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N. I. Zayats, PhD (Engineering), assistant professor (BSTU)
Yu. N. Khrol, assistant lecturer (BSTU)

STATISTICAL PROCESS CONTROL

Statistical process control methods and possibility of their use to solve quality problems of the output products have been discussed in the article. Variability of the technological process and its effect on the output products quality have been characterized. Situations which claim interference in the technological process have been described. Different types of Shewhart control cards have been considered: simple control cards by variables and alternative attributes, cards with warning boundaries, cumulative sums cards, exponentially weighed moving averages cards. Besides univariate control cards, Hotteling multivariate control cards and cumulative sums cards which are used to control multi-parameter technological process are discussed in the article. Fields of application of different types of control cards are described.

Introduction. Increase of the technical and organizational levels of the production process based on large-scale implementation of modern advanced technologies, technological equipment, forms of production organization and wide use of international standards ISO 9000 is the basis of solving the production quality problem.

The standards ISO 9000 focus on the process approach to quality control and the use of statistical methods for valid decisions making at all stages of the product life cycle. In accordance with the standard requirements, the organization must plan and implement the monitoring, measurement, analysis and improvement processes which are necessary to demonstrate processes compliance, continuous rise of efficacy, quality management system, etc. using appropriate techniques, including statistical ones.

Laying particular emphasis on such processes as measurement, analysis and continuous perfection of functioning processes, standard ISO 9000 induces organizations to use statistical process control methods. This is due to the fact that international experience gained over many decades, has shown high efficiency of statistical methods to solve problems in manufacturing, service and other areas.

The success and relevance of statistical process control methods is explained primarily by economic reasons. Thus, the first publications in the 40-s of the last century reported about repeated lowering of rejects and loss of cash due to statistical methods. For example, the use of statistical methods by Motorolla allowed to reduce the amount of rejects and financial losses more than twofold at the assembly plant; the implementation of statistical methods allowed to low the defect rate from 8,000 to 500 ppm at the Russian enterprise "Instrum-Rand" within six months [1].

However, statistical methods are still not widely used both at the enterprises of our country and at Russian enterprises. Russian scientists think that there are many reasons for this:

– Ignorance of the modern approach towards process improvement by the first persons of the state (and sometimes a lack of desire for improvements);

– The apparent complexity of the process control statistical methods, leading to their a priori alienation;

– Lack of information by the staff in the sphere of statistical process control methods, which does not afford to use them properly in practice and to interpret the obtained results correctly;

– The presence of a large number of publications, overloaded with complex mathematical calculations, which makes them difficult to be understood by practicing engineers [1].

Main part. Statistical Process Control, or *SPC,* is a continuous improvement of processes methodology based on statistical thinking and variability theory, which uses simple and effective techniques to analyze and solve problems [2]. Seven traditional statistical process control methods (the so called "simple quality tools") are widely used and refer to such simple and effective techniques. These seven methods are: checklists, Pareto diagrams, cause-and-effect diagrams (Ishikawa diagrams), histograms, stratification (layering), scatter diagrams, control cards.

Currently, these methods have been further developed, standardized and are recommended for use in order to improve quality as well as to detect and analyze emerging and existing problems (Fig. 1) [3].

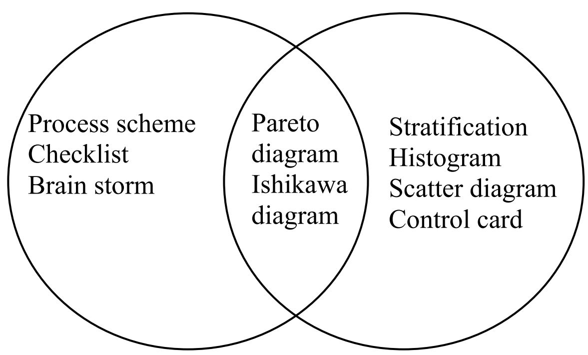

Fig 1. Sphere of application of quality "tools":
1 – problem identification; *2* – problem analysis

From the above mentioned statistical methods, control cards which were first proposed by W. Shewhart in 1924 are a practical tool to decide the necessity of interfering into the technological process.

Two types of variation causes of a technological process are considered in the control cards theory. One group of causes is connected with the peculiarities of the process: tool runout, machine disorder, change of the components quality, deviation from the technological process, etc. These are all assignable causes and they can be eliminated while aligning the process. Another group are common accidental causes of the process variability due to the action of different chance causes.

Continuous improvement of the process is to reduce the impact of accidental causes and to exclude the assignable ones.

Shewhart control cards allow to detect the presence of assignable process variability causes. Control card (control chart) (CC) is a graphic representation of the technological process dynamics, allowing to detect the problem at the moment of its occurrence in a real time. Measurement number and time are laid off as abscissa on the control cards. Statistics calculated according to the periodic sampling control results is laid off as an ordinate on the control cards (*X* , *S, R, Me,* etc.). Statistics way out beyond the control boundaries confirms the technological process way out from the state under statistical control (Fig. 2). Lower and upper control limits (LCL and UCL, respectively) are carried out on CC at a distance of three standard deviations (± 3σ). In this case, 99.73% of all the measured parameter values will be within the control limits of the process in a stable condition which obeys the normal law. Boundaries ± 3σ are boundaries of the internal variability resulting from the assignable causes determined by the preliminary results of the technological process researches [4].

