BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi" din Iaşi
Volumul 66 (70), Numărul 1, 2020
Secţia
CONSTRUCŢII DE MAŞINI

USING THE SQC METHODOLOGY TO EVALUATE THE QUALITY OF PROCESSING AND PRODUCTS

BY

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Received: January 10, 2020
Accepted for publication: March 7, 2020

Abstract. Manufacturing quality assurance is one of the most important requirements of modern industry. In order to evaluate and control the quality of the manufacturing processes, it is necessary to define and measure some quality parameters. These, also called quality criteria or characteristics, are quantitative or qualitative properties used to highlight the quality requirements imposed on products and/or their components. In industrial practice these techniques are known as methods of statistical quality control of SQC. The main advantage of this method is to highlight in advance the trends that appear in the manufacturing process, which allows intervention in the process and its regulation before the appearance of non-compliant products. The most powerful tool is represented by the control charts that follow the evolution of the process in terms of centered and dispersion. Then the process capability will be determined by comparing its performance with the prescribed quality specifications. Based on a statistical analysis, it is possible to estimate a possible percentage of waste resulting from the process.

The paper reviews the main stages of application of statistical methods of process quality control, as well as the study of a concrete case of application of these methods.

Keywords: process; quality; evaluation; control chart; capability.

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1. Introduction

In the modern economy, quality is the key factor of the business, in order to maintain the position and the competitiveness on the market. Increasing customer satisfaction and continuous quality improvement should characterize the policy of each organization.

Improving quality aims to eliminate non-compliant products. This means reducing process variability. Statistical methods play an important role in assessing variability. The processes must be only under the influence of a normal, random variability, as small as possible. The strong variability, introduced by the so-called special causes of variation, which produce great disturbances of the processes, must be quickly identified and eliminated (Pyzdek and Keller, 2009).

Each product is defined by a multitude of parameters, called quality parameters. Each of these parameters varies randomly, so that two products will not be identical.

2. Quality Characteristics

Quality has a complex character, which is determined by the large number of qualities that the product must meet to be considered quality.

Quality characteristics are used to assess or evaluate quality.

The quality characteristics are extremely diverse. A classification of them is briefly presented below.

By nature, quality characteristics can be technical, economic or social.

According to the importance, the quality characteristics are divided into functional (basic, absolutely necessary, fundamental) and non-functional (secondary, minor).

According to the mode of expression, the following categories of quality characteristics are distinguished: measurable (directly measurable, indirectly measurable, comparable to a standard, psychosensory) and attributive.

According to the degree of generality, the quality characteristics can be specific to each product or common (reliability, durability, maintainability, availability, maintenance).

According to the direction of optimization, the quality characteristics can be: target, which must be met as accurately as possible, which must be maximized (benefits, sustainability, etc.) and which must be minimized (consumption, pollutants, etc.).

Before starting the process control, the quality characteristics that will be monitored must be established. In most cases, technical, functional and measurable characteristics will be chosen.

3. Statistical Process Control

The field of quality control adds a vast domain of knowledge and techniques, managerial and statistical, in order to control and ensure the continuous improvement of product quality (Oakland, 2003).

The basis of the statistical analysis is the determination of the numerical values of the main statistical parameters: arithmetic mean, median, dispersion, standard deviation, etc. This analysis aims to determine whether the distribution of characteristic values is close to the normal distribution. The next step is to calculate the statistical parameters. The purpose of statistical control is to keep the manufacturing process out of adverse influences that may disrupt the quality of manufactured products.

3.1. Tests for Sample Averages

Another way to check whether a distribution satisfies the condition of normality is to analyse whether it differs statistically significantly from the normal curve. The best known tests for this condition are Kolmogorov-Smirnov and Shapiro-Wilk (Montgomery, 2012).

In order to test the normality of the distribution, it is not necessary to take into account the results of both tests, but only one, the one from the test that is best suited to the sample size. The Kolmogorov-Smirnov test is used to test large data sets while the Shapiro-Wilk test is more suitable for a smaller sample, such as 50 numbers or less.

The analysis of the normality of the distribution can be done visually, by the method of histograms or by the method of the probability network.

For practical applications in process quality control, the central limit theorem can be used (Oakland, 2003). According to this, the distribution of the arithmetic mean of the samples will approach a normal distribution, especially since the samples have a larger size. Thus, the process average μ will be approximated by the average of the sample averages $\bar{\bar{x}}$ given by Eq. (1) and the standard deviation s will be given by Eq. (2).

$$\mu = \bar{\bar{x}} = \frac{\sum_{i=1}^{k} x_i}{k} \quad (1)$$

$$s = \frac{\sigma}{\sqrt{n}} \quad (2)$$

In Eq. (2) n is the number of pieces of samples. The value σ is the standard deviation of the population.

3.2. Control Charts

One of the most important tools of statistical process control is the control charts. Depending on the quality characteristics followed, control charts for attributes or variables can be used.

The control charts for variables, known as Shewhart charts, follow the evolution in time of a parameter that characterizes the process centred and of a parameter related to the dispersion. The most used are the charts for mean and range ($\bar{x}$, R) (Jensen *et al.*, 2006).

