geq 20$). Data shall not be sorted out (see example in the Appendix, isolated outliers are the exception, given technical reason, or proved by a statistical outlier test).

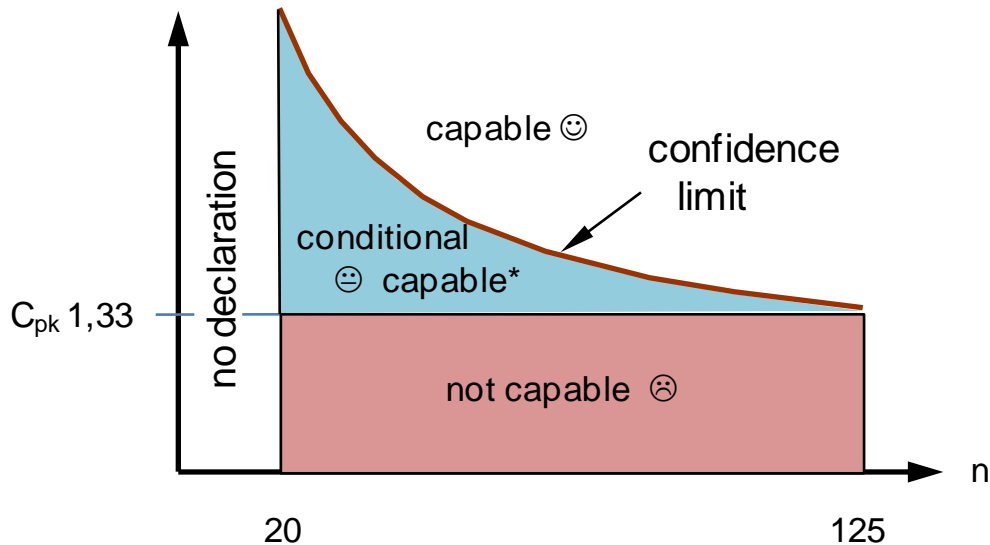
If the sample size is $n < 125$, the requirement applies with reference to the lower confidence limit (confidence interval 95%, table by analogy with VDI/VDE 2645).

n	$C_{pk} \geq$
20	1.67
25	1.59
30	1.54
40	1.48
50	1.44
60	1.41
70	1.39
80	1.37
100	1.35
125	1.33

$$c_{pk} \geq 1.33 \frac{\left(1 + \frac{1}{2n}\right) \sqrt{\frac{n-1}{\chi_{n-1, \alpha}^2}}}{\left(1 + \frac{1}{2n_{spec}}\right) \sqrt{\frac{n_{spec}-1}{\chi_{n_{spec}-1, \alpha}^2}}}$$

with $n_{total} = 125$

Process Capability Studies



* conditionally capable is not permissible for specified criteria, L and S classifications and category-A threaded fasteners!

