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USE OF STATISTICAL REGULATION IN MAINTENANCE PROCESSES

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Abstract:

In a submitted paper we are going to deal with possibilities in using statistical instruments and methods of product quality management and with application of simulation modeling in production and maintenance introducing procedures on examples being solved in mechanical engineering companies in Slovakia.

1 Introduction

1.1 Manuscript preparation

The most widely used are in operative quality management. Seven basic Instruments enable solving problems of quality improvement in manufacturing areas from a condition determination through production sheets, through looking for ways and possibilities of their solution up to a statistical regulation of improved processes [1]. The basic Instruments include a check list, a histogram, causes and consequences diagram, Paret´s analysis, correlation diagram, flowchart and a regulation diagram. These Instruments have been used also in solving a defined aim of the work. Significance and importance of use of statistical Instruments and quality management methods in processes when welding a connector on a copper wire of glued carbon brushes in an unnamed company [2].

2 Basic classification of statistical methods

2.1 Basic Information

The concept of stability is derived from the systems theory. Several different definitions of the system stability can be found in the literature. Most of them refer to the concept of the point/state of balance and define the stability of a system as its ability to return to the state of balance after the disturbances that caused the instability have ceased. The stability of a production system will be understood as maintaining the steady state of the system for a certain assumed period.

The statistical methods and instruments used in an industrial practice can be divided in three categories:
1. simple (basic, elementary) statistical methods,
2. medium demanding statistical methods,
3. more demanding statistical methods [3].

Simple methods include seven instruments:
- check tables and recorders, histogram, flowchart, correlation diagram, Paret´s analysis, causes and consequences chart (Ishikawa´s diagram) and regulation diagrams.

Medium demanding and more demanding statistical methods include e.g.:
- Analysis of a measuring system, verification of a manufacturing equipment capability, verification of a process capability, statistical inspection, FMEA [4].

Quality control can be defined by STN EN ISO 9000:2005 as a part of quality management aiming to meet the quality requirements.

Statistical quality control is a part of a quality management, in which the procedures of mathematical statistics are used. There are three basic areas of a statistical quality control:
- statistical process regulation
- statistical (selective) inspection
- methods of experiment designing.

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In the process the inputs are transformed to a product, on which the quality characteristics and quality indicators can be defined. Main problem of quality improvement is a reduction of variability of quality indicators values. Usually the variability of values of quality indicators can be reduced based on obtained results and to find such combination of levels of variables being controlled, that optimizes a process performance. After having indicated the most important variables, having effect on a process, often it is very useful to simulate relations between input variables and quality indicators of the product. When we know character of relations between variables, the techniques of a statistical regulation of the process can be applied in an effective way – one of an instrument of a so called on-line quality control, enabling monitoring of a process and maintaining it in a requested condition. A process of an implementation of methods of a statistical quality control in organizations usually starts by applying a statistical inspection (it relates a selective inspection, when a decision is taken, whether a batch is to be accepted or not based on results from selection or selections made from this batch), and goes on by implementation of a statistical regulation in a process and then often the methods of experiment designing start to be applied [5].

Based on these facts and after consultation in a company the following conceptual and simulation model has been proposed. The simulation model of a working place is composed of a set of three production machines, containers and conveyors for parts with random period intervals between failures, time period of a maintenance provided by repairmen. The machines process the parts with random intervals of manufacturing operations. To simplify a model the personnel servicing the machines is not depicted.

2.2 Statistical regulation of processes

Statistical regulation of a process is a set of instruments for maintaining a process stability and improvement of its capability through a reduction of variability. A fundamental question in an organization aimed at the quality is a question, to which extend is it capable to meet the expectations of the customers. When the expectations of the customers are defined, it is necessary that the supplier is able to quantify an extent he can satisfied such expectations. A product, which should be appropriate for a use, should be generally produced in a stable or a repeatable process. It means that a process should be able to produce products with an acceptable variability of defined indicators of quality in terms of their defined aims or values.

Statistical regulation of a process represents a preventive approach to a quality management, as it enables interventions into a process based on a timely detection of variations in a course of a process aiming to keep it for a long-time on a requested and stable level. Achieving and keeping a process on a requested and stable level is dependent on a comprehensive analysis of process variability, when it is needed to detect, how the process functions, what are its limitations and their reasons, whether they repeat and what kind of affect do they have on a process. So a statistical regulation of a process can be defined as an immediate and continuous control of a process, which is based on a mathematical-and-statistical assessment of product quality. It provides information for operative and timely interventions into a process [6].

