TEQ Training & Consulting GmbH | Stephan Conrad| September 2013

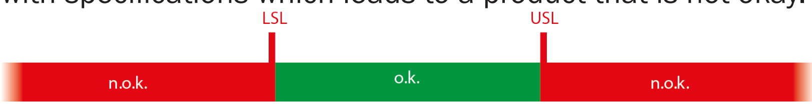
One-sided and Natural Specification Limits in Process Capability Analysis

One-sided specification limits in the calculation of capabilities raise questions time and time again, especially when it comes to the difference between simple “one-sided limits” and “one-sided specifications with a natural limit”. This article illustrates the most important issues and provides you with possible solutions. However, first we are going to explain the meaning of “one-sided specification limits” and how to distinguish them from a “natural limit on one side”. The process capability results we are going to obtain can also be transferred to machine capabilities (C_m/C_{mk}) and preliminary process capabilities (P_p/P_{pk}), of course.

Two – one – zero – natural limits?

Two-sided specification limits

Two-sided specification limits consist of two limits between which a certain proportion of characteristic values falls. A characteristic may exceed both specification limits. In this case it proves nonconformity with specifications which leads to a product that is not okay.



Examples

- Linear dimensions, e.g. the width of a license plate
- Line voltage required to operate a microwave
- Diameter of a threaded hole

One-sided specification limits

One-sided specification limits consist of a single upper or lower limit restricting the characteristic. The characteristic may exceed the limit (in case of an upper limit) or fall below the limit (in case of a lower limit) which proves nonconformity with specifications and thus leads to a product that is not okay. The tolerance interval is never restricted to the other side since the characteristics the process produces in this range of values do not cause nonconformity.

Examples

- Minimum stripping force for cable connections
- Strength of a shelf made of glass
- Maximum storage temperature for frozen food
- Maximum authorized mass of a vehicle

or

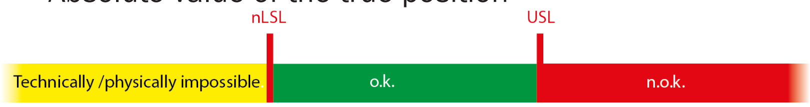
Technological / physical / natural tolerances

There is a special case of one-sided specification limits. They just have a single specification limit;

however, they also consist of a second limit – a natural limit the characteristic is not able to exceed for technological or physical reasons. Moreover, this "natural" limit often equals the target value of a process, i.e. the "best possible" process result.

Examples

- Flatness of a table top (it cannot be flatter than flat...)
- Roundness of a shaft (it cannot be rounder than round...)
- Imbalance
- Absolute value of the true position



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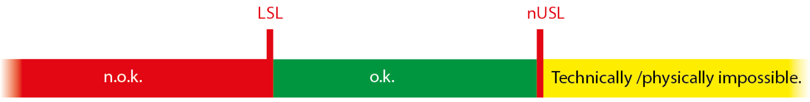


An additional special feature about technological / physical limits is that the "natural" limit is even the only kind of specification limit that the characteristic recognizes "of its own accord". A characteristic is able to exceed any limit specified by any design engineer; however, it is not able to exceed a natural limit. Processes are unable to exceed these limits and will adapt to the respective situation. The result is on the one hand that...

- processes with a natural limit tend to produce a skewed distribution as soon as their values approach the "natural" limit. On the other hand...
- the variation range of a stable and qualified process is clearly restricted to the area between the specification limit and the technological / physical / natural limit.

This kind of limit is simply referred to as "natural limit" in the following.

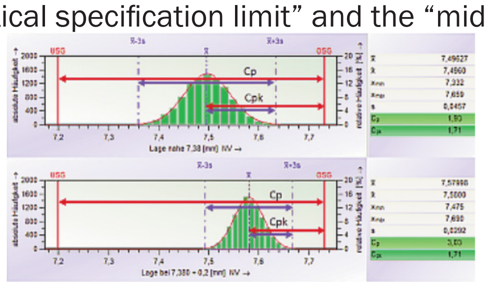
The game "Pitch and Toss" illustrates the phenomenon of a skewed distribution very well. The players throw a coin at a wall and the coin landing closest to the wall is the winner. This process will always lead to a skewed distribution of tosses. However, if you replace the wall by a white line on the floor, you will get a nice and clean normal distribution, even though the players' behaviour is the same.