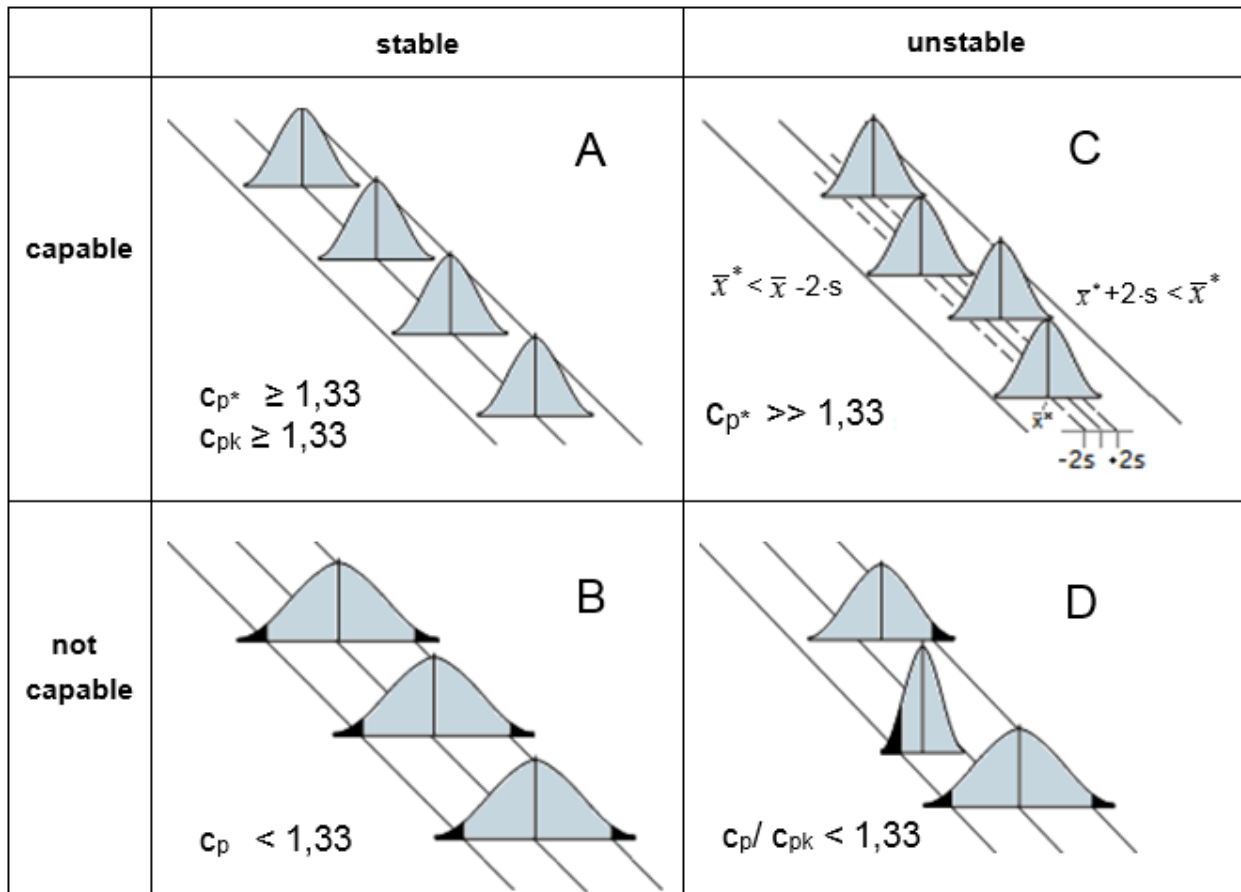
Boundary conditions

In order for the indexes to be calculated the process data must correspond to the statistical basics such as stability and controllability. Capability and stability are prerequisites for a forecast of the process. This should be taken as meaning that the capability indexes are not merely used to describe the performance of a process but instead they serve for reliably mapping how the process can be expected to perform in the future.

If capability indexes are calculated with non-stability (non-controllability) as a hypothesis, the risks involved with application of these factors is borne by the process owner. These calculated values are merely for a process description; they do not reflect on capability.

Processes are described by their capability and stability. In simplified terms, processes can be said to be in the following possible states:

Process Capability Studies



These states are identified by dividing the data, for example from the process capability study or from control charts, chronologically into single samples, see section *Sample Size*. State A is preferable to all others. It indicates that the process is both capable and stable. This state shall be achieved, because it returns no rejects in practice.