Basic principle of an analysis and improvement of processes and systems, defined by W. Shewhart is based on a presumption, that variability of values of quality indicators are caused by two kinds of causes:

- Random causes; the causes being a permanent part of a process or a system and that influence all components of the process.
- Definable causes; the causes that are not a permanent part of a process or a system; however they come into being due to specific circumstances.

A process or a system, which is affected only by random a cause is called a stable process, it means, that it is in a statistically managed condition. Only natural variability is involved in a stable process or in its products. It means, that a variability of output values can be predicted in statistically defined limits. A process, whose outputs are influenced by random as well as definable causes is called a non-stable process, it means, that it is in a statistically non-mastered condition. It is called non-stable as variability on various time sections is non-predictable. When the definable causes are identifiable and they are removed, the process becomes stable [6].

3 Determination of a statistical stability of a manufacturing process

Statistical process control (SPC) is a method of quality control which employs statistical methods to monitor and control a process. This helps to ensure that the process operates efficiently, producing more specification-conforming products. In manufacturing, quality is defined as conformance to specification. However, no two products or characteristics are ever exactly the same, because any process contains many sources of variability. In mass-manufacturing, traditionally, the quality of a finished article is ensured by post-manufacturing inspection of the product. Stability of a manufacturing process means a capability to observe technical and technological regulations and specified limit values in a certain time period. Aiming to reveal the causes why the process is violated, therefore it is necessary to deal with such analysis enabling to reveal and eliminate them. SPC uses statistical tools to observe the performance of the production process in order to detect significant variations before they result in the production of a sub-standard article. There are many methods and techniques for system modeling, while a broad range of advanced IT packages for process modeling is available in the market. Statistical analysis and a process regulation are interlinked and at the same time they influence stabilization of a manufacturing process in three phases.

- Definition of an instability of a manufacturing process,
- Introducing a process from instable into a stable condition,
- Keeping a process in a stable condition [7].

A regulation diagram ($\bar{x}, R$) for a diameter and a range was used to define an instability of a manufacturing process, which is one of the most widely used regulation diagrams due to its simplicity. An essence of this diagram is a superior sensibility to revealing of extreme values within a subgroup.

The diagram predicates about stability or instability of a monitoring process, i.e. whether the process has been mastered. Aiming to define a stability of a requisite amount of 125 products within 2 hours time intervals the subgroups consisting of 5 products were sampled being assigned for an analysis. Value from processing of a descriptive statistics for a mean value and a range is presented on the table (Table 1). The values of the measured quantity enter the assessment process, arranged in ascending order according to individual groups. Descriptive statistics offer us maximum, minimum and mean values.

Table 1 Table of a descriptive statistics for a mean value and a range

Variable	Desccriptive statistics			
	Mean	Minimum	Maximum	Range
Subgroup 1	43,26	43,12	43,36	0,24
Subgroup 2	43,24	43,18	43,31	0,13
Subgroup 3	43,17	42,99	43,32	0,33
Subgroup 4	43,19	43,11	43,38	0,27
Subgroup 5	43,26	43,16	43,37	0,21
Subgroup 6	43,15	43,03	43,28	0,25
Subgroup 7	43,25	43,16	43,33	0,17
Subgroup 8	43,21	43,11	43,31	0,20
Subgroup 9	43,19	43,04	43,29	0,25
Subgroup 10	43,23	43,11	43,35	0,24
Subgroup 11	43,14	43,04	43,25	0,21
Subgroup 12	43,17	43,07	43,24	0,17
Subgroup 13	43,22	43,01	43,39	0,38
Subgroup 14	43,15	42,99	43,27	0,28
Subgroup 15	43,23	43,14	43,36	0,22
Subgroup 16	43,17	43,05	43,36	0,31
Subgroup 17	43,27	43,20	43,34	0,14
Subgroup 18	43,09	42,98	43,18	0,20
Subgroup 19	43,21	43,11	43,37	0,26
Subgroup 20	43,18	43,05	43,23	0,18
Subgroup 21	43,18	43,08	43,30	0,22
Subgroup 22	43,21	43,17	43,26	0,09
Subgroup 23	43,17	42,97	43,32	0,35
Subgroup 24	43,14	43,00	43,19	0,19
Subgroup 25	43,20	43,09	43,30	0,21

Analysis of stability of a manufacturing process:

The data measured were analyzed using the Palstat software. Its main task is a computer aided support to a statistical regulation of a process, monitoring and taking measures of processes, verification of processes and machines capabilities. It facilitates a definition, which remedies are to be implemented in a process in order to achieve its stability and so cost reduction as well due to defectiveness. Value from processing of using the Palstat software are preseted in the figure 1.

