Measurement Process Capability – Trends and Approaches

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Abstract

A measurement control system ensures that measuring equipment and measurement processes are fit for their intended use and its important in achieving product quality objectives. The following paper introduces theoretical foundations for determination of the measuring process capability. Defines three capability indexes in short and recommended use of the C_{pm} index.

Keywords

statistical process control, measurement process control, capability index, Taguchi function

1 Introduction

Several years can be observed attempts to standardise evaluation of the processes (whether production or measurement) capability. Such attempts have not been successful yet. Many factors must be taken into account – processes heterogeneousness, changing requirements, wide variety of used technological means. Therefore big production enterprises (General Motors, Volkswagen, Siemens, Bosch, etc.) have established their shop methodologies for the evaluation of the processes capability. Capability of measurement processes is searched similarly to that of production processes most often.

Process capability means ability of the process to meet technological or other requirements, i.e. to fulfill demands put on it.

Measurement process capability is determined by total variation caused by random reasons influencing the process. Variation is caused by variability of the measured quantity values that are not connected to the measurement conditions and must be excluded. Therefore it is recommended to perform preventive measurements. In those texts check standards are measured by the measuring equipment being tested.

Variability of the measured data (caused by the measurement process) as well as the systematic deviation from the required values is observed during evaluation of the measurement process capability. Both such efforts are determined by the technological development of the measuring instruments. Due to the technical innovations (incorporating electronics enabling predictive diagnostics, autocalibration, automatic correction of the output signal according to the status of the measuring instrument) variability of the measurement process is decreasing and the effort for its centering improve capability of the measuring instruments (see Fig. 1). Economical savings represent the direct impact – possibility for better setting of the production process, decreasing of the number of nonconforming products and resulting the increased production efficiency.

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2 Indexes of the measurement process capability

Several types of the process capability indexes exist. They differ one another by calculation method, by properties as well as by intended use. But their design principle is approximately the same. The ratio of prescribed (required) accuracy and really achieved process accuracy is always observed.

According to philosophy of the quality control approach, capability indexes of any process can be divided to the capability indexes of the first and second generation.

Design of the *first generation* capability indexes (C_p, C_{pk}) is based on classical philosophy of the statistical process control. According to that philosophy all measurement results within required tolerance interval are intended to be *good*. Mea-

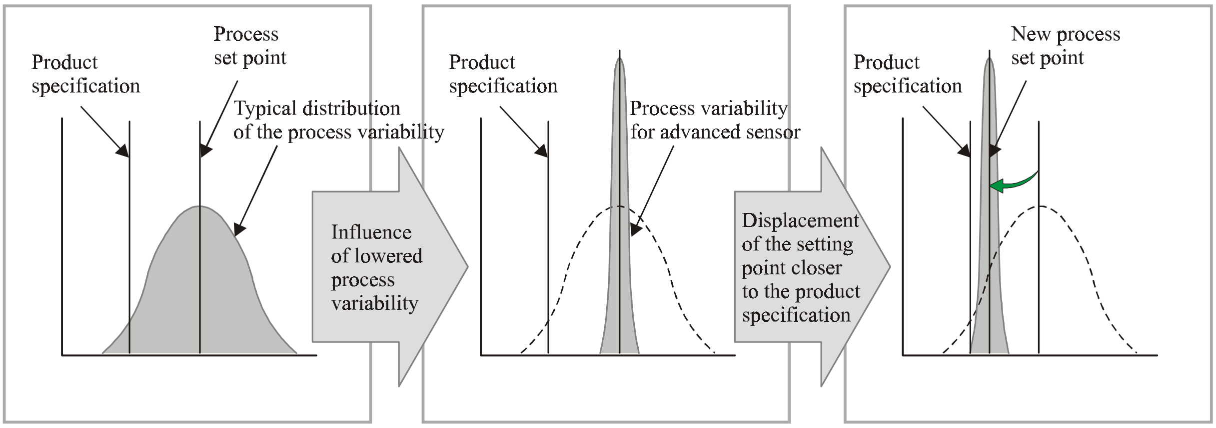

Fig. 1 Influence of the measurement process variability and the effort for its centering

surements outside tolerance interval are considered to be *bad*.