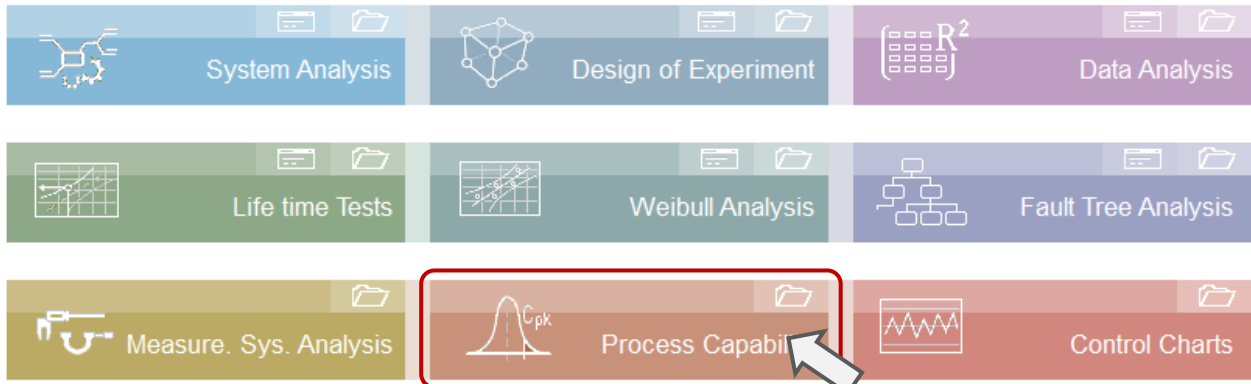
State C, although capable, is not stable or controlled, no reliable forecast can be made regarding future capability. A position consistently to one side of the mean values is also undesirable. The suggestion is: if the distributions of the single samples are one-sided at the lower or upper tolerance limit, the mean value \bar{x}_i shall be no more than within $\pm 25\%$ of the tolerance middle. For normalized consideration this means a maximum mean value offset of $\pm 2s$. In this instance standard deviation s is related to the process capability study with $n = 125$. Note that this is applicable only to processes with unavoidable drift, for example the "allowance" for tool wear. If C_p is not significantly greater than 1.33, in the control chart, the warning limit will frequently be overshoot and the probability of violation of the control-intervention limit increases accordingly! Establish the cause of fluctuation (e.g. tool changes, batches, shifts). Design of experiment (DoE) tests can be applied to quantify the effects of the influences.

In state B it is necessary either to improve the process toward A or introduce suitable measures to prevent the dispatch of faulty units.

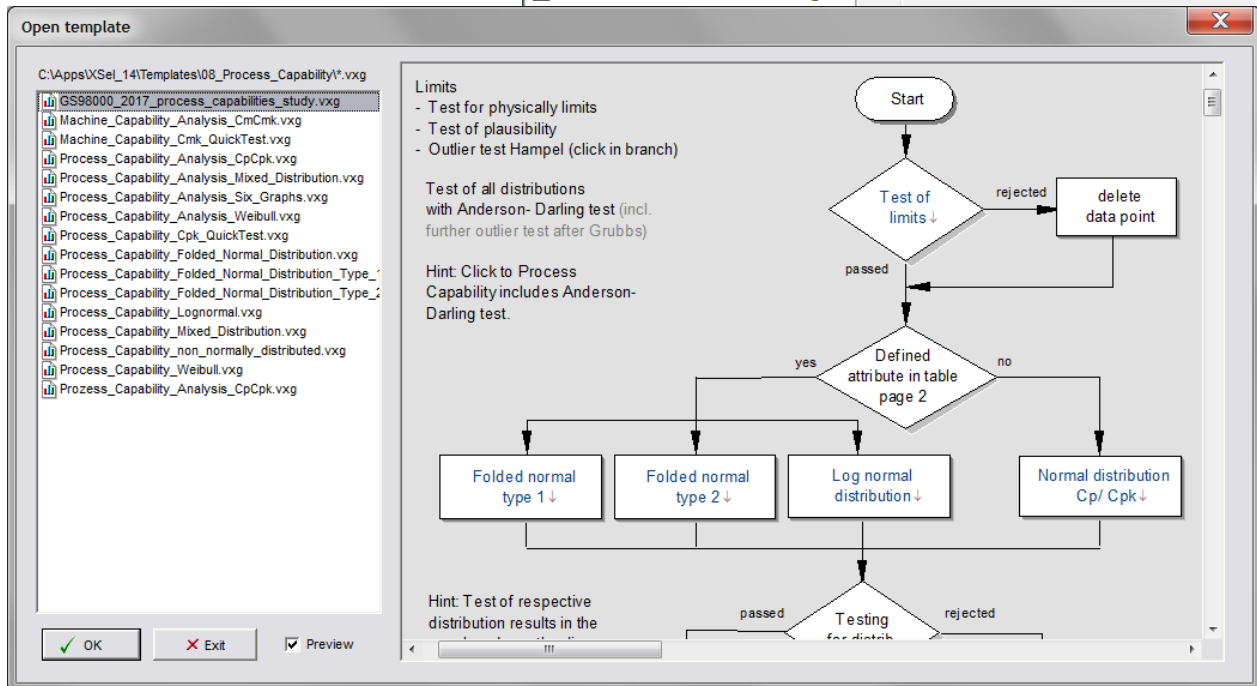
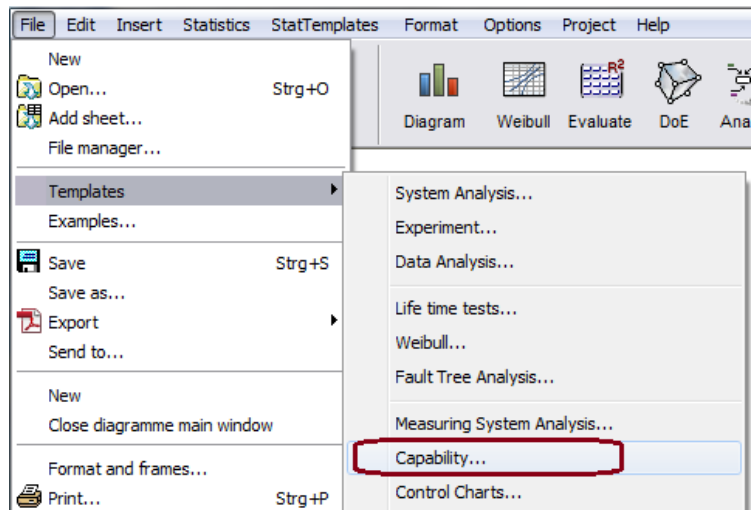
Process Capability Studies