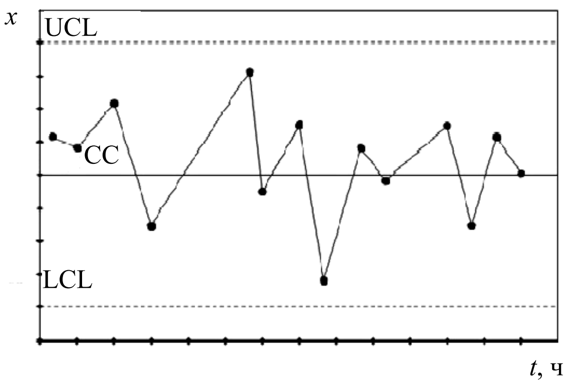

Fig. 2. General view of a control card (chart)

Obviously, the technological process will be suitable to meet the consumer requirements if: 1) he is in the state under statistical control (i.e. within ± 3σ) and 2) the inherent internal variability of the process will be lower than the determined manufacturing tolerance.

Continuous Shewhart control cards analysis helps to monitor the technological process state. Moreover, any process can be in one of the following four states.

1. Perfect condition (the process is completely statistically controllable, all products meet the specific tolerances, the natural variability of the process is less than the specified permissible limits).

2. Threshold state (the process is sufficiently controlled, but a number of defective goods is produced). To terminate the output of defective goods it is necessary either to increase tolerance (by consent of the consumer) or to lower variability and to improve the process.

3. Process state "on the brink of chaos" (the process is not statistically controlled: even though the total output meets tolerance conditions by 100%, the process can get out of control at any moment).

4. State of "chaos" (the process is out of control, defective goods are produced).

There is no need to interfere with the course of the process if it demonstrates controlled variability which provides compliance of the manufactured products with the specified requirements, i.e. the process is stable and reproducible, However, if the process variability in the controlled state does not provide product compliance with the requirements, i.e. the process is stable, but is not reproducible, the process variability can be reduced only by changing the process itself.

It is necessary to identify and eliminate a specific cause of variability, i.e. local interference in the process is required, if the process demonstrates uncontrolled variation, i.e. it is not stable.

To date, a number of different types of control cards shas been developed [5]. To improve the controlled process and for the sake of effective diagnosis it is recommended to select the appropriate control cards. Depending on the type of the control, control cards are divided into two groups: quantitative attributes and qualitative (alternative) attributes.

The following types of control cards are used according to the quantitative (measured) attribute: arithmetical average cards (*X*); medians (*Me*); individual values cards (*X*); ranges cards (*R*); mean square (standard) deviations cards (*S*); moving ranges cards (R_1) [6]. The first three types of cards follow the position of the center, and the rest - the dispersion of the investigated parameter. Double control cards that provide simultaneous control of these two parameters are used more often. Today, the most widespread combinations of double control cards according to their quantitative attribute are: average values and ranges cards; medians and ranges cards; individual values and moving range cards [6].

A number of units inappropriate with the specified requirements or sample inadequacies are determined using alternative attribute control. As a result the following control cards are built: inappropriate units number cards (pr), inappropriate units fraction cards (p), inadequacies number cards (c), and inadequacies number per one unit cards (u).

In addition to these Shewhart simple cards more complex types of control cards are used nowadays: cards with warning boundaries and cumulative sums cards. These cards are more sensitive towards the process imbalance.

Control cards with warning boundaries are cards, which besides regulation boundaries have warning boundaries (usually ± 2σ). The process is considered to be statistically out of control when statistics values are away beyond control limits and when several values successively get in between control and warning boundaries.

Cumulative sums control cards are based on the sequence analysis methods. They are used to detect a small shift of the process. The sum of average deviations from the target is used as controlled statistics i.e. $\sum(\overline{X}-\mu_0)$. To interpret control cards of cumulative sums two ways are used: graphic – V-masks and numerical – dwelling time (Paget Scheme) [7].

Exponentially weighed control cards of moving averages based on the exponential smoothing are used along with the cumulative sums control cards to detect small constant process shifts [7].

All of these cards are univariate, i.e. they are single attribute quality cards. However, product quality is often characterized by several factors. In this regard, more complete information about the stability of the technological process can be obtained by using multivariate methods of statistical process control MSPC (Multivariate Statistical Process Control).

Cumulative usage of Shewhart univariate cards is considered to be effective if controlled indexes are uncorrelated. If the quality indexes are correlated, the use of Shewhart cards cannot give an objective assessment of the state of the technological process. Shewhart cards on the principal components or Hotteling multivariate control cards are recommended to use for these purposes [7].

Hotteling multivariate control card is in fact the same as the Shewhart control card, in which generalized Hotteling statistics T^2 is used:

$$T^2 = n(\overline{X_t} - \mu_0)S^{-1}(\overline{X_t} - \mu_0),$$

where n - sample volume; $\overline{X}_t$ – vector of averages in instantaneous samplings; μ_0 – vector of targeted averages; S – sample estimate of covariance matrix.

Hotteling control cards with warning boundaries allow to increase (by 10–23%) control sensitivity towards process breakdown significantly [7].

Several versions of the cumulative cards generalization are suggested for the quality assessment of the multi-parameter technological process. In particular, in order to control p quality indexes W. Wooden and M. Ncube proposed to use the appropriate numbers of univariate cards of cumulative sums for each index [8].

Two cumulative multivariate procedures are proposed by S. Crozer. T-statistics (square root from Hotteling statistics T^2) is determined and these statistics accumulated sum is built for each observation in the COT scheme (CUSUM of T).

The scheme in which initially cumulative sums for each of p quality indexes are determined, turned to be more effective. Further T-statistics is built according to these sums [9].

Conclusion. Thus, nowadays quite enough number of statistical tools has been developed to analyze and regulate both one-parameter and multi-parameter processes allowing to make the optimal choice according to the specific conditions of the technological process in order to maximize detection efficiency of the expected process breakdown.

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