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# APPLICATION OF STATISTICAL METHODS AT COPPER WIRE MANUFACTURING

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Six Sigma is a method of management that strives for near perfection. The Six Sigma methodology uses data and rigorous statistical analysis to identify defects in a process or product, reduce variability and achieve as close to zero defects as possible. The paper presents the basic information on this methodology.

*Key words:* methodology six sigma, process of improvement, measurement of the company processes, copper wire

**Rabljenje statističkih metoda pri proizvodnji bakrene žice.** Six sigma je metoda menangmenta koja se približava savršenosti. Ova metodologija rabi podatke i oštru statističku analizu na identifikaciji grešaka u procesima ili proizvodima, s ciljem snižavanja varijabli, te dostići nultu razinu grešaka. Članak daje temeljni očevid na ovu metodu.

*Ključne riječi:* metodologija six sigma, postupak usavršavanja, izmjera procesa tvrtke, bakrena žica

## INTRODUCTION

The application of statistical methods is universal. In direct or indirect form, they are part of everyday practice. The Statistical Methodology (SM) as tools of the quality management is currently not doubted. The introduction of standards known as ISO 9001: 2000, VDA 6.1, QS 9001, ISO TS 16949 or the implementation of the TQM Model in practice (responding to the Lean Management system, or the Six Sigma) brings improvements into other areas of company functions thereby contributing to higher competitiveness in the area of quality. The submitted problem, considered as a scientific branch, can be classified into a cross-sectional area of quality management, because, the field of quality management (modem approaches such as TQM and the Six Sigma) is focused on the improvement of processes. Depending about areas, the process is going through (either it is about the processes in retail, banking, health, mechanical engineering or metallurgy), i.e. the applied methodology is indifferent [l].

Intentions is to continuously improves manufacturing processes, as well as nonmanufacturing processes, to generate the pressure on all levels of management, to introduce the new, modem systems of improvements, which cannot be imagined without using the exact methods, mostly based on mathematicai statistics. One of such a sophisticated system of quality improvement is the Six Sigma Methodology.

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## IMPLEMENTATION OF THE SIX SIGMA SYSTEM

Six Sigma system is performed as a sixstage process. Stages 1-4 build the fundament of the system, whereas, stages 5-6 are about the implementation of the Six Sigma system. The implementation model of the Six Sigma System is illustrated in Figure 1.

Stage One is about a commitment of top management, Le. teaching the senior managers on the principles and tools involved. This step is followed by the development of a managerial infrastructure which supports the Six Sigma system.

Stage Two is abt. gathering of information. It involves intensive communication with company's customers, suppliers and the staff as well. Information re-

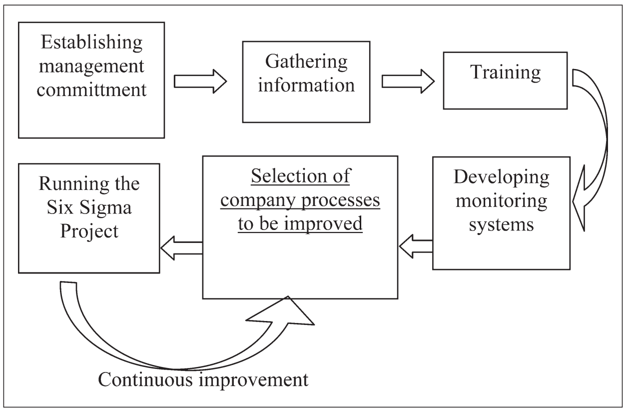


**Figure 1.** The implementation model of the Six SigmaElementary Level

garding the conditions underlying the processes have to be improved, such as the supply chain, are obtained from the customers and from the suppliers as well. The information analysis helps us to identify the obstacles blocking our road towards success.

Stage Three, Six Sigma System training of the entire company take the place. There are established goals of the training to be carried out from the top management staff down to the lowest leveJ. The level of training achieved may be viewed, for example, as being awarded a Black or a Green belt. Holder of black belt is Head of the Six Sigma project team. He has to be involved in problem solving, whereas Green belts are prerequisites for the members of the Six Sigma project team.

Stage Four, as the part of implementation of the Six Sigma, has to be established a system of monitoring. As the main goal consists in continuous improvement, support on the part of the managerial framework is a prerequisite to success. Then comes the period to setting up a system of monitoring. Strategic goals and key company processes should be matched with measures of adequate levels, Le. internal or external (customer satisfaction) [2].

Stage Five, selected company's processes has to be improved. On elementary level, when some of the problems are identified as worthless activities or sub processes, mapping of the current key processes takes the place. Selected are only the sub processes needed to be improved and then follows the definition of the Six Sigma project. The concept of the project is to make up of the DMAIC cycle where, among the first, define the problems within the process that need to be improved. Then, setting of goals has to be achieved in the course of the process. The existing system is to be subject of measurements; consequentIy, valid and reliable measures are necessary to be established to conduct research. The analysis of results will help to define the area between "if-then" and "should-be".

Stage Six, having performed the analysis, the system is starting to form a new way how to do the job, which has to improve or to confirm the processes while employing methods of simulation and statistics. The implementation of improvements is preceded by a project plan which will develop and report the changes within the organization. Result are, the new, improved management system modifications are institutionalized, forming a system ofmodifying replacements and stimulations, planning of company resources, budgets etc. It involves development of documented suitable system and monitoring system such as the ISO 900 1:2000. Finally, the information is transformed to make the results of the project accessible for other systems [3], [4].