Using Visual-Xsel 14.0

Start Visual-Xsel or use menu **File/New**. Select the **Process Capability**



or open via **File/Templates - Capability**

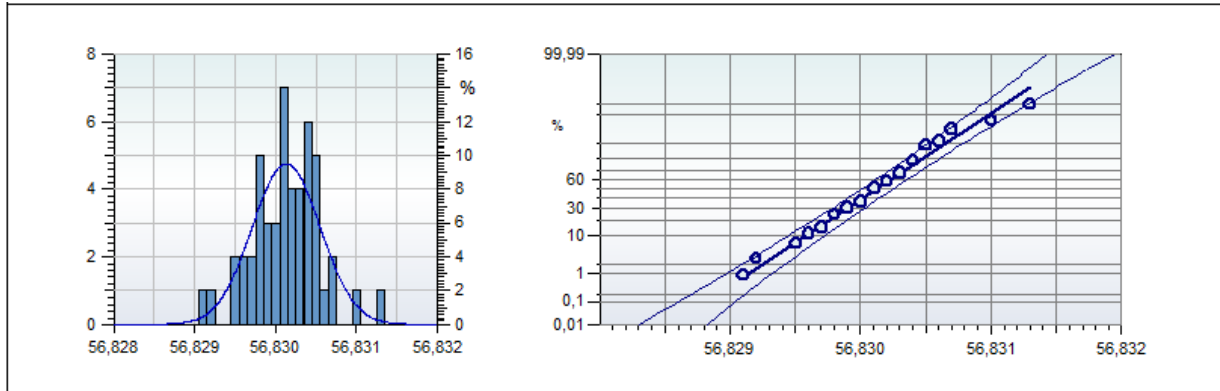


Process Capability Studies

Open the method you are going to use by holding down the mouse button and pressing Ctrl at the same time.

