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Using control charts X-R in monitoring a chosen production process

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ABSTRACT

Purpose: A new approach to production process monitoring in organization using control chart type X-R has been presented.
Design/methodology/approach: The possibility of use of basic element of Statistical Process Control (SPC method) is connected with continuous quality improvement of each production process in an enterprise. Interdependence of the quality research methods and production process's requirements have been taken into account.
Findings: At the present time the metallurgical enterprises should integrate quality management system and quality control with customer's requirements, with defined both parameters of processes and quality methods. Such kind of strategy will enable to achieve success for these companies.
Research limitations/implications: Control chart type X-R is very important quality tool. Its determined statistical measures are recorded properties of product obtained as a result of inspections taking randomly samples of products in the determined place of the process. Aim of control chart type X-R is observation and registration of the changeability of the characteristic of the researched element of the production process.
Practical implications: The example of implementing control chart type X-R shows possibility of monitoring chosen parameters of production process according to an idea of defect prevention. Usage of this method allows for monitoring of production process, providing opportunities for cost reduction, and maintaining of production process stability.
Originality/value: Application of basic element of Statistical Process Control in polish metallurgical companies have been presented.
Keywords: Quality control; Statistical Process Control; Control charts; Changeability and stability of process

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1. Introduction

The development of the technology and innovation, optimization of processes, growing requirements with regard to the productivity of the quality and of the costs, cause the appearance of new possibilities of managing organizations. This new activities of management are more and more creative, elastic, orientated to tasks, being aimed at raising the value of the enterprise.

So, improving the enterprise becomes deliberate and planned action at the share of functioning divisions of organization, including processes carried out in it. It regards both the organizational quality of the entire information system of the enterprise, the structural and technological aspect and the quality of individual stages of formation of the product, and also the final product, and the date of fulfilling the realization of orders.

Comprehending the quality in the organization is an aspect dynamically developing along with growing requirements of the customer. Aiming to offer products to customers on the quality level expected by them, the organization must be focused on continuous improvement.

The enterprise should flexibly react to amendments happening on the market based on the quality and to monitor action inside the organization in order to preserve the earlier worked out level of the processes and final products quality.

Confirmation of such thinking is the description contained in the standard EN ISO 9004:2000. According to standard EN ISO 9004:2000 point 4.1: "Leading and operating an organization successfully requires managing it in a systematic and visible manner. Success should result from implementing and maintaining a management system that is deigned to continually improve the effectiveness and efficiency of the organization's performance by considering the needs of interested parties. Managing an organization includes quality management, among management disciplines".

The practice of many companies shows that one of ways of reaching the assumed quality of processes and products is using the quality estimation methods.

2. The process in the quality viewpoint

In an enterprise its actions and thinking should be oriented on processes, which are included in the quality management system. Therefore quality of the product is not only a result of production process, but of the whole chain of process.

According to the accepted definition in the standard ISO 9000:2008 "process is defined as "set of interrelated or interacting activities which transforms inputs into outputs".

A current model of the organization is a system of four basic ISO 9001:2008 chapter, containing requirements concerning [1-4]:

- **Management responsibility** - management commitment, customer focused quality policy, planning, responsibility, authority and communication, management review.
- **Resource management** - provision of resources, human resources, infrastructure, work environment.
- **Product realization -** planning of product realization, customer-related processes, design and development, purchasing, production and service provision, control of monitoring and measuring equipment.
- **Measurement, analysis and improvement -** monitoring and measurement, control of nonconforming product, analysis of data, improvement.

A PDCA cycle /Deming's cycle: plan, do, check, act/ was integrated into model of the organization. The PDCA cycle falls within the scope of the inside loop, and the effectiveness of processes of constant improvement starts and finishes on the responsibility of managements (Fig. 1) [2]. An ability of the system to deliver products fulfilling predefined requirements is improved.

An input state can be material or the information converted as a result of the process into the final product or service, or ready information. For the accomplishment of the process among others an equipment, methods, knowledge, abilities, human capital and his knowledge will be indispensable resources.

In particular one should emphasize the role of defining expectations of the customer - there is a customer at the beginning and at the end of this model, who in the deliberate way or no, defines specific requirements concerning products and / or of services.

According to standard EN ISO 9004:2000 point 4.1: " Top management should establish a customer -oriented organization - by defining systems and processes that can be clearly understood, managed and improved in effectiveness as well as efficiency, and by ensuring effective and efficient operation and control of process and measures and data used to determine satisfactory performance of the organization".

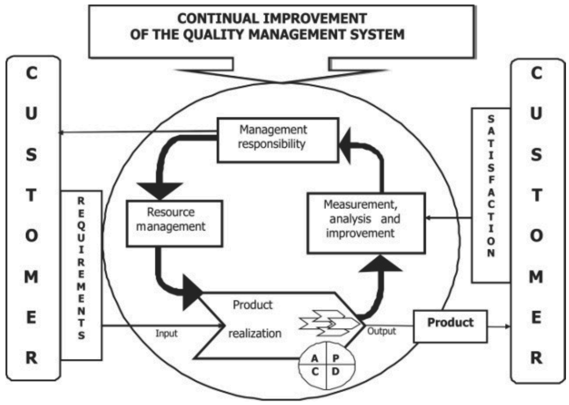

Fig.1. Model of a process-based quality management system [4]

A system of constant improvement and improving is an important element of the activity of the quality organization. This system should be defined by the organization, and then implemented and maintained in the systematic way. Its aim is constant improving of all systems of the organization which cooperate with themselves for achieving the joint purpose. The system of constant streamlining must make three things [5, 6]:

- must hold process under the strict control.
- must keep them under the control and to make treated processes from them, that is this way to control these processes so that they are predictable and holding on within the limits of the acceptable tolerance.
- must continuously improve processes, helping to achieve the best target values, that is to eliminate the waste, to simplify processes and to solve the cycle of not-ending problems.