Second generation capability index (C_{pm}) is rising from new approach to the quality improvement (Taguchi approach). It is not enough to know that measurements are so called *good* (being within the tolerance interval) but important is knowledge on *how good* they are. Such index enables to determine whether the values of the searched quality index approach to the tolerance limits even when all measurement results fit within the tolerance.

2.1 Process capability index C_p

Process capability index C_p is a simple relative number comparing value of the required process variability (required tolerance interval) to a natural process variability (natural tolerance interval).

For measuring process given by expanded uncertainty U, capability index C_p is calculated as

$$C_P = \frac{2U}{6\sigma} = \frac{U}{3\sigma} \tag{1}$$

where s is a process standard deviation.

Whenever requirements put on measurement process are given by tolerance interval T, such interval must be defined first. Tolerance interval T is defined as a difference between the upper tolerance limit UTL and the lower tolerance limit LTL. That means $T = UTL - LTL$. Capability index C_p is calculated in this case as

$$C_P = \frac{UTL - LTL}{6k\sigma} \tag{2}$$

where $k = 3$ to 10.

Capability index C_p expresses only the *potential* process capability. It does not represent the position of the natural tolerance interval considering the position of the required tolerance interval. Therefore it does not give a clear answer whether measured value of the searched quality indicator fits within the tolerance interval. Another disadvantage of the C_p index is the fact that it does not represent the conformity of the measurement process average mean $\overline{\overline{X}}$ to a check standard nominal value X_0.

2.2 Process capability index C_{pk}

Capability index C_{pk} reacts to deviation of the measurement process average mean $\overline{\overline{X}}$ from check standard nominal value X_0 (see Fig. 2). Index is calculated as

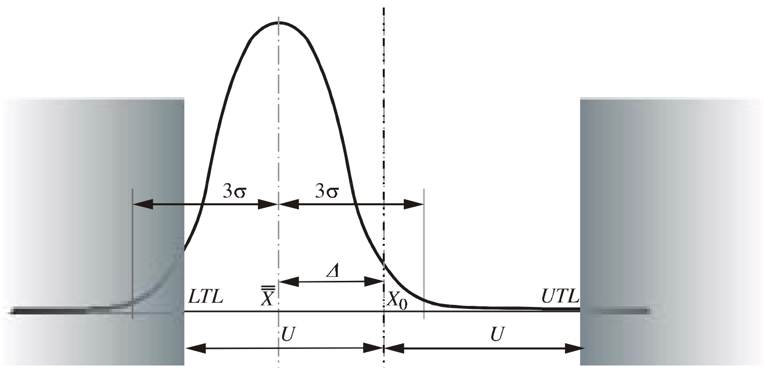

Fig. 2. Design of the C_{pk} index

$$C_{pk} = \frac{U - |\Delta| - U_{KE}}{3\sigma} \quad (3)$$

where U_{KE} is the check standard uncertainty, $\Delta = X_0 - \bar{\bar{X}}$.

2.3 Process capability index C_{pm}

Practical experiences showed that demand for a low percentage of check standard measurements (or measurements performed directly on products or processes) falling outside the tolerance limit T is not satisfactory. Few information are obtained on spare measurements. Most interesting information is about the *quality* of individual measurements i.e. how far are measurements performed on check standard from the nominal value X_0 of the check standard or from tolerance limits respectively.

G. Taguchi and T. C. Hsiang designed a *loss function* as a new approach to production process quality improvement in 1985 [5]. This dissipation function can be adapted fully to the measurement process. Its use is intended for decreasing the variability around the target value of searched quality indicator, i.e. around the check standard nominal value (see Fig. 3).

Process capability index C_{pm} defined by Taguchi is based on equation (1) and is defined as

$$C_{pm} = \frac{UTL - LTL}{6k\tau} = \frac{U}{3\tau} \quad (4)$$

where t is standard deviation around the check standard nominal value X_0. Taguchi advises to calculate this deviation as $\tau = \sqrt{\sigma^2 + (\bar{\bar{X}} - X_0)^2}$.