The instructions in the floating bubbles will guide you through the procedure. The output for the example of the normally distributed process capability is:

(*Process_Capability_Analysis_Cpk.vxg*)



Specification	Measured values	Statistical values
Sollwert x_{soll}	56,830	\bar{x} 56,830
Toleranz T	0,0040	$\bar{x} - 3s$ 56,829
	R 0,0022	$\bar{x} + 3s$ 56,831
	n ges 50	$6s$ 0,0025
		s 0,0004

Normal distributed

$$C_p = \frac{T}{6 \cdot s} \quad 1,272 \leq 1,585 \leq 1,898$$

$$C_{pk} = \min \left\{ \frac{OSG - \bar{x}}{3 \cdot s}; \frac{\bar{x} - USG}{3 \cdot s} \right\}$$

$$C_{pk \text{ ist}}: \quad 1,175 \leq 1,482 \leq 1,790$$

$C_{pk} \text{ calc.}$

$C_{pk} \text{ required}^*$
1.442

$$T_{\min/Cp=1,33} \quad 0.0034$$

$$T_{\min/Cpk \text{ required}} \quad 0.0039$$

Process capable (C_p , C_{pk}) and stabil

Process-/Machine-Capability “Quick – Test”

To proof several attributes the template *Process_Capability_Analysis_CpCpk.vxg* *Process_Capability_Analysis_CmCmk.vxg* is useful. To open this template the following steps are necessary. Open Visual-XSel or use the menu File/New. Click to Capability or use File/Templates/Capability....

Open one of the templates and follow the speech bubble.

Process Capability Studies

Fill your data by using the Link „Paste“ in the speech-bubble.

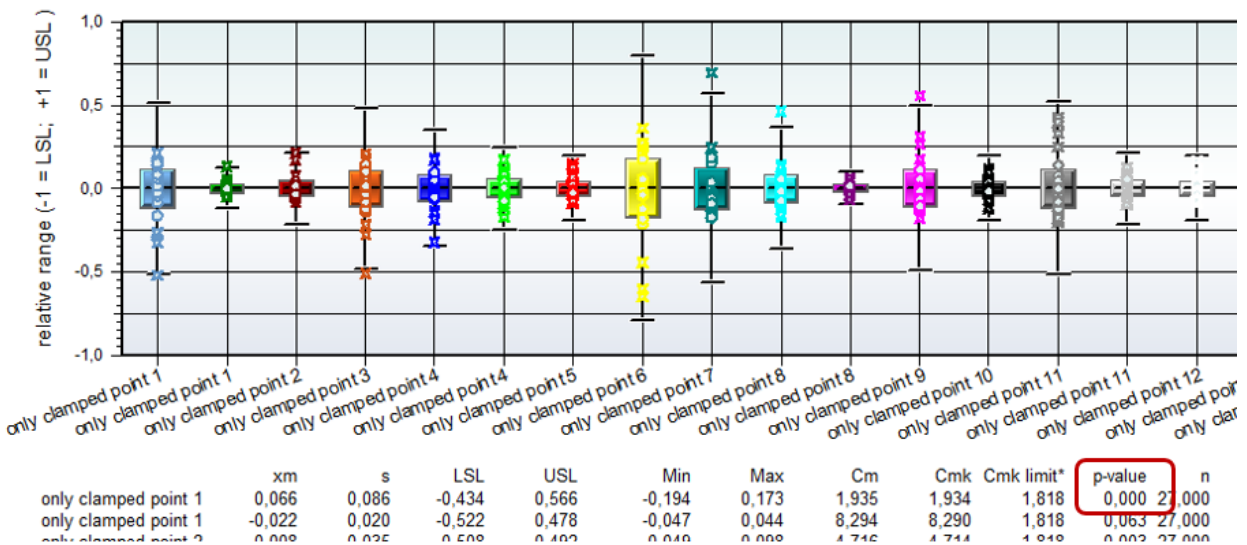
Then fill manual the USL/LSL before starting the macro with F9 or with the icon where the next speech-bubble appears.

	A	B	C	D	E	F
1		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
2	USL	15,3	15,3	15,3	15,3	15,3
3	LSL	15,05	15,05	15,05	15,05	15,05
4	1					15,115
5	2					15,16
6	3					15,18
7	4	15,16	15,161	15,179	15,169	15,191
8	5	15,192	15,161	15,148	15,165	15,137
9	6	15,161	15,194	15,164	15,149	15,117
10	7	15,189	15,216	15,141	15,176	15,133
11	8	15,152	15,144	15,159	15,177	15,142

The results are listed above the Box plots. It is recommended to use a confidence for C_{pk} , which regards the sample size (C_{pk} -limit).