3. The production system and quality. Changeability of the process

In the area of the production sphere, in which previously designed quality materialises in the real object, systems and production processes take place. While a production department bears responsibility for productions, the responsibility for achieving the appropriate quality in the process must also be considered in frames of implementation of the production [6, 7].

So, a quality of the production is a degree of fulfilment of requirements put in a production process or the more widely comprehended production system [8-10].

In literature it is assumed, that the production system constitutes the system designed and organised on purpose composed of material, energy and information, exploited by the man and serving for producing determined products (goods and services) in order to satisfy customers diverse requirements [7, 11-13].

The production system consists of five basic components [7, 14]:

- input vector X, composed of all factors of the production;
- output vector Y, composed of final products, services, as well as harmful waste of production polluting environment,
- T - processes of transforming, the input vector X into the output vector Y called a production process;
- of process of managing the system;
- of material, energy and information link between mentioned above components of the production system.

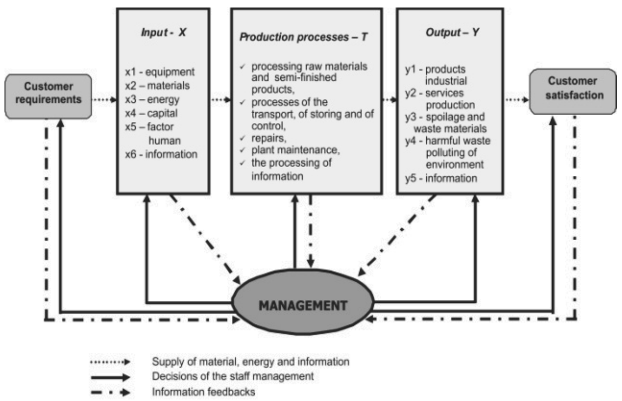

Fig. 2. The production system [7]

Such a system (Fig. 2) confirms a fact that the production system is a set of mutually coupled elements. But, each of these elements can constitute the system alone in oneself, depending on the accepted hierarchy and the level of the system relation [7, 15].

Henceforth, a production process will be understood as the set of essential actions mutually coupled for producing specific product/service in the current organizational structure of the enterprise [16].

Decisions, understood as deciding one of available ways of acting or behaving in determined circumstances, made in a production process are most often backed up with results of conducted inspections what is needed for the correct accomplishment of the process [17, 18].

The division of the decision according to the analytical criterion is following [17, 19]:

- conventional (made without applying computational proceedings),
- assessed (made after applications of proper computational proceedings, helpful in deciding).

We distinguish also strategic decisions (e.g. about beginning or finishing a given process, for amendment to the stuff), intervention decision (changes of conditions of realization of the process) [19].

Therefore possible to draw a conclusion, that there are no decisions concerning a production process, which in a bigger or smaller scale wouldn't influence its quality. Technological process are a main part of a production process, which change the shape, the form, dimensions or physicochemical properties of raw materials, of materials or semi-finished product changing them into elements, of which composing finished product [8, 20, 21].

The technological process is divided into technological operations which are carried out on one working position. Theses operations are supplemented by support operations, taking place between them, according to the specific plan (e.g. picking material up from the magazine, the transport between operation, measuring and test operations, sending to the magazine the ready product/element), creating a production process (Fig. 3) [22-24].

To ensure that results of the completion of the production process are compatible with expectation/requirements of the customer, it should be identified and planned and constructed in supervised conditions, based on quality management and quality engineering [25, 26].

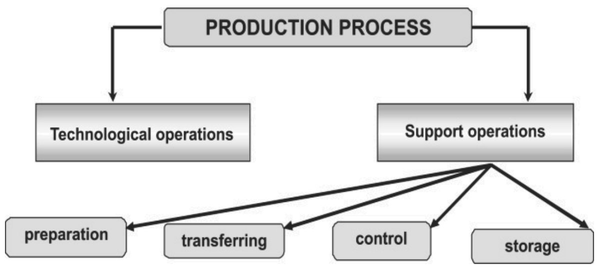

Fig. 3. Structure of production process [23]

The processes should be analysed, judged and improved first from viewpoint of values which they bring to customers. Considering the interrelation and influences of processes, as well as expectations of customers one should comprehend organizations as the whole [27, 28].

Distinguishing process doesn't mean that they will be carried out and managed in isolation from one another. The organization should consciously function according to the process approach and system approach in quality management [26-28].

This aspect is characterized by [26, 27]:

- required determination of connections of all processes and their mutual interactions,
- "translating" general aims of the organization into purposes of processes,
- putting emphasis on the most important processes for the organization of a point from view of the added value.

Creating the Quality Management System in the point concerning the product realization, one should pay attention to the need of applying quality methods of monitoring all operations executed in a production process.

Every production process, of continuous and discreet character, generates products inevitable with changeability of properties. If results of measurements of the given properties of the product show no changeability, it is due to the insufficient accuracy of the measuring method [21, 24].

The scatter is inseparable characteristic of every production process; independently of kind and the technological level of this process. Properties of products are random variables, so to their description it is possible to apply statistical techniques. These known methods exploit estimation of parameters, tests of the significance, analysis of random signals [21, 24, 29].

In industrial practice sources of causes disrupting processes are classified for example with the graph of Ishikawa (Fig. 4) [30]. The acquaintance of the theory of the changeability is one of the most tremendous tools the enterprise can use. This theory lets improve the organization, as well as gives the possibility of the constant upgrade [31]. We can say, that the theory of the changeability is a key-element in "puzzle" which the highest management should compose if wants the enterprise to function correctly [31].

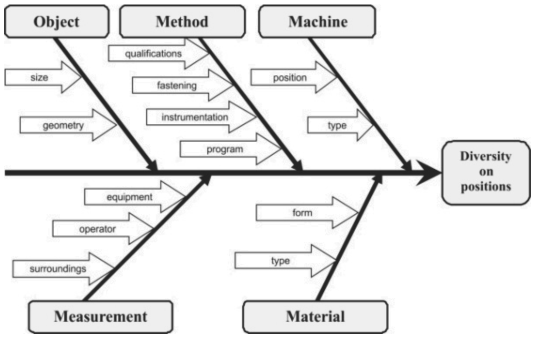

Fig. 4. Causes of scatterings in the process according to Ishikawa [30]

The practice shows that people don't understand the changeability: they notice trends where they aren't; they try to describe the natural changeability as events of special meaning; they punish and award people for things on which the workers have no influence; they don't understand current action (enterprise, the production process); they cannot correctly predict or made plans next time; they have a limited ability to make improvements [31-33].