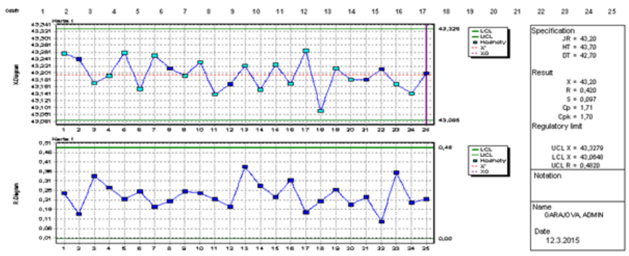

Fig. 1 Histogram and critical value of a testing statistics at exponential distribution [own resource]

It stems from a regulation diagram for a mean and a range that a process is statistically mastered. Regulation limits were exceeded in neither case, so the process appears as a stable one. We can say that a regulation diagram for this particular process had been properly chosen [7]. Information about a fact, whether the values of an attribute sufficiently approach a normal distribution was obtained through an analysis of values plotted into a probability grid.

Result of normal distribution test is shown in the figure 2.

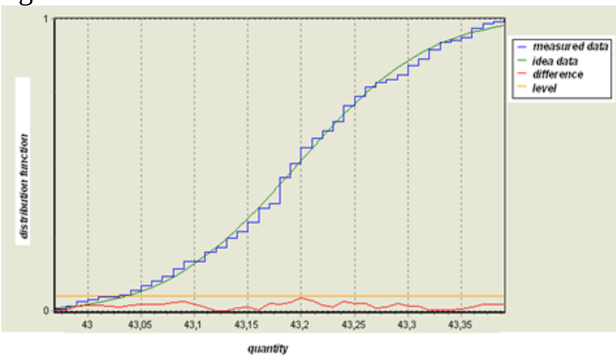

Fig. 2 Normal distribution test

A green line suggests ideal values and a blue line points at real measured values. A red line shows a difference in terms of significance of measured values. Resulting values are presented in the figure 3.

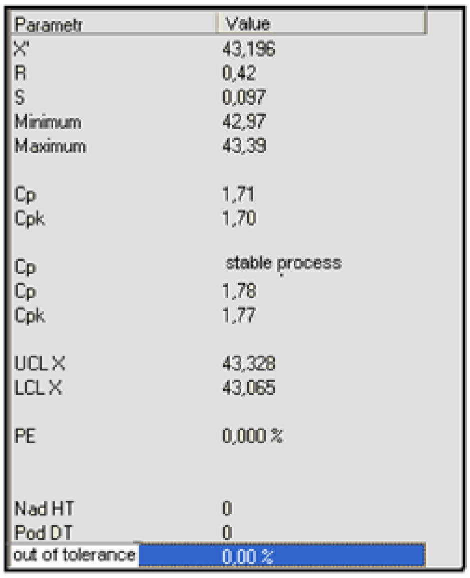

Fig. 3 Assessment of SPC analysis

SPC is method of measuring and controlling quality by monitoring the manufacturing process. Quality data is collected in the form of product or process measurements or readings from various machines or instrumentation. The data is collected and used to evaluate, monitor and control a process. SPC is an effective method to drive continuous improvement. Statistical Process Control is based on the analysis of data, so the first step is to decide what data to collect. There are two categories of control chart distinguished by the type of data used: Variable or Attribute. It stems from resulting analyses that a particular process of welding a connector onto a copper line of a carbon brush is stable, so the customer´s requirement was met; it means that series production can be started. Then we acted upon a check plan. In the next part we were focused on a saw production line, where the dimensions of pieces cut away are collected with a slide gauge with a digital display, which is considered as an objectionable in terms of number of faulty pieces.

In addition to an improved manufacturing process through an implementation of a SPC method, we planned to adopt a new measuring method on a given line. As we can see in the table thereinafter, we analyzed measurements in three operators, who had taken measures of a cutting angle in ten products with three repetitions. Resulting values are presented in the table 2.

