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THE APPLICATION OF SPC METHODS TO DOCUMENT AND MANAGE PROCESSES FROM THE VIEWPOINT OF QUALITY

Abstract: *The basic concept of Statistical Process Control is based on a comparison of data obtained from the process with the calculated control limits and based on that drawing conclusion about the process. SPC is a set of methods and procedures for collecting, processing, analyzing, interpretation and presentation of data in order to assure the quality of products and production processes. Using and R control charts to determine changes and trends of change characteristics of the process in order to achieve the set of standards and improve process performance. Aim is: To show an example of application software tools in a system of quality, the level of direct quality management, based on data included in the manufacturing.*
Keywords: *Statistical Process Control, control chart, Matlab*

1. INTRODUCTION

Application of software tools in data processing in the field of quality assurance, control and quality management is today encompassed by a single module of CIM system (*Computer Integrated Manufacturing)* known as CAQ module (*Computer Aided Quality*).

The aim of this thesis is to show an example of software application in a system of quality, the level of direct quality management based on the data included in the manufacturing.

Typical example of CAQ management system is Statistical Process Control (SPC), which is based on monitoring and following parameters of production, identifying trends and differences between normal and unusual states, using techniques of mathematical statistics. These analyses are suitable for direct manufacturing, since they allow processes to run with additional work and scrap products reduced to minimum, but there are clearly defined procedures for their application.

Statistical process control includes a great number of statistical methods, but this thesis will only focus on one method, predicted for evaluation of machine capability by measuring natural tolerance and identifying trends using $\overline{X}$ and R control charts. After that follows the presentation of the results of the programme for monitoring machine capability and identifying trends by using $\overline{X}$ and R control charts, which was designed by software pack MATLAB.

2. PROCES CAPABILITY AND STATISTICAL PROCES CONTROL

In order to perform an objective evaluation of the extent to which the process meets or does not meet customer's needs, certain process capability methods have been developed. These methods are based on quantitative indicators of process performance, so-called process capability indices, that represent a relation between process distribution and tolerance limits determined by the specification.

Process capability studies are high level tools of quality management. None of the quality management activities, such as quality design, planning and equipment management, management of improvement process, etc. in any process in the organization would be possible without the understanding of process capability. If it is not known what occurs during the process, then it is impossible to determine if the process has satisfied the demands, let alone predict results of the process in terms of managing its course. Managing the process means leading it in a direction where it can provide maximum capability in “a controlled state”, and only the increase of process capability leads to process improvement. Having that in mind, process capability studies have grown into a system of statistical process control, which is usually referred to as “SPC and continuous improvement". This method represents a tool with which a process can be understood, governed and with continual improvement made into a “safe process”.

SPC is a control cycle made of machine system - tool - work piece – measuring device, while the control limits of this cycle represent the characteristics of the quality of process results. For each systematic deviation from required values, established by measuring equipment, SPC control cycle will activate certain measures.

Control charts are used, as an assistance tool to identify systematicity and coincidences, with intervention limits for given characteristic, so in this function they are often called quality control charts.

3. STATISTICAL ANALYSIS

Statistical analysis is a procedure in which given process data are processed further and it represents mathematical analogy of physical changes of random variable. It represents a tool for generating results, on which decision-making criteria are applied in order to gain control process parameters. These criteria are determined by statistical study of process mechanisms.

3.1 Determining natural tolerances

According to normal distribution principle 99, 37% of all values of process characteristics, even the measured ones, are expected to be in the interval $\left[\overline{\overline{X}}-3\sigma;\overline{\overline{X}}+3\sigma\right]$.

where: $\overline{\overline{X}}$ - represents sample mean

σ- is standard deviation of a sample.

Based on this, criteria for estimating ‘natural tolerance’, T has been established,

$$T_{prir} \approx 6\cdot\sigma$$

In most companies this criteria is also applied for machines with the exception of the companies using modern technology where requirements for machine capability are more strict.

In that case of efficient machines, it is predicted that 99,994% of measured data (and all process results) will be within specified tolerance limits, for the process "under statistical control", which makes the interval $\left[\overline{\overline{X}}-4\sigma;\overline{\overline{X}}+4\sigma\right]$. Therefore, estimate of natural tolerance is:

$$T_{prir} \approx 8\cdot\sigma$$

This obvious difference in the estimate of overall natural tolerance and natural tolerance of the process of the machine itself was established in order to ensure that the process of efficient machine does not have a significant influence on decision-making in general process performances. This ensures, in capable processes, that 99,37% of the data which corresponds to the interval $\left[\overline{\overline{X}}-3\sigma;\overline{\overline{X}}+3\sigma\right]$, is definitely kept within the tolerance for a long period of time.