Every measured output variable and every measured variable of the process are characterized by a certain changeability [31].

The method of the measurement can not be able to detect of this changeability, since the changeability can be too small, the measurement of the changeability can be impossible from other considerations, but the changeability always appears [31-33].

The changeability appearing in every process or system is inevitable, but if too big, the cost of its appearance an turn out to be disproportionately high, whether as the cost of materials, maintenance costs, the cost of the payment, or the cost resulting from the time consumption. For example: final product (service) does not fulfil the requirements of the customer; parts (modules) can badly fit supplies can come too irregularly to preserve the flow of the production without the expansion of warehouses; excessive delays in payments can cause money troubles or loss of the cooperator, the bad functioning of a sales department can cause loss of customers. The reduction in the changeability is a necessity. And so understanding the nature of the changeability is essential [31-33].

Until recently understanding of changeability by the senior staff in enterprises, and farther by these employees was surprisingly wrong. Meanwhile the modern theory and the practice of reducing the changeability are already over 75 years old. The Western Electric Company in Chicago had (in the year 1924) trouble with producing the uniform and reliable telephone equipment. At first managed to improve the quality of the equipment, but after reaching certain level it turned out that more and more intensive efforts of reducing the changeability often caused the opposite effect than planned [31-33].

The company invited for the aid the young Bell Laboratories physicist - Walter Shewhart. He discovered, that the changeability of each of fragmentary processes (operation, sub processes of the production process) is made of up two qualitatively different types of the changeability [31-33]:

- "own" changeability, arising from the "random" reasons, called also "general" which perform the role of the "noise" constantly present in this process. These causes are always present and are subject to change only in case of changing the process.
- changeability arising from "assigned" reasons, called also "special" which perform the role of "signals" (this last name comes from fact that it is possible to detect the presence of such a changeability thanks to the ability of the identification of signals pointing out to this presence). Special causes appear occasionally (at least from the moment of the appearance of such a cause, action can already be the equal of it). Generally, special causes have effect on processes in the way impossible to predict and usually increase the changeability.

This simple Shewhart's discovery was a brilliant one at the same time. Without it, systematic, consistent and effective reducing the changeability would be impossible. Shewhart was an author of statistical process control (SPC method). SPC ideas created basis under comprehensive philosophy of managing according to Deming [34].

Shewhart's method - SPC is applicable not only to production processes, but to any other processes, including service, renovation, administrative systems, bookkeeping, financial analyses, sale. Significance of Shewhart's observation is proved by following conclusions [31, 35-39]:

- all sets of data contain the noise [associated with the existence of data containing signals (arising from special causes)],
- with the first step on the road to managing any process and making the changeability smaller is distinguishing the current changeability between general and special causes,
- in case that special causes appear, the output of the process isn't stable in the time and we can say nothing about what changeability one should expect in the immediate future. To the moment of identifying and removing all substantial special causes of the changeability of the process, these causes affect the process in the unpredictable way. As a result, in case of appearing of special causes, judging effects of amendments is impossible in the project, effects of amendments to preparing employees, the elect of the amendment to materials from the supplier. *And so systematic identifying and removing special causes of the changeability of the process are the essential and necessary first steps on the road to the reduction of the process changeabilities.*
- the changeability resulting from the existence of general causes can be reduced onlyas a result of correcting very process. To sum up: *in case that in the process or the system only own changeability is observed, it is possible to achieve the improvement exclusively thanks to the action of the executive committee changing the very process or the system.*

The system from which special causes of the changeability were removed is called ***stable***. We also say, then the system is in the state of *statistical regulation*. So a stable system is such a system which working is predictable within the limits of only general causes of the changeability. The system which is stable, is characterized by the lowest changeability possible for it - only the amendment to very system can still reduce the changeability. Stability of the process is it not natural state [35, 39].

The fact that the process is stable doesn't mean that its operation is satisfactory. The output can not fulfil the requirements for the recipient through certain or all the time. In addition the total own changeability determines the ***"ability" of process***. The purpose which goes beyond the ability of the process cannot be achieved differently than by the amendment to this process or spoiling other processes in the system [39].

Conclusion: both seeking signals and analysis of the ability of the process are conducted with statistical tools. In particular, very simple and astonishingly effective tool of detecting signals in the process are control charts suggested by Shewhart.

4. Control charts and their analysis

During a production process all products are produced more or less in similar conditions. It is also possible that features of individual products can be slightly different on account of appearing random mistakes, which disrupt the process. However the size of these mistakes isn't enough big so that controlling every produced element becomes necessary. Therefore in practice a statistical control is applied (so-called sampling), on the representative group of products what allows for reducing time and money needed for inspecting all products, and the performance received in this way is very accurate and display the real course of the process [35-39].

The control charts is a form on which determined statistical measures of products properties are recorded as a result of inspection taking randomly samples of products in the determined place of the process. The form of the control chart can be adopted to examining the quality of the process with one statistical measure (single-parametric chart), for example values of the average, or for simultaneous examination the quality of the process with the help of two or of more statistical measures, for example a value of the average and the range [35, 37-39].

We should exactly determine what parameters of the product will be controlled and on the basis of these evidences select control chart appropriate for our needs. The control charts are used for observation and the registration of the changeability of the characteristic of the researched element of the production process. Their interpretation is based on the normal creation and distribution. Recording result of measurements take place by writing on control charts the value of characteristic reading from taken samples. Such operation allows for fast and effective identifying and eliminating causes disrupting the process [31, 37-39].