Table 2 Analysis of measurements operators

	operator A			operator B			operator C		
	1st series	2nd series	3rd series	1st series	2nd series	3rd series	1st series	2nd series	3rd series
1	89,341	89,016	89,825	90,033	90,175	91,133	91,100	89,791	90,525
2	89,692	88,908	89,333	89,691	90,400	89,566	90,300	91,041	90,691
3	88,691	88,891	89,175	89,566	90,358	89,366	89,883	90,441	90,066
4	89,716	90,441	89,066	89,491	90,400	89,858	89,283	89,975	89,991
5	89,491	90,258	89,091	89,375	90,200	90,973	89,033	89,941	89,750
6	89,550	90,083	89,300	90,116	89,725	88,866	90,366	90,025	90,583
7	89,558	89,966	88,883	90,350	89,116	89,750	89,983	90,775	90,558
8	89,575	89,975	89,708	88,800	90,383	89,066	91,008	90,208	90,583
9	88,858	88,608	90,100	90,008	90,073	89,325	90,841	90,200	90,075
10	88,891	89,850	89,916	90,316	90,666	90,483	90,033	90,600	89,966

We used a measuring system analysis (MSA), to define a capability of that particular measuring gauge, namely through indicators of repeatability and reproducibility. MSA is defined as an experimental and mathematical method of determining the amount of variation that exists within a measurement process. Variation in the measurement process can directly contribute to our overall process variability. A measurement systems analysis (MSA) is a thorough assessment of a measurement process, and typically includes a specially designed experiment that seeks to identify the components of variation in that measurement process. The analysis of this measuring method is based on tolerance. Acceptable tolerance range of a cutting angle is 91,5 up to 88,5 degrees and a mean required value has got 90 degrees. In the under mentioned table there are situated the measured values expressed as a variance, or a discrepancy from a mean value and characteristics for computation of required indicators

Resulting values are presented in the table 3. The data are from the monitored production process

where:
R – range of values in particular operators
R – a mean of value ranges
X – a mean of measured values

Table 3 Table of a descriptive statistics

	operator A									
	1	2	3	4	5	6	7	8	9	10
1 series	-0,659	-0,308	-1,309	-0,284	-0,509	-0,450	-0,442	-0,425	-1,142	-1,109
2 series	-0,984	-1,092	-1,109	0,441	0,258	0,083	-0,034	-0,025	-1,392	-0,150
3 series	-0,175	-0,667	-0,825	-0,934	-0,909	-0,700	-1,117	-0,292	0,100	-0,084
R_A	0,809	0,784	0,484	1,375	1,167	0,783	1,083	0,400	1,492	1,025
$\bar{R}_A$	0,940	$\bar{X}_A$	-0,541							
	operator B									
	1	2	3	4	5	6	7	8	9	10
1 series	0,033	-0,309	-0,434	-0,509	-0,625	0,116	0,350	-1,200	0,008	0,316
2 series	0,175	0,400	0,358	0,400	0,200	-0,275	-0,884	0,383	0,073	0,666
3 series	1,133	-0,434	-0,634	-0,142	0,973	-1,134	-0,250	-0,934	-0,675	0,483
R_B	1,100	0,834	0,992	0,909	1,598	1,250	1,234	1,583	0,748	0,350
$\bar{R}_B$	1,060	$\bar{X}_B$	-0,079							
	operator C									
	1	2	3	4	5	6	7	8	9	10
1 series	1,100	0,300	-0,117	-0,717	-0,967	0,366	-0,017	1,008	0,841	0,033
2 series	-0,209	1,041	0,441	-0,025	-0,059	0,025	0,775	0,208	0,200	0,600
3 series	0,525	0,691	0,066	-0,009	-0,250	0,583	0,558	0,583	0,075	-0,034
R_C	1,309	0,741	0,558	0,708	0,908	0,558	0,792	0,800	0,766	0,634
$\bar{R}_C$	0,777	$\bar{X}_C$	0,254							

Analysis of the process capability was performed based on data obtained from regulation cards filled in with a sufficient ranges of values. Statistical Process Control is based on the analysis of data, so the first step is to decide what data to collect. There are two categories of control chart distinguished by the type of data used: Variable or Attribute. Statistical process control was developed as a feedback system that aids in preventing defects rather than allowing defects to occur. One element of a process control system is control charts.

Variable data comes from measurements on a continuous scale, such as: temperature, time, distance, weight. Attribute data is based on upon discrete distinctions such as good/bad, percentage defective, or number defective per hundred. We drew the above mentioned regulation diagram for a median and a range so that we can analyze a particular process. We can see from diagrams, that in the process there are no definable causes and it is statistically mastered. So additional requirement for analyzing of the process capability was met. Analysis through SPC regulation diagrams is shown in the figure 4.