How do these specification limits affect the calculation of capabilities?

Two-sided specification limits

The method you use to calculate capabilities in case of two-sided specification limits is generally known.

- C_p describes the relationship between the tolerance and the 99.73% process spread.
- C_{pk} describes the relationship of the distances between the "middle of the distribution and the critical specification limit" and the "middle of the distribution and the process variation limit".



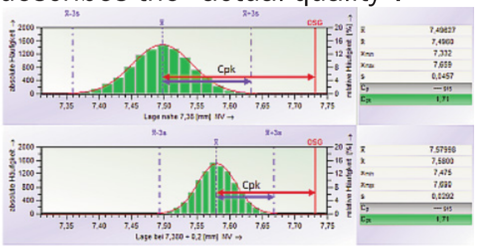
The following rules also apply to two-sided specification limits.

- C_{pk} is always less than or equal to C_p ($C_{pk} \leq C_p$).
- When the process is centred in the tolerance interval, $C_{pk} = C_p$.
- C_{pk} describes the “actual quality”.
- C_p describes the “maximum obtainable process quality”.

One-sided specification limits

Since a second limit is missing in case of one-sided specification limits, you cannot calculate the tolerance width and thus C_p.

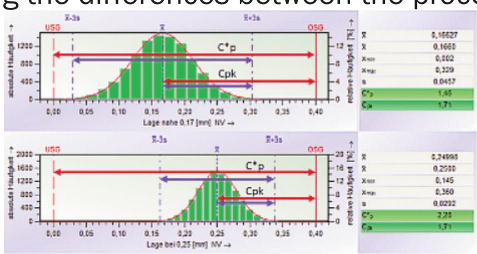
- C_p cannot be calculated.
- C_{pk} describes the “actual quality”.



Unfortunately, there are cases where the “actual quality” of two completely different processes seems be identical (see example above). The capability indices do not indicate the fact that the second process includes less variation but is closer to the specification limit. Both processes have a C_{pk} amounting to 1.71 and seem to be equally suitable for the respective task. At least by now we have come to realize that the “actual quality” C_{pk} expresses only refers to the characteristics’ quality of “not exceeding specification limits”. Capability, however, means much more; it is more than just another word for fraction nonconforming. Of course, the second process indicates a higher potential and has a considerably higher process-inherent quality due to its minor variation. This type of information is only provided by the relationship between C_p and C_{pk}. C_{pk} alone is not able to offer this kind of information and C_p cannot be calculated in case of one-sided limits.

Technological / physical / natural tolerances

What happens to a one-sided specification limit having a natural limit on one side? Even in this case, C_{pk} describes the “actual process quality”. However, the absolute limit opens up the unique opportunity to describe the differences in process-inherent quality. You just have to replace the missing second limit with the available natural limit and you will be able to calculate a kind of “pseudo” C_p clearly showing the differences between the processes.



In this case, the following rules apply.

- C_{pk} describes the “actual quality”.
- C_{pk} might exceed $C*_p$ and thus indicate that the process is closer to the natural and “good” limit.
- C_p does not describe the “maximum obtainable process quality”.

Since this C^*_p value is a special kind of C_p, it is important to highlight this fact in form sheets. qs-STAT offers several options to underline the nature of this value. As shown in the graphic above, you may add a star to this C^*_p value. Moreover, the software is able to illustrate natural limits in the form of a dashed line. Eventually, codes 15 and 915 as well as the colour coding in form sheets provide a clear indication. Additionally, you may specify in the evaluation strategy whether you want to apply C^*_p to assess the quality of a process automatically.

Industry practice

In the manufacturing industry, this option is applied in various ways. You are provided with three typical interpretations in the following. The companies mentioned below have configured and released the respective structures in qs-STAT.