The control chart introduced on Fig. 5 is built from three basic elements [29, 35, 37, 39]:

- Shift of specification - it is an element which contains primary information concerning the name of the controlled process, the number and the type of the chart, or the period of validity of control chart.
- The table with the result - it is a place, in which results of made measurements are recorded, on the basis of which the graph is formed. Such a table should be drawn in order to take the number of the sample into account, space for entering calculated values.
- A graph of the process - it is a place, in which it is possible to observe behaviour of the entire process and statement whether he will run smoothly, or is disrupted. This graph consists of three basic lines:
  - Central line - which describes the medium value from everyone put on the chart values,
  - Upper Control Line (UCL) - it is an upper control limit, after the exceeding which we are informed about maladjustment the process,
  - Lower Control Line (LCL) - it is a lower control limit. These control limits are moved away from the central line by 3 σ.

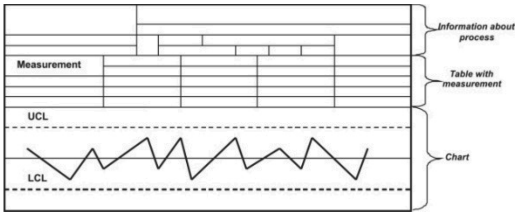

Fig. 5. Example of control chart

At keeping control charts three groups of statistical parameters are applied (Table 1) [35, 37-39].

In Table 2 types of control charts applied in Statistical Control Process have been described [29, 35, 37-39].

Control charts can be [39]:

- Single-path - when only one statistical parameter related to one features is examined.
- Two-path- when two parameters being characteristic of a quality of the element are checked.
- Multi-path - when more than two statistical parameters or more than two features of the product are inspected.

In practice two types of Shewhart's control charts are applied in production process (Fig. 6) [29, 35, 37-39]:

At the numerical evaluation

In the event that we make direct measurements of the characteristic of the type: temperature, weight, length in analysed samples or process, then the received results we write in control charts of the numerical type, since they have numerical character. Before using such control charts we should remember about it, that the distribution of the collected results is a normal distribution, therefore an important aspects here is checking the normalcy of distribution. The basic advantages of these control charts are:

- Possibility of concluding about the current state of the process.
- Possibility of forecasting future states.
- Possibility of keeping the control chart from the very beginning of the process.

Table 1.
The primary groups of statistical parameters useful in creating control charts [35-40]

Group I - Apply to measures of the averages value	
arithmetic average $\bar{x}$	$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$ where: x - next values of the feature in the sample; n - number of the sample
median M	centre value of the organised set in the order of the growing or diminishing value the feature in the sample.
Group II - Apply to measures of the scattering	
range R	$R = x_{max} - x_{min}$ where: x_{max} - the greatest value of the measured the feature in the sample x_{min} - the smallest value of the measured the feature in the sample
mean square deviation s	$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$
Group III - Concerning other the feature in the sample	
of extreme values x_{max} and x_{min}	
numbers of discordant units in the sample c	
of fraction of discordant units of the sample p	$p = \frac{c}{n}$ where: c - number of discordant units in the sample; n - number of the sample

Table 2.
Types of control charts [29,35-40]

Name of the control chart	The scope, conditions of the application and the advantages and disadvantages of the control chart
1. Control chart X-R the average values and the range in the sample.	The chart can be applied, when the controlled characteristic is measurable and has a normal distribution. Advantages: Easiness of applying, small samples (n = 2-10). Disadvantages: For every controlled characteristic should keep the separate chart, it isn't possible to apply gauges, the range R reacts strongly to untypical values.
2. Control chart X-s the average values and the mean deviation in the sample.	Using the chart like in pos. 1. Advantages: Small samples (n = 2-10). The mean deviation ignores untypical values so strongly as the R range. Disadvantages: Greater labour intensity caused by calculating of the mean deviation s, it isn't possible to apply gauges, for every controlled characteristic should keep the separate chart.
3. Control chart M-R of the median and the average range.	Using the chart and her characteristics like in pos. 1, with it, that: appointing of the median M is simpler than of the X arithmetic mean. Disadvantages: The median doesn't take all values into account in the sample.
4. Chart D-G of smallest and biggest value in the sample.	Using the chart like in pos. 1. Advantages: Easiness of applying, requires no calculations, small samples (n = 2-10). Disadvantages: For every controlled characteristic should keep the separate chart, it isn't possible to apply gauges, R reacts strongly to untypical values.
5. Control chart of the defectiveness in the sample.	The chart can be applied both when the controlled characteristic is measurable, and when it is non-measurable, independently of the type of the distribution of this feature. Advantages: Easiness of applying, it is possible to record results of the control of the any number of the characteristic on one chart, it is possible to apply gauges. Disadvantages: Big numerous of the sample and no enough sensitivity of amendments to the technological process.
6. Control chart with the number of bad units in the sample.	Using the chart and its property like in position 5.

At the alternative evaluation

Control charts of this type are applied if we don't want to inspect measurable features of the element, but when we are interested in - for example a number of imperfect units in produced series or the number of not conforming products. In other words, keeping such control charts consists in separating good products from bad and for writing results of analyses in such a control chart.

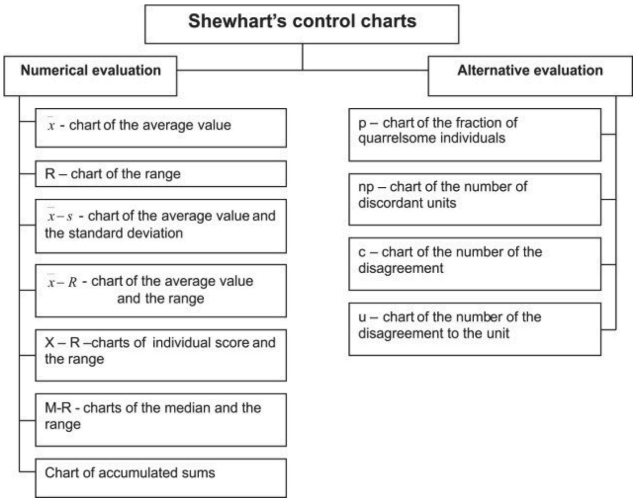

Fig. 6. Shewhart's control charts - basic division [29, 35-39]