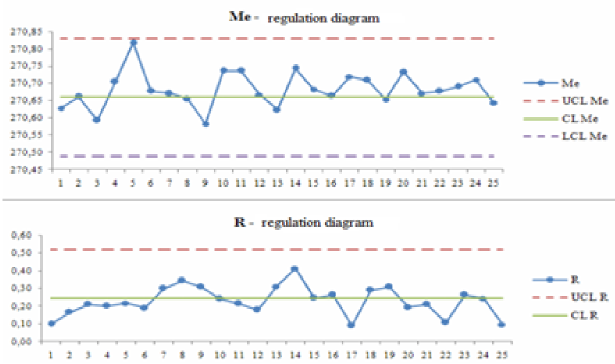

Fig. 4 Analysis through SPC regulation diagrams.

Computation of the indexes of process capability
Based on the same data as we had drawn regulation diagrams, we compute a capability index Cp, which expresses what we are able to achieve and Cpk, showing us a fact – what we had achieved and therefore a fact about the process condition. We analyzed a capability of this particular process using Minitab 12 software for Windows results of which are stated hereinafter in the figure 5.

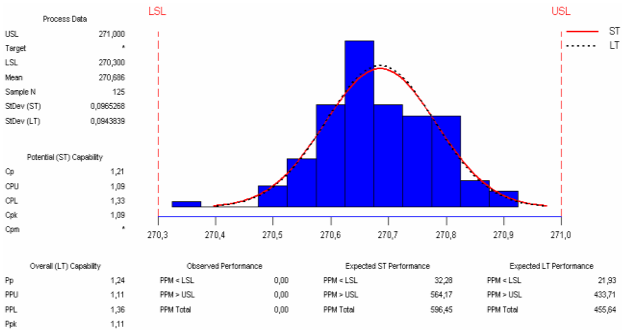

Fig. 5 Assessment of an analysis through a histogram

Another suitable approach that is appropriate to assess the processes in the company by means of mathematical analysis is a tool Histogram and critical value of a testing statistics at exponential distribution. Histograms are graphs that display the distribution of your continuous data. They are fantastic exploratory tools because they reveal properties about your sample data in ways that summary statistics cannot. The histogram shows sample data. On the other hand, the customized distribution line will try to find a probability distribution function for monitored quantity that has the maximum probability of creating a distribution that exists in monitored sample. It is well known that, the exponential distribution is one of the fundamental lifetime models and is widely used for describing a failure mechanism of a system. Applications of this distribution in survival analysis and reliability theory are presented in statistical literature. Therefore, there is a clear need to check whether the exponential distribution is a reasonable model for the observations.

Testing statistics χ^2 = 8,54. A critical value of χ^2 distribution in such case has a value of χ^2 < χ^2<0,95,4=13,124. So $\chi^2 < \chi^2_{0,95,4}$. As a testing statistics is smaller than a critical value of χ^2 distribution, H_0 on a significance level α=0,05 is not refused and therefore we can note with credibility 0,95 that a time period between failures is a random variable, which has an exponential distribution. The elements is presented in the figure 6.

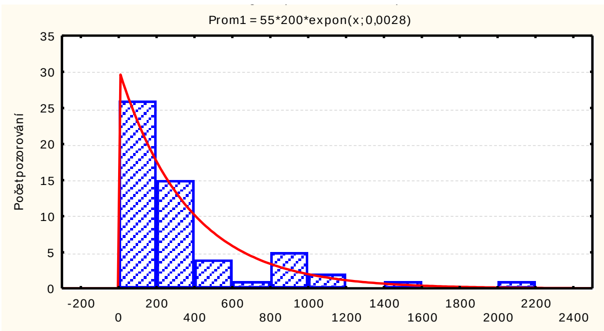

Fig. 6 Histogram and critical value of a testing statistics at exponential distribution

4 Results and discussion

The above mentioned methods were developed in real conditions of a company, which its manufacturing area concentrated into production of carbon materials, semi-finished products and finished pieces. It has been acting in electrical engineering, mechanical engineering, transport, automotive industry, chemical and metallurgical industry etc.

5 Conclusion

When performing an analysis in presented outputs we can note, that the processes are statistically mastered, but a prediction tool is missing for a maintenance crew intervention that should in an appropriate way to influence a next development. Statistical processing of data provides us with a basic for an analysis of a present condition, which is a base for predicative measures. In practice, it is very advantageous to use modeling and simulations based on the obtained statistical data using SPC. Simulation and evaluation predict the process and we do not have to spend money on failures or adverse events that would actually occur. Operations performed on a model instead of the actual production system do not disturb the stability of production processes. Treating a model as a duplicate of the actual system enables, inter alia, the transfer of the conclusions from the studies performed on the computer model to the actual production system. The use of statistical analysis methods allows us to predict in which direction the monitored processes will go. The article presents several possibilities of using SPC analyzes, which were performed in the past in various companies in order to improve maintenance processes.

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