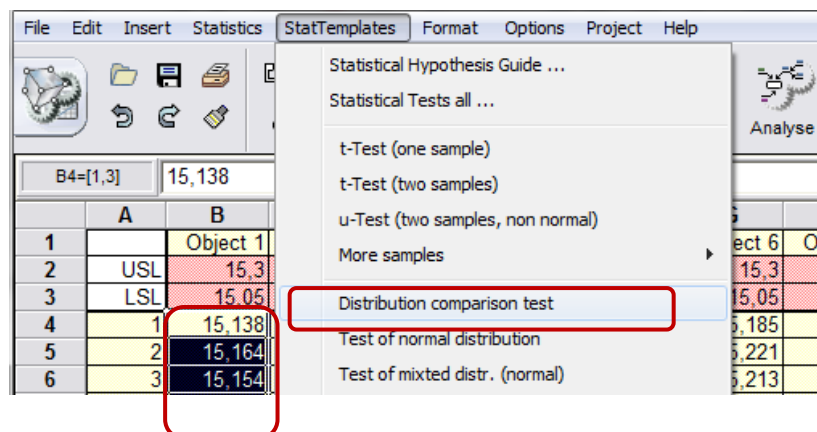
If the attribute is not normal distributed (p -value < 0.05), it has to be checked an alternative distribution.

Quick test for machine capability several characteristics



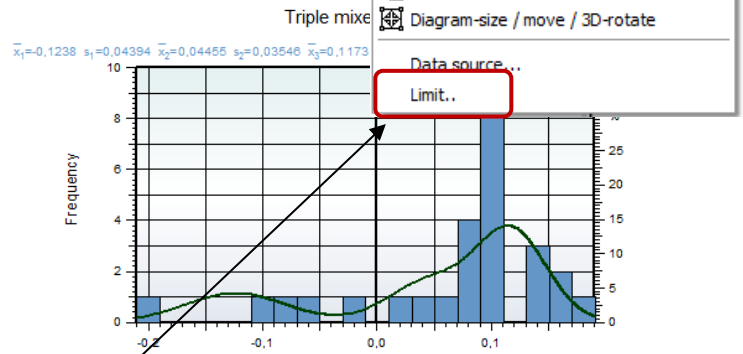
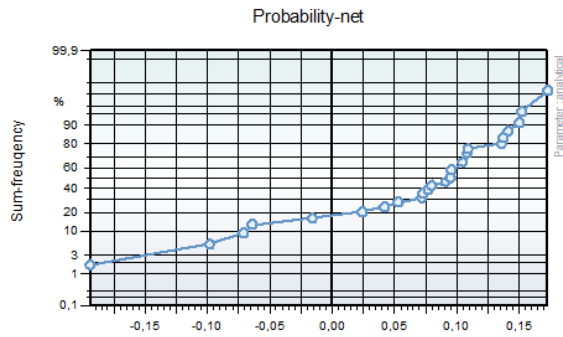
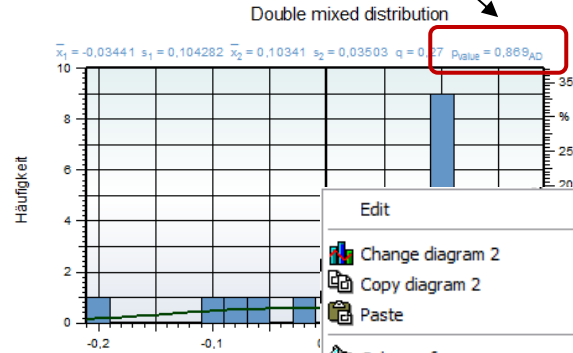
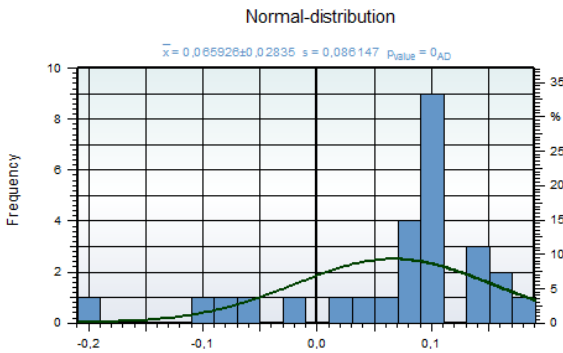
For this go into the spreadsheet /table T1 and mark the data for the regarded column beginning at row 4.