Changes of average values from samples which the setting appoints for appearing of disturbance in the process and their possible causes are following [29, 30, 35, 37, 39]:

a) Results of measurements are evenly distributed around the central line, not crossing admissible area in addition. The process proceeds perfectly.
b) Admissible area was crossed the process is disqualified
c) Seven next points increase what perhaps will lead to exceeding acceptable limits. Blunting the tool can be a cause.
d) Variation periodically repeating itself to the measured value. An influence of amendments to the daily employer's working can be a cause.
e) The small scattering around the central line causes that the process is too accurate, and consequently is not very economic.
f) Too great instability of process. It can be reason bed steering or bad putting measuring tools.
g) Change of site the measured value. An amendment to material, adjusting the machine or the manner of the measurement can be a reason.
h) Single output beyond admissible area.
i) Seven values lie above or under the central line. It can be caused by improper steering the machine or the measuring tool.

In Figures 7-12 (test 1-6) sequences of points (trends) has been described. This trends signal about danger of upsetting the process.

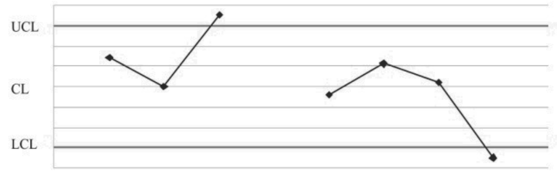

Fig. 7. Test 1: one point outside the red control line

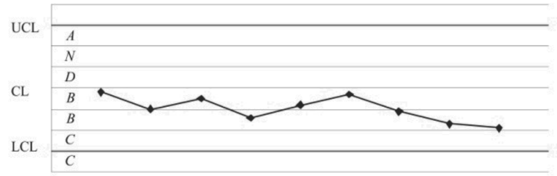

Fig. 8. Test 2: nine next points in the zone B

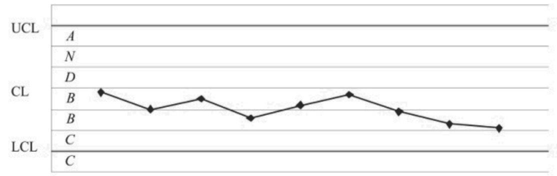

Fig. 9. Test 3: six next points constantly growing or decreasing

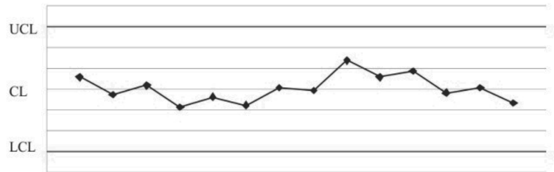

Fig. 10. Test 4: fourteen points constantly increasing or decreasing

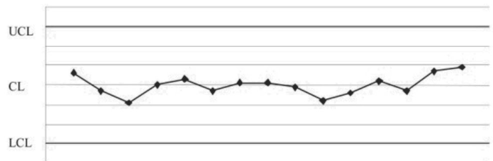

Fig. 11. Test 5: fifteen next points below or above the central line

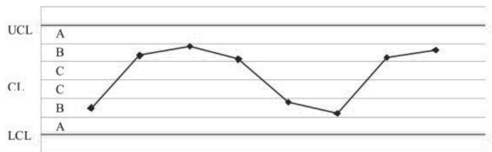

Fig. 12. Test 6: eight next points on both websites of the central line but none in the zone C

Stages of action in case of the statement that the process is upset [29, 39]:

- To repeat measurements of features for all units in the sample.
- To check all calculations of statistical measurements.
- Taking the next sample with measurement this sample and marking the point on the control chart. If findings of the examination don't confirm upsetting, no additional steps take place. But if the result repeated itself then it is necessary to notify the management about detected irregularities.
- Stopping the production.
- Seeking reasons for upsetting.
- Sorting of products which were produced as imperfect and of the ones produced according to assumptions.
- After detecting disturbances resuming the production takes place.

5. Using the control chart X-R in a production process of round rods ribbed

In the enterprise of the iron and steel industry a need of using control charts was stated. Researches concerned round bars ribbed for reinforcing concrete (Table 3). For elaborating control charts up a RB500 kind was chosen. RB500 kind of the nominal diameter ø 16 mm and theoretical mass 1 meter 1.58 kg. For the chosen process five researches were conducted in two-week spaces (series 1-5).

Table 3.
A summary of nominal diameters ribbed round bars for concrete reinforcement offered by chosen company

Nominal diameter d (mm)	*10*	*12*	*14*	*16*	*18*
Theoretical mass(kg)	0.62	0.89	1.21	1.58	2.00
Nominal diameter d (mm)	*20*	*22*	*25*	*28*	*32*
Theoretical mass (kg)	2.47	2.98	3.84	4.83	6.31

Production process of ribbed round bars consists of the following stages:

1. Supply of billets.
2. Taking of mill feedstock and heating it for the rolling process.
3. Designation of the product and its traceability.
4. Technical protection of the production process.
5. Planning the production.
6. Quantitative and qualitative control of supplied billets.
7. Soaking in the furnace.
8. Transportation of billets for rolling.
9. Rolling in the mill line.
10. Control of the intermediate and final dimension of the rolled band.
11. Cutting the band.
12. Cooling in the water-cooling line.
13. Control of the amount of roll down of billets rolling across lines.
14. Trimming to the demanded dimension.
15. Cooling in the air-cooling line.
16. Control of the shape, the dimension and the surface.
17. Taking a sample and performing researches.
18. Packaging bars.
19. Binding bars.
20. Weighing the bunch of bars.
21. Marking bars.
22. Giving the quality status.
23. Transporting to the place of the storage.