In the case of the mean chart, five horizontal lines are defined.

The centreline *CL* with the given value of Eq. (3), the upper action line *UAL*, located at *3s* from the centreline, with expression (4), the upper warning line *UWL* with expression (5), where *A* is a coefficient depending on the sample size.

$$CL = \bar{\bar{x}} \quad (3)$$

$$UAL = \bar{\bar{x}} + A\bar{R} \quad (4)$$

$$UWL = \bar{\bar{x}} + \frac{2}{3}A\bar{R} \quad (5)$$

Similarly, draw the lower warning line *LWL*, located at *2s* below the centre line, with the expression (6), and the lower action line *LAL* with the expression (7).

$$LWL = \bar{\bar{x}} - \frac{2}{3}A\bar{R} \quad (6)$$

$$LAL = \bar{\bar{x}} - A\bar{R} \quad (7)$$

In all these equations $\bar{R}$ represents the average of the amplitudes of the samples given by Eq. (8).

$$\bar{R} = \frac{\sum_{i=1}^{k} R_i}{k} \quad (8)$$

Similarly, the control chart for amplitude will be drawn, whose control lines are given by Eqs. (9)-(13), where D_1, D_2, D_3, D_4 are coefficients depending on the sample size.

$$CL = \bar{R} \quad (9)$$

$$UAL = D_1\bar{R} \quad (10)$$

$$UWL = D_2\bar{R} \quad (11)$$

$$LWL = D_3\bar{R} \quad (12)$$

$$LAL = D_4\bar{R} \quad (13)$$

During the manufacturing process, samples will be extracted at certain time intervals. The mean and range of each sample will be determined and the values will be marked on the control charts. Depending on the position of the points in front of the control lines, assessments and decisions will be made about the development of the manufacturing process.

3.3. Capability Index

The way in which the manufacturing process meets the prescribed quality requirements is appreciated by the capability index c_p , with the expression given by Eq. (14), in which *USL* represents the upper limit of the quality specification and *LSL* the lower limit.

$$c_p = \frac{USL - LSL}{6\sigma} \tag{14}$$

If the process is not centred, the capability index will be determined with Eq. (15).

$$c_{pk} = min\left\{\frac{USL - \mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right\} \tag{15}$$

4. Case Study

We analysed two machine tools that cut some steel semi-finished products to a length of 60 ± 0.5 mm. 25 samples consisting of four pieces were taken in the order of manufacture, and for each sample the arithmetic mean and range were calculated. The results are presented in Table 1.

Table 1
Experimental Results

Sample number	Machine I		Machine II	
	Mean	Range	Mean	Range
1	60.10	1.7	60.16	0.5
2	59.92	2.7	59.87	0.4
3	60.37	3.3	60.17	0.6
4	59.91	2.2	60.05	0.2
5	60.01	3.4	60.15	0.3
6	60.18	1.5	59.72	0.7
7	59.67	2.7	59.83	0.5
8	60.57	3.6	59.84	0.4
9	59.68	2.8	60.14	0.6
10	59.55	2.5	60.12	0.3
11	59.98	2.2	59.97	0.2
12	60.22	1.7	60.24	0.2
13	60.54	3.0	60.01	0.5
14	60.68	2.4	60.12	0.4
15	59.24	2.8	59.74	0.6
16	59.48	1.5	59.91	0.5
17	60.20	3.2	59.88	0.1
18	60.27	2.5	59.95	0.2
19	59.57	1.4	60.15	0.3
20	60.49	2.3	60.12	0.4
21	60.10	2.2	60.06	0.5
22	59.92	2.7	59.91	0.4
23	60.37	2.1	60.12	0.6
24	59.91	3.0	60.05	0.2
25	60.03	0.9	59.97	0.6

With the Eqs. (3)-(13) the values for the control lines were calculated. The results are presented in Table 2.

Table 2

Control Lines Values

Lines values	Machine I		Machine II	
	Mean chart	Range chart	Mean chart	Range chart
Upper action line	61.80	6.19	60.31	1.05
Upper warning line	61.21	4.65	60.21	0.79
Central line	60.04	2.41	60.01	0.41
Lower warning line	58.86	0.69	59.81	0.12
Lower action line	58.28	0.24	59.71	0.04

With these values the control charts presented in Figs. 1-4 was drawn.

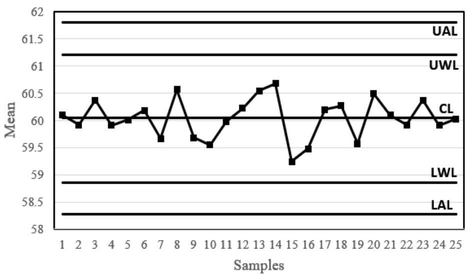

Fig. 1 – Machine 1 control chart for mean.