Use the „Distribution comparison test“. If the data includes negative values, now an alternative template will be started.



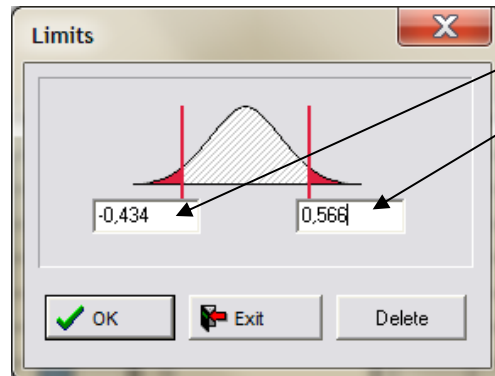
Process Capability Studies

For the example of the data from the first column, the Double mixed distribution is the best choice (best p-value). Click to an arbitrary element of this chart...



and use the right mouse button and select "Limit". Type the defined tolerances from the table in the two fields.

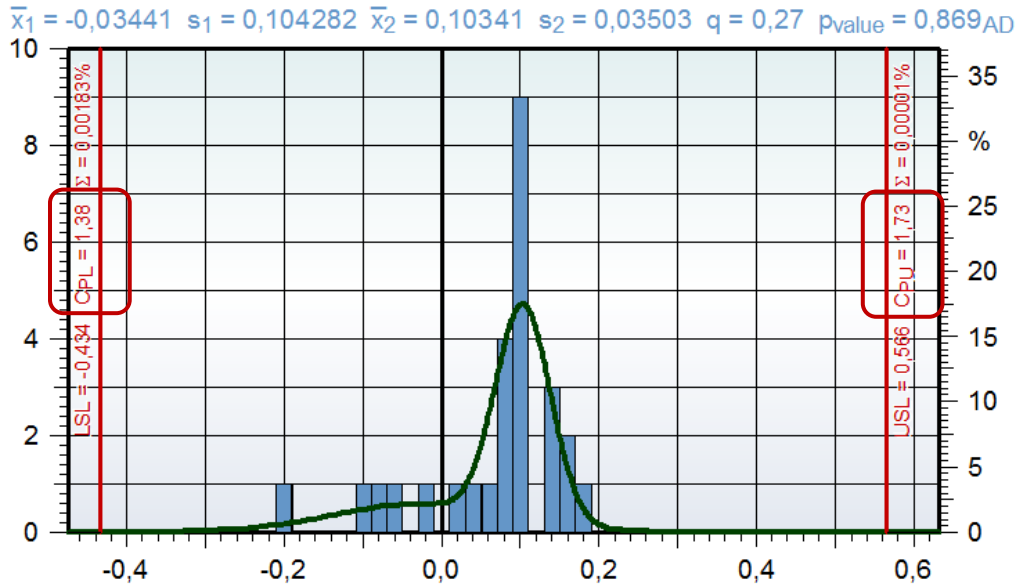
	A	B
1		only clamp only
2	USL	0,566
3	LSL	-0,434
4	1	-0,098
5	2	0,091
6	3	0,016



Process Capability Studies

The vertical limits show the C_{pL} and the C_{pU} index. In this case it is to interpret as C_{mk} (min value of both).

Double mixed distribution



In this case the required value of 1.67 is not fulfilled. Please note: Normally it is not allowed to have mixed distribution for the machine capability. So even if you have reached the $C_{mk} \geq 1.67$, the process has to be improved. It must be analyzed what is the reason for the mixed distribution.