## APPLICATION OF THE METHODOLOGY

Application of above mentioned methodology has been performed in a metallurgical plant, where the main goals of the project were focused on elimination of defects on the manufactured products, i.e. on copper wires. The project became urgent owing to dissatisfaction and frequent complaints of the customers on poor quality leading to both, los ses of the clients and the non proportional ri se in the costs of remedy. The entire project was conducted employing the method of DMAIC:

**Defining the problem -** based on the application of the QFD methodology as critical factors, unambiguously, defined two parameters, the percentage of wire tear at the customers and the oxide contents. These two parameters form the fundamental and most critical elements of improvements deserve full attention. Part of this step involves the compilation of map of processes which characterize the manufacture of copper wires. [7]

**Measurement -** discrete random variable, as a fundamental characteristics of measurement, characterize the number of turns, Le. turnings of the meter-long section of an 08 mm by 360° It was called the "turn to tear". Measurements were performed in the concrete conditions of the production line. For economical reasons, however, testing or verification of hypotheses has been performed under laboratory conditions. In laboratory conditions has to be optimized the entire technology process of copper wire manufacturing in order to achieve the required parameters.

**Analysis -** aim was to achieve a next status: to prevent copper wires with required parameters from tearing in the process of manufacturing, while retaining the required quality in term of properties. To achieve this solution, we have decided to adopt the Plackett-Burman plan, Le. monitoring of 14 factors affecting the tear of wire at the customer's places. As monitoring of the main echoes was necessary to be performed with customers agreements, we have to be focused explicitly on monitoring of the echoes "turn to break" (Figure 2.) process. Two levels were assigned to each factor. The experiments have proven unambiguously the factor of purity of the copper.

The reports involve, apart from the histograms and box-plot graphs, also the results of the Anderson DarIing test for normality, which in both cases has proved positive. Except the basic characteristics of files,

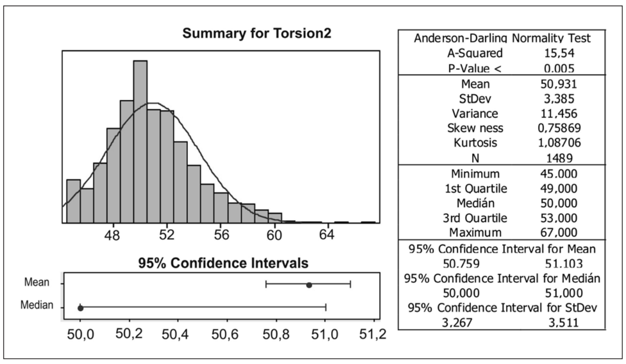


**Figure 2.** Results of the turn to tear test Oxygen

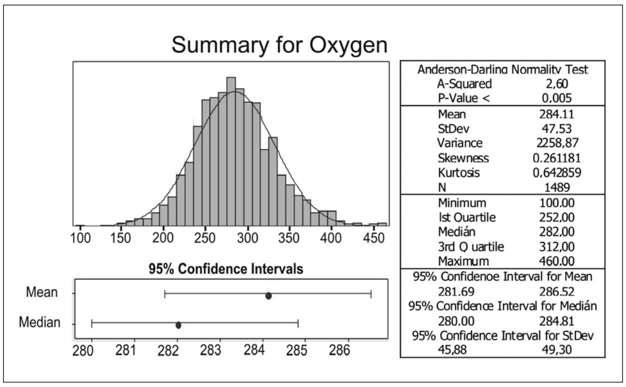


Figure 3. Results of the test focused on oxides of the surface

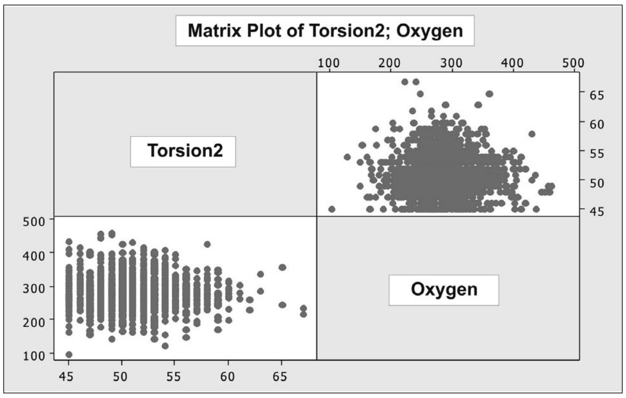


Figure 4. Paired correlation diagrams of the "turn to tear" variables and the surface oxide contents

they also provide 95 % confidential intervals for the mean value, median and the standard deviation.

**Suggestions for improvements -** aimed at reducing the contents of surface oxides causing tear of Copper wires. Based on this results, obtained both form the Analysis and the laboratory Measurements, we can formulate the hypotheses as follows:

**Hypothesis 1**: Apart from the laboratory findings of cast particles in a basis of iron, the tears are significantly affected also by the purity of the copper. Only through increasing the purity of copper is it reasonable to increase the temperature of the cooling medium.

The results of planning the experiment, forms the documentation of formulating the Hypothesis l, bear no statistical importance. Consequently, additional experiments has to be performed as soon as the manufacturing process of copper wires has been launched. In case when the