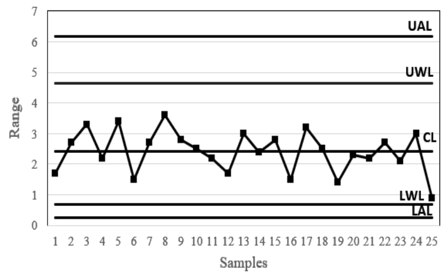

Fig. 2 – Machine 1 control chart for range.

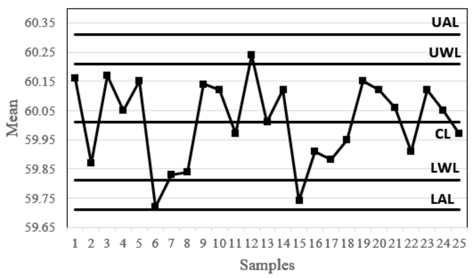

Fig. 3 – Machine 2 control chart for mean.

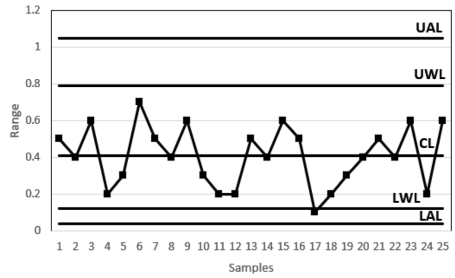

Fig. 4 – Machine 2 control chart for range.

In Fig. 1 is shown the control chart for the mean of machine 1. It is observed that the process is under control, none of the control lines being violated. There is a warning signal, represented by the trend formed by samples 10-14.

Fig. 2 shows the range control chart for machine 1. It is observed that the process proceeds under control. Samples 8-12 can be a signal of attention, but only from a theoretical point of view, the meaning being to increase the accuracy of the process.

In Fig. 3 is presented the control chart for the mean for machine 2. It is observed that the process is generally under control, being present some attention signals, represented by samples 6, 12, 15.

Fig. 4 shows the range control chart for machine 2. It is observed that the process proceeds under control. There is a warning signal, represented by the trend formed in samples 17-21.

In order to have a complete picture of the process, the capability index will be determined for each machine with the Eqs. (14)-(15). It will also be estimated the proportion of defects produced with the Eqs. (16)-(17), in which Z represents the number of standard deviations between mean and the specification limit.

$$Z_1 = \frac{USL-\bar{x}}{\sigma} \tag{16}$$

$$Z_2 = \frac{\bar{x}-LSL}{\sigma} \tag{17}$$

The results are shown in Table 3.

Table 3

Calculated Values for Capability Index and Defective Proportion

Calculated values	Machine 1	Machine 2
σ	1.17	0.20
c_p	0.142	0.83
c_{p1}	0.131	0.81
c_{p2}	0.153	0.85
Z_1	0.393	2.45
Z_2	0.461	2.55
D_1	34.8%	0.71%
D_2	32.3%	0.53%
D_t	67.1%	1.24%

5. Conclusions

The statistical analysis allows a precise evaluation of the way in which the production process takes place. Although the processes carried out by the two machine tools are statistically stable, they do not meet the prescribed quality specifications. Thus both machines will produce parts outside the specified limits. In the case of machine 1 there is an adjustment error, the average process being 60.04 mm. But the machine tool suffers in terms of accuracy, the dispersion being very large. A percentage of approx. 34.8% of the production will be located above the upper limit of the specification, and a percentage of continued production on a machine with a percentage of scrap of 67.1% is unacceptable. The machine must be stopped immediately and actions must be taken to identify and remedy the causes of quality problems. Regarding machine 2, the situation is a bit better, the percentage of scrap being 1.24%. However, in this case too, quality improvement actions should be started because the situation can get worse very easily.

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UTILIZAREA METODELOR SQC PENTRU EVALUAREA CALITĂȚII PROCESELOR ȘI A PRODUSELOR

(Rezumat)

Asigurarea calității fabricației este una dintre cele mai importante cerințe ale industriei moderne. Pentru evaluarea și controlul calității proceselor de fabricație sunt necesare definirea și măsurarea unor parametri ai calității. Aceștia, numiți şi criterii sau caracteristici de calitate, sunt proprietăţi cantitative sau calitative folosite pentru evidenţierea cerinţelor de calitate impuse produselor şi/sau componentelor lor. În practica industrială aceste tehnici sunt cunoscute ca metode ale controlului statistic al calității SQC. Avantajul principal al acestei metode este de a evidenția din timp tendințele care apar în procesul de fabricație, ceea ce permite intervenția în proces și reglarea acestuia înainte de apariția produselor neconforme. Cel mai puternic instrument este reprezentat de fișele de control care urmăresc evoluția procesului din punct de vedere al reglajului și al dispersiei. Apoi se va determina capabilitatea procesului prin compararea performanțelor acestuia cu specificațiile de calitate prescrise. Pe baza unei analize statistice se poate estima şi un eventual procent de rebut rezultat din proces.

În lucrare sunt trecute în revistă principalele etape de aplicare a metodelor statistice de control a calității proceselor, precum și studiul unui caz concret de aplicare a acestor metode.