Researches series No. 1 (Tab. 4, Fig. 13)

Table 4.
Input data for calculations for control chart X-R

Measurements in the sample			Average	Range
1	□□3	3		
1.603	1.578	1.553	1.578	0.050
1.616	1.580	1.553	1.583	0.063
1.594	1.585	1.573	1.584	0.021
1.620	1.600	1.586	1.602	0.034
1.614	1.611	1.607	1.611	0.007
1.618	1.606	1.597	1.607	0.021
1.632	1.572	1.527	1.577	0.105
1.633	1.577	1.539	1.583	0.094
1.604	1.597	1.590	1.597	0.014
1.613	1.601	1.592	1.602	0.021
1.613	1.553	1.508	1.558	0.105
1.618	1.600	1.588	1.602	0.030
1.633	1.601	1.557	1.597	0.076
1.591	1.585	1.573	1.583	0.018
1.602	1.602	1.602	1.602	0.000
1.614	1.594	1.574	1.594	0.040
1.616	1.592	1.556	1.588	0.060
1.585	1.575	1.559	1.573	0.026
1.599	1.587	1.578	1.588	0.021
1.633	1.619	1.599	1.617	0.034
1.656	1.584	1.530	1.590	0.126
1.593	1.590	1.588	1.590	0.005

For X:	For R:
$\bar{\bar{X}} = 1.591$	$\bar{R} = 0.044$
UCL = 1.636	UCL = 0.113
LCL = 1.546	LCL = 0.000

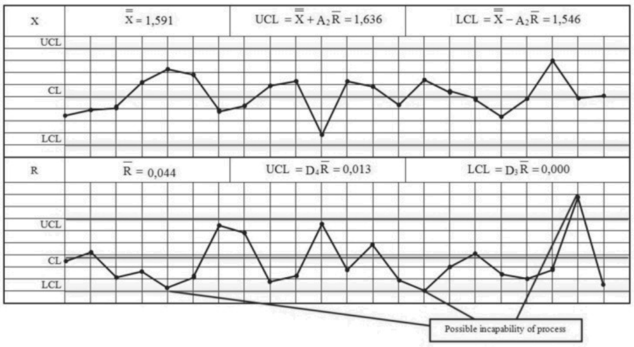

Fig. 13. Distribution of the X line and R line for series no. 1

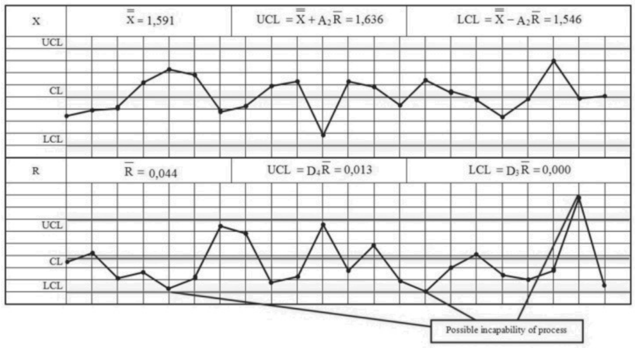

Fig. 14. Distribution of the X line and R line for series no. 2

Researches series No. 2 (Tab. 5, Fig. 14)

Table 5.
Input data for calculations for control chart X-R

Measurements in the sample			Average	Range
1	2	3		
1.627	1.627	1.627	1.627	0.000
1.632	1.624	1.610	1.622	0.022
1.640	1.572	1.522	1.578	0.118
1.609	1.571	1.539	1.573	0.070
1.618	1.606	1.597	1.607	0.021
1.619	1.593	1.570	1.594	0.049
1.626	1.570	1.529	1.575	0.097
1.605	1.581	1.545	1.577	0.060
1.568	1.564	1.557	1.563	0.011
1.603	1.581	1.553	1.579	0.050
1.599	1.563	1.536	1.566	0.063
1.606	1.598	1.593	1.599	0.013
1.618	1.607	1.587	1.604	0.031
1.616	1.584	1.540	1.580	0.076
1.581	1.567	1.556	1.568	0.025
1.592	1.585	1.581	1.586	0.011
1.591	1.579	1.570	1.580	0.021
1.650	1.570	1.514	1.578	0.136
1.583	1.576	1.569	1.576	0.014
1.574	1.619	1.599	1.617	0.034
1.627	1.584	1.530	1.590	0.126
1.607	1.590	1.588	1.590	0.005

For X:	For R:
$\overline{\overline{X}} = 1.585$	$\overline{R} = 0.047$
UCL = 1.633	UCL = 0.121
LCL = 1.537	LCL = 0.000

Researches series No. 3 (Tab. 6, Fig. 15)

Table 6.
Input data for calculations for control chart X-R

Measurements in the sample			Average	Range
1	2	3		
1.628	1.610	1.598	1.612	0.030
1.615	1.607	1.602	1.608	0.013
1.622	1.606	1.596	1.608	0.026
1.625	1.613	1.604	1.614	0.021
1.645	1.615	1.582	1.614	0.063
1.634	1.626	1.621	1.627	0.013
1.650	1.645	1.637	1.644	0.013
1.629	1.615	1.592	1.612	0.037
1.636	1.600	1.576	1.604	0.060
1.631	1.603	1.581	1.605	0.050
1.606	1.598	1.593	1.599	0.013
1.623	1.609	1.583	1.605	0.040
1.613	1.608	1.600	1.607	0.013
1.598	1.586	1.580	1.588	0.018
1.625	1.620	1.612	1.619	0.013
1.677	1.605	1.560	1.614	0.117
1.667	1.622	1.562	1.617	0.105
1.592	1.567	1.536	1.565	0.056
1.611	1.563	1.533	1.569	0.078
1.629	1.579	1.511	1.573	0.118
1.602	1.594	1.580	1.592	0.022
1.647	1.586	1.507	1.580	0.140

For X:	For R:
$\overline{\overline{X}} = 1.603$	$\overline{R} = 0.048$
UCL = 1.653	UCL = 0.124
LCL = 1.554	LCL = 0.000