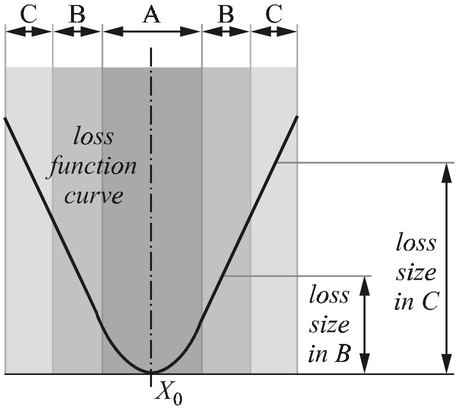

Fig. 3 Taguchi loss function

Observing equation (4) one can see that increasing process variability s^2 causes increasing of the denominator and therefore decreasing the C_{pm} index. Again retreating of the measurement process average mean $\bar{\bar{X}}$ from check standard nominal value X_0 increasing the denominator value and resulting decreases the C_{pm} index value.

2.4 General remarks on capability indexes

If the process is centered, measurement process is always capable when capability index value (C_p, C_{pk}, respectively C_{pm}) exceeds 1. Practical recommendation considers minimal admissible value 1,33. The reason is that certain variability is always presented and process is never fully in statistically controlled status. Therefore indexes value ³ 1,33 is recommended for established processes. Newly adopted process should produce capability indexes with values ³ 1,50, extremely precise measurements should have value ³ 1,66 [4], [6].

Process standard deviation s is usually unknown in practical situations and must be estimated. Usually is estimated as

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X})^2} .$$

Its substitution to expressions (1), (2) and (3) gives just estimation of individual indexes. It is a random variable with probability distribution. Therefore calculation of the index interval estimation is recommended. This interval contains the true value of the index with probability of 1 - a. Objective proof of process capability (index gets value exceeding 1,33) brings statistical test.

2.5 Example

Lets calculate capability indexes C_p, C_{pk}, C_{pm} and compare them. Basic parameters of the measurement process: check standard nominal value is X_0 = 20 mm, measurement process average mean $\bar{\bar{X}}$ = 20 mm; measurement process uncertainty U = 0,02 mm, check standard uncertainty U_{KE} can be neglected, standard deviation s = 0,004 mm. Then capability indexes

C_p = 0,02/(3×0,004) = 1,666

C_{pk} = (0,02-0)/(3×0,004) = 1,666

$C_{pm} = (0{,}02)/(3\sqrt{(0{,}004^2+0^2)}) = 1{,}666;$

While $X_0 = \overline{\overline{X}}$, process is centered and all capability indexes are equal. However such status is very rare in technical practice.

After parameters change to $X_0 = 20$ mm, $\overline{\overline{X}} = 19{,}995$ mm (other parameters remain the same), capability indexes get following values:

$C_p = 0{,}02 / (3\times 0{,}004) = 1{,}666$ (without change)

$C_{pk} = (0{,}02-(20-19{,}995)/(3\times 0{,}004)=1{,}25$

$C_{pm} = (0{,}02) / (3\sqrt{(0{,}004^2+(20-19{,}995)^2}) = 1{,}04$

Process is not centered in this case while $X_0 \neq \overline{\overline{X}}$. Capability index C_p did not record falling-off the process capability by remained variability. Indexes C_{pk}, C_{pm} are able to record infrigement of the required value by untouched process variability.

After another parameters change to $X_0 = 20$ mm, $\overline{\overline{X}} = 19{,}99125$ mm, $s = 0{,}004$ mm calculated capability indexes obtain following values:

$C_p = 0{,}02/(3\times 0{,}004)=1{,}666$ (without change)

$C_{pk} = (0{,}02-(20-19{,}99125)/(3\times 0{,}003)=1{,}25$ (without change)

$C_{pm} = (0{,}02)/(3\sqrt{(0{,}003^2+(20-19{,}99125)^2})=0{,}72$

Capability index C_{pk} is not able to record changes of the measurement process average mean $\overline{\overline{X}}$ towards tolerance limit in the case of changed standard deviation. Only C_{pm} capability index registered such change.

3 Conclusions

Presented paper defines in short three most applicable methods for calculation of the measurement process capability. Shows some deficiencies of the C_p and C_{pk} capability indexes that are used almost exclusively in nowadays practice. Capability index C_{pm} represents best the real measurement process capability.

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