As the representativeness of the sample increases with the increase of the number of measured parameters, we introduce correction factor K, which approximates the sample to the population:

$$T_{prir} \approx K \cdot \sigma$$

With the increase of sample size, that is, total number of measured parameters N, value K is asymptotically leaning to number 6, which can be noticed in table 2 for this coefficient.

3.2 Making decisions about the process based on natural tolerance

Process is controlled only if it is functioning within its natural tolerance limits, that is to say, if it follows normal distribution, which does not necessarily mean that it is functioning within specified tolerance fields.

If the natural tolerances of the process are smaller than specified tolerances, the process is „*under statistical control*".

In terms of the classification of the process, the process is „capable" if its range, i.e. natural tolerance, uses the range of specified tolerance only up to 75%, which the premise is based on. Therefore, controlled process can be "*under control*" even if it is not capable.

3.3 Machine/process capability

Understanding the essence of the nature of a process is based on the study on its capability (efficiency), while its management is based on process stability. These features are measured by following capability indices:

- *Cm / Cp – machine/process capability index* is a simple index that relates allowed variation within tolerance limits to the measure of inherent or natural variation of the process. However, this index does not show how process mean relates to the tolerance mean, so it often appears as a measure of process "potential".
- *Cmk / Cpk – Critical Machine/process capability index* does not only measure process variation in relation to specific tolerance, but it also considers the position of process mean. This indicator is often called "the measure of process capability" in relation to "the measure of process potential" (Cp).

Table 1 – Classification of the processes according to their capability

PROCESS	EFFICIENCY	STABILITY	MEASURES
A	good (C_p≥1,33)	Good (C_p≥1,33)	Allow continuance of the process
B	good (C_p≥1,33)	Poor (C_{pk}<1,33)	Quality control charts
C	poor (C_p<1,33)	Poor (C_{pk}<1,33)	Sorting and analyzing the process

3.4 Making decisions about the machine/process based on capability index and critical capability index

At first characteristic values of these indices should be considered and what they represent for the process in general.

According to these characteristic values capability index and critical capability index a classification of the process was adopted as shown in table 1.

3.5 Control charts

For measurement control of the on-going process "quality control charts" are used as a tool with which a capable (efficient) process is lead to become a stable one as well, in other words, to ensure that controlling characteristics of quality is leaning towards nominal value. Control charts show when a process goes "out of control", identify the appearance of systematic causes, and represent the foundation for process analysis and process capability studies, and most importantly, they enable process management in an undisturbed manner when all of the products are coherent or adjustment in case of variations.

Quality control charts are in essence control charts, with the difference that they are not a sole graphic view of the value of quality feature of the process for a long period of time, but they are used to monitor current and predict future state of the process.

Depending on the type of the process being managed, in practice two types of control charts are used:

- $\overline{X}-R$ Control charts, which are very sensitive to changes, in cases when the technological process must be run within narrow range of tolerance limits; in other words they correspond to the most of technological processes in various manufacturing capacities (which is why they are most often applied)
- $\overline{X}-\sigma$
  Control charts that are applied when it is suitable or necessary to work with a great number of pieces in the test/subgroup This corresponds to precisely those technological processes with long operation or procedure time, and at the same time with a great number of pieces being processed, while the process itself is characterized by comparatively big variations.

This thesis will show only $\overline{X}-R$ control charts.

4. TESTING MACHINE CAPABILITIES FOR MECHANICAL PROCESSING BY MEASURING ITS NATURAL TOLERANCE

This section describes the procedure for testing machine capability for mechanical processing by measuring its natural tolerance.

The objective is to estimate the machine capability in manufacturing to permanently and systematically maintain the quality according to specified tolerance and analyze deviations by means of statistical analysis of processed data of the representative sample.

Procedure includes the following steps:

1. Standard deviation, calculated with the formula as follows:

($S=\sigma$ for $N\geq 50$)

$$S=\sqrt{\frac{N\cdot\sum_{i=1}^{N}X_i^2-\left(\sum_{i=1}^{N}X_i\right)^2}{N\cdot(N-1)}}$$

where:

X_i- is measured value of quality parameter on i-work piece,

N- is the number of sample elements

2. Average value of elements in the sample is illustrated with the following formula:

$$\overline{X}=\frac{\sum_{i=1}^{N}X_i}{N}$$

3. Estimate of natural tolerances is:

» With "symmetrical" characteristics:

$$T=K\cdot S,$$

» With "asymmetrical" characteristics:

$$T = \overline{X} + \left(\frac{1}{2} \cdot K \cdot S \right),$$

Where K is a constant that has different values depending on the size of sample N and it is given in table 2.