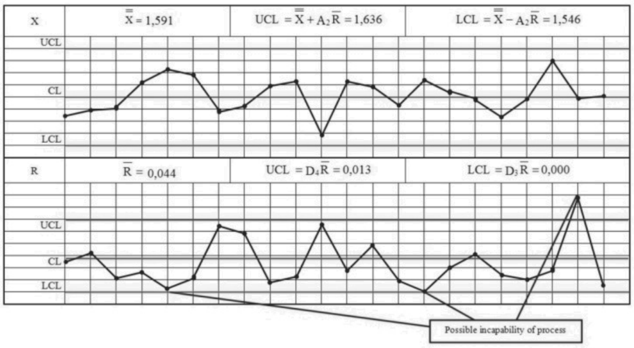

Fig. 15. Distribution of the X line and R line for series no. 3

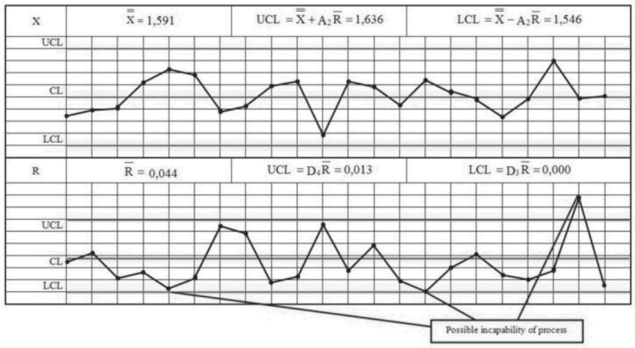

Fig. 16. Distribution of the X line and R line for series no. 4

Researches series No. 4 (Tab. 6, Fig. 16)

Table 6.
Input data for calculations for control chart X-R

Measurements in the sample			Average	Range
1	2	3		
1.608	1.596	1.587	1.597	0.021
1.645	1.585	1.546	1.592	0.099
1.609	1.591	1.564	1.588	0.045
1.581	1.575	1.563	1.573	0.018
1.569	1.565	1.558	1.564	0.011
1.602	1.588	1.574	1.588	0.028
1.650	1.546	1.472	1.556	0.178
1.611	1.599	1.590	1.600	0.021
1.611	1.599	1.581	1.597	0.030
1.607	1.607	1.607	1.607	0.000
1.638	1.621	1.598	1.619	0.040
1.654	1.618	1.564	1.612	0.090
1.602	1.574	1.558	1.578	0.044
1.656	1.612	1.538	1.602	0.118
1.633	1.585	1.552	1.590	0.081
1.618	1.594	1.579	1.597	0.039
1.644	1.608	1.584	1.612	0.060
1.624	1.610	1.587	1.607	0.037
1.611	1.611	1.611	1.611	0.000
1.624	1.610	1.602	1.612	0.022
1.629	1.588	1.532	1.583	0.097
1.644	1.599	1.527	1.590	0.117

For X:	For R:
$\bar{\bar{X}} = 1.594$	$\bar{R} = 0.054$
UCL = 1.650	UCL = 0.140
LCL = 1.539	LCL = 0.000

Researches series No. 5 (Tab. 7, Fig. 17)

Table 7.
Input data for calculations for control chart X-R

Measurements in the sample			Average	Range
1	2	3		
1.594	1.578	1.559	1.577	0.035
1.583	1.583	1.583	1.583	0.000
1.634	1.572	1.534	1.580	0.100
1.618	1.578	1.553	1.583	0.065
1.602	1.554	1.518	1.558	0.084
1.627	1.563	1.529	1.573	0.098
1.602	1.569	1.542	1.571	0.060
1.662	1.578	1.494	1.578	0.168
1.592	1.577	1.553	1.574	0.039
1.615	1.585	1.552	1.584	0.063
1.622	1.580	1.547	1.583	0.075
1.599	1.593	1.584	1.592	0.015
1.651	1.604	1.536	1.597	0.115
1.611	1.593	1.569	1.591	0.042
1.593	1.588	1.580	1.587	0.013
1.609	1.593	1.574	1.592	0.035
1.627	1.584	1.550	1.587	0.077
1.608	1.596	1.587	1.597	0.021
1.597	1.597	1.597	1.597	0.000
1.631	1.615	1.605	1.617	0.026
1.627	1.609	1.585	1.607	0.042
1.634	1.627	1.620	1.627	0.014

For X:	For R:
$\bar{\bar{X}} = 1.588$	$\bar{R} = 0.054$
UCL = 1.643	UCL = 0.139
LCL = 1.533	LCL = 0.000

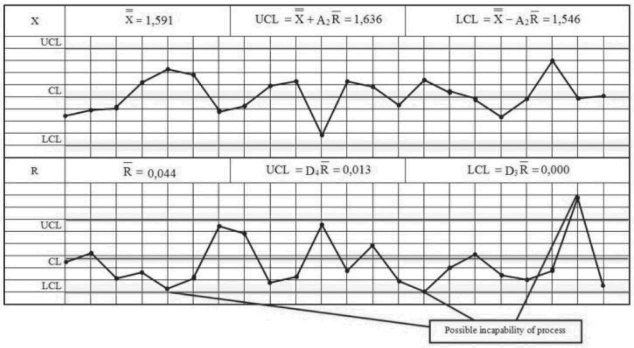

Fig. 17. Distribution of the X line and R line for series no. 5

6. Summary

In contemporary world a good quality of products is a factor which decides of the item position of the company on the market. Having and applying quality certificates is practically a condition necessary to become known on European or world markets. The customer no longer makes choice between the quality and the price; he wants to receive the good quality product of low price [34, 40].

Quality management methods help to realize requirements of customers and contribute to more efficient functioning of enterprises.

Action associated with the quality requires methods applied accordingly, depending on needs, of statistical methods and expert methods, in order to get the highest quality of offered products. Statistical methods, in particular designed and monitored control charts, enable graphical visualising measurements of processes. They also describe stability and repeatability of those processes.