Aim: "We want to collect all available information; however, we evaluate characteristics with a natural limit only; this evaluation is based on C_{pk}."
Solution: Calculate C_p, show the result but do not evaluate this statistic based on a limit.
Applied by: GM Powertrain and Volkswagen

Aim: "Our process landscape needs processes with a minimum variation. This is why we demand $C_p \geq 1.xx$ and $C_{pk} \geq 1.yy$."
Solution: Specify a reasonable limit for C_p.
Applied by: Renault or as an example even the "Q-DAS 1 Part" evaluation strategy

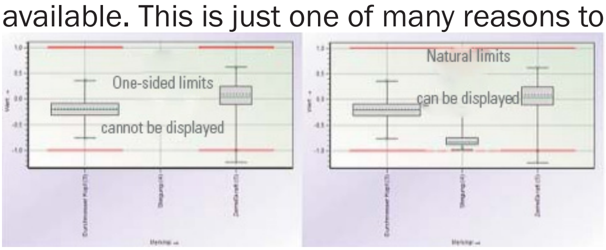
Aim: "We are satisfied with the evaluation of C_{pk}, C_p is less important for us."
These companies often tell us that they do not want to confuse their employees with necessary exceptions.
Solution: Just do without the calculation.
Applied by: Daimler, BMW and Bosch

Thinking out of the box

The approach to use natural limits as "pseudo" specification limits is not restricted to this kind of application.

It is common practice in measurement system analyses to calculate the statistics C_g/C_{gk} and %GRR based on natural limits. It is thus obvious that you calculate the expected variation range in case of two-sided limits from the natural and the specified limit, so the calculation is identical. You always evaluate C_g only at a specific limit!

Some graphics that are based on standardisations require two specified limits. As an example, a box plot having a standardised scale will not show any characteristic when there is only one limit available. This is just one of many reasons to specify natural limits.



Searching for descriptive distributions, it may be reasonable to restrict the offset parameters of a distribution to a range that is feasible in practice. This is another reason for specifying a natural limit.

A clear approach avoids misunderstandings. You often provide allowances instead of absolute values. A tolerance of 8+0.01/-0 having allowances of 0.01 and 0 quickly leads to misinterpretations when talking about a "natural, absolute limit" in colloquial speech. For a better understanding, think of a storage temperature of 5°C in the fridge – this temperature shall never fall below 0°C, of course. However, "zero" in neither case equals a natural limit.

So we have come to the next issue causing confusion. Even if we specify a maximum storage temperature, a temperature always has a natural absolute zero at 0 Kelvin, i.e. -273.2° Celsius. However, this natural limit is neither relevant to the process nor a target value for our storage temperature. The same applies to linear dimensions - or are you aware of any negative length? This is the reason why we do not consider this natural limit, it is irrelevant. These processes are thus referred to as process with a "one-sided specification limit".

What do standards say about this topic?

The standards about process capability underwent a drastic change. ISO 21747 was meanwhile replaced by ISO 22514-2 of the ISO series "Statistical methods in process management – Capability and performance" in 2013. This standard, however, only describes the calculation of two-sided and one-sided specification limits. The special case of natural limits is not mentioned at all, neither in a positive nor in a negative way. The reason might be that the experts of the DIN and ISO technical committees still use different approaches. The fact that the method of natural limits is neither mentioned nor excluded is nowhere near to the fact that they are not permissible. Such an interpretation would only lead to the fact that most of today's common quality methods are not permissible. However, it is quite the opposite. These methods are developed in practical applications and are only implemented as a technical standard after an elaborate testing phase and in case of sufficient economic interest. Only if these standards describe a specific approach, other methods are considered to be incorrect. This is not the case in this example.

Summary

In accordance with these advanced calculation methods, you have to add some rules for capability indices.

- C_{pk} always describes the "actual quality".
- C_p ... describes the two-sided limits of the "maximum obtainable process quality" and is thus always greater than/equal to C_{pk}. In case $C_{pk} = C_p$, the process is centred in the tolerance interval.
  ... can be less than C_{pk} in case of a natural limit; however, only if the process is close to the target value ("A C_{pk} value exceeding C_p is only possible in case of natural limits!").
  ... cannot be calculated in case of one-sided limits.

This method is not inconsistent with a standard requirement and applies in different ways in practice. The interpretation of these rules depends on the company's quality philosophy. In general, I always recommend thinking about why you would refuse to get additional information about C_p in case of natural limits.

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