Table 2 — Correction factor values for calculating T

N	30	40	50	60	70	80	..	∞
K	7,8	7,5	7,3	7,1	7,0	6,9		6,0

Symmetrical characteristic is a characteristic whose variability can be symmetrically divided in relation to nominal value (it can have positive and negative values in relation to it, such as length, force etc.)

Asymmetrical characteristic is the one whose variability can be divided only asymmetrically in comparison to nominal value (it can have only positive values in relation to it and for example, form errors such as: roundness, eccentricity, etc.).

4. Determine DGR and GGR, i.e. minimum and maximum allowed value of nominal measure (according to specified tolerance)
5. Calculate machine capability index:

» when there is upper and lower tolerance limit,

$$C_m = \frac{T}{T_{prir}}$$

» in case when there is only one tolerance limit,

$$C_m = \frac{2 \cdot (X_o - DGR)}{T_{prir}}$$

$$C_m = \frac{2 \cdot (GGR - X_o)}{T_{prir}}$$

6. Calculate machine capability index:

» when there is upper and lower tolerance limit,

$$C_{mk} = \frac{2 \cdot Z}{T_{prir}}$$

where

$$Z = \min \left(\overline{X} - DGR;\ GGR - \overline{X} \right)$$

» when there is only one tolerance limit,

$$C_{mk} = \frac{2 \cdot Z}{T_{prir}}$$

where $Z = \overline{X} - DGR$ or $Z = GGR - \overline{X}$

7. Compare calculated values of C_m and C_{mk} with the values given in the table for testing machine capability based on C_m and C_{mk} depending on the level of importance of quality parameter in order to estimate machine capability, with consideration to the level of parameter relevance.

According to relevance quality parameters are classified as follows:

- critical, where impermissible deviation brings human lives in danger,
- primary, where impermissible deviation leads to stopping the basic function of the product,
- relevant, where impermissible deviation questions the compliance with legal regulations and
- secondary, where impermissible deviation leads to difficult usability of the product which results in dissatisfaction of the customers and disappointment because of failed expectations.

8. Global opinion on machine capability is the one that corresponds to the column that satisfies both C_m and C_{mk} values.
9. Based on the conclusions on capability it is possible to define the priorities of correction interventions that are to be applied for "conditionally capable machines" and the "incapable" ones.

Planned interventions are defined in the table control/actions to be undertaken depending on capability evaluation.

The following are possible interventions:

a) intervention of coherence of technical documentation (drawings, operation charts, etc) which involve the requirements for the technology to run a check of actual need for maintaining natural tolerance (T) and the potential for its expansion.

b) correction interventions on the machine that include maintaining or replacing the machines.

These corrections are predicted for the following situations:

» If the machine is “conditionally capable”

» When the machine is “not capable”

in case when it is not possible to change the regulations (see case a)

c) interventions on the control of the machine which include:

» Application of control charts $\overline{X}$ and R

» Occasional tests of variability in regular periods of time, machine capability.

5. RESULTS OF THE TEST OF MACHINE CAPABALITY FOR MECHANICAL PROCESSING BY USING QUANTITATIVE INDICATORS AND CONTROL CHARTS $\overline{X}-R$

In the actual example, the testing was conducted for the special machine type "ALFING" for fine processing of elevation ∅ 88,9 of K7 bearing of gear wheel for vehicle type GAMA "S" Data collection was performed consequently on 60 samples which from the statistical point of view is enough for the process capability study, but not enough for monitoring the course of the process with $\overline{X}-R$ control charts (it takes are least 125 measurements). For the sample to be representative from statistical point of view, the chart should be drawn again when there is enough data collected.

Based on the information about the process, the following data are entered in the programme:

- N=60 – number of samples,
- T=0,035 mm – specified tolerance,
- GGR=88,91 – maximum allowed value of the measured characteristic (upper limit),
- NOMVR=88,9 – nominal value,
- TPRIR= K*S – formula for calculating natural tolerance (NT),
- nPG=5 – number of member in the subgroup (for drawing up the control charts),
- Specified deviations go both ways
- Characteristic is symmetric,
- Characteristic is of primary relevance

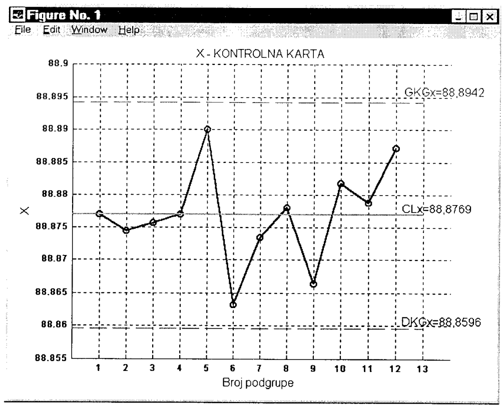
After the software application has processed the data, the results are shown in the command window:

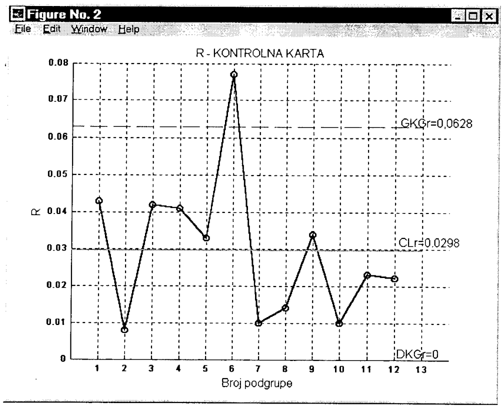
K=7,1
R=0,082
N=60
NOMVR=88,9
GGR=88,91
DGR=88,875
T=0,035
Xsr=88,8769
S=0,01477
Tprir=0,10487
Cm=0,33375
Cmk=0,036236
Cmin=0,036236

Graphic control charts are also shown on screen (Picture 1).

Using the software pack MATLAB for statistical analysis and graphic interpretation of observed process in narrow sense, the following conclusions have been made:

- Machine is “not capable”, while the percentage of defect work pieces is larger than 0,27% This can easily be shown with a simple analysis of measured values, where it can be noticed that more parameters fall out of the specified tolerance field. It is also noticed that the distribution is shifted towards lower tolerance limit (DGR), while impermissible deviations are below DGR. Capability and potential index values in given examples are as follows: Cm=0,33375, and Cmk=0,036236. These values point to necessary actions that should be undertaken as soon as possible in accordance with the table for testing the machine capability based on calculated C_m and C_{mk} indices depending on the level of relevance of quality parameter,





Picture 1. Control charts - graphics

- Observing $\overline{X}-R$ control chart it can be concluded that on R chart one point is out of control limits (6 subgroups), while on $\overline{X}$ chart there are no points out of control limits. There is no presence of shifting or trends, though the number of measurements is not enough to accept this conclusion as valid As it has already been mentioned, the basic principle is that the process is under control as long as the points on the chart are within control limits.. Since in the given example one point on R chart is out of control limits, it can be concluded that the process is "out of statistical control". The next step is determining the causes and after that undertaking activities in order to bring the process back under control. Furthermore it is necessary to test the process again in order to check the adequacy of undertaken measures, calculate new control limits and draw them on new control charts, and then repeat process analysis procedure.

6. CONCLUSION

Quality has more and more significance in the performance triangle: expense-time-quality. Increased quality demands require using methods for providing quality even before manufacturing process has started, already in the stages of creating the product.

CAQ systems provide generating quality according to consumers' needs, alongside integration of all other processes in one company.

The biggest benefit CAQ system brings is most certainly the fact that it enables successful managing of great amounts of data that appear in the field of ensuring quality, while it also provides information flow in an accurate and time-efficient manner, which would be unthinkable without using the computer data processing systems This justifies the efforts for procuring appropriate hardware and software platform in order to satisfy the new demands concerning integration of data processing system in the company.

Statistical Process Control (SPC) has a significant role in quality management. Characteristic of any real process is certain level of deviations that have specific or general causes. SPC's main task is to provide statistical indicators when there are specific causes of variations, but also to avoid sending wrong signals when there are only general causes. However, if the product was not designed properly in the very beginning (e.g. due to errors in design or installation), SPC cannot raise the level of quality.

Control charts, together with process capability study are high level tools for process control and they represent a combination of numerical and graphical methods in statistic process control.

Based on all above mentioned, it can be concluded that application of software tools in quality control has a big significance in terms of time-saving, accuracy and flexibility which finally results in quality improvement with reduced costs. However, we should bear in mind that improvement process is never complete. Having this in mind, efforts must be made in creating a universal software application for integration of programme and data.

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