Using the statistical process control (SPC) in metallurgical enterprises allows for measuring, researching, estimating and controlling one or a few parameters of the product. A comparison of results with requirements, in order to state, whether with reference to every of these properties the unanimity was achieved is also possible. The statistical quality control of the process for the organization means preventing occurrence of defects, lets for minimizing losses thanks to the systematic identification and analysis of key-processes and the direct control. Very often SPC is recognised as the advanced technique of acting in Six Sigma methodology.

References

[1] EN ISO 9000:2005 standard, Quality management - Fundamentals system and vocabulary.
[2] J. Ketola, K. Roberts, Demystifying ISO 9001:2000 - part 1, Quality Progress 34/9 (2001) 65-70.
[3] J. Ketola, K. Roberts, Demystifying ISO 9001:2000 - part 2, Quality Progress 34/10 (2001) 44-47.
[4] EN ISO 9001:2008 standard, Quality management systems - Requirements.
[5] B. Czyżewski, Statistical methods in quality control of technological processes, NOT, Poznan, 1995 (in Polish).
[6] E. Deming, Quality, productivity and competitive position, University of Cambridge, 1982.
[7] I. Durlik, Organization and production, PWE, Warsaw, 1992 (in Polish).
[8] M. Dudek, D. Szewieczek, Usage of quality methods: Failure Mode and Effect Analysis (FMEA) and Statictical Process Control (SPC) as a element of continuous improvement of production process, Proceedings of the 12th International Scientific Conference "Achievements in Mechanical and Materials Engineering" AMME'2003, Gliwice-Zakopane, 2003, 317-321.
[9] M. Brzeziński, Organization of primary production processes, Lublin, 1998 (in Polish).
[10] G. Bounds, L. Yorks, M. Adams, G. Ranney, Beyond total quality managements, Towards the emerging paradigm, New York, Mc Graw-Hill, 1994.
[11] I. Durlik, Quality engineering - strategy and designing of production systems, Placet, Warsaw, 1993 (in Polish).
[12] I. Durlik, The aspects of designing of production systems, Organization and Managing 3 (1994) 39.
[13] T. Karkoszka, Improvement of chosen process based on the occupational health and safety criterion, Journal of Achievements in Materials and Manufacturing Engineering 37/2 (2009) 735-742.
[14] S. Lis, Organization and economic of Production Process in machine industry, PWN, Warsaw, 1984 (in Polish).
[15] L. Wasilewski, The example of quality strategy in industry, ORGMASZ, Warsaw, 1994 (in Polish).
[16] D.C. Montgomery, Introduction to statistical quality control, John Wiley & Sons, New York, 1991.
[17] A.V. Feigenbaum, Total quality control engineering and management, Mc Graw-Hill Book Co., New York, 1961.
[18] J. Juran, Quality control handbook, Mc Graw-Hill, New York, 1974.
[19] R.L. Liberatore, Teaching the role of SPC in industrial statistics, Quality Progress 34/7 (2001) 89-94.
[20] E. Kindlarski, Quality of products, PWN, Warsaw, 1988 (in Polish).
[21] S. Hongyi, Comparing Quality Management practices in the manufacturing and service industries: learning opportunities, Quality Management Journal 8/2 (2001) 53-71.
[22] K. Ishikawa, Guide to quality control, Asian Productivity Organization, Tokyo, 1987.
[23] S. Sudoł, Economic and organization of company, PWE, Warsaw, 1989 (in Polish).
[24] S. Tkaczyk, M. Dudek, Methodology research of quality in industry, Proceedings of the 7th Scientific International Conference "Achievements in Mechanical and Materials Engineering" AMME'1998, Gliwice-Zakopane, 1998, 513-516 (in Polish).
[25] S. Tkaczyk, Quality assurance system in metallurgical and machine industry, Mat. CEEPUS PL 013/97, Gliwice-Rousse-Miskolc-Bratislava-Ljubljana, 1997, 31.
[26] R. Kolman, Quality engineering, PWE, Warsaw, 1992 (in Polish).
[27] K. Mijanovic, J. Kopac, Environmental management inside production systems, Journal of Materials Processing Technology 162-163 (2005) 759-765.

[28] C.-H. Kuo, J.-C. Tsai, New Tolerance Analysis Model for Normal Mean Shift in Manufacturing Process, Materials Science Forum 594 (2008) 339-350.
[29] A. Hamrol, W. Mantura, Quality Management, theory and practice, PWN, Warsaw, 2005 (in Polish).
[30] A. Iwasiewicz, Quality Management, PWN, Cracow, 1999 (in Polish).
[31] www.statsoft.pl.
[32] J. Bank, Management by quality, PWN, Warsaw, 1996 (in Polish).
[33] H.H. Steinback, Total quality management, Warsaw, 1998.
[34] M. Dudek, Quality methods ace and factor of functionality and improvement preproduction of organization sphere Proceedings of the Nationwide Scientific Conference „Management of organization of project oriented" UMCS'2004, Lublin, 2004, 89-93 (in Polish).
[35] E.M. Saniga, D.J. Davis, T.P. Williams, Economic, statistical and economic - Statistical design of attribute charts, Journal of Quality Technology 27/1 (1995) 56-73.
[36] M. Bevilacqua, F.E. Ciarapica, G. Giacchetta, B. Marchettii, Implemetation of a quality procedure based on Delphi method and the ISO/TS 16949:2009 in the production of stainless steel tubes for automotive exhaust systems, International Journal of Quality& Reliability Management 28/8 (2011) 841-866.
[37] L. Wasilewski, Statistical methods of improvement of products, ZETOM, Warsaw, 1994 (in Polish).
[38] J.M. Myszewski, Management of changeability, Systemic view of statistical methods in quality management, ORGMASZ, Warsaw, 1998 (in Polish).
[39] M. Dudek-Burlikowska, Quality estimation of process with usage control charts type X-R and quality capability of process Cp, Cpk, Journal of Materials Processing Technology 162-163 (2005) 736-743.
[40] T. Karkoszka, D. Szewieczek, Integrated method of technological processes estimation in materials engineering, Journal of Achievements in Materials and Manufacturing Engineering 24/1 (2007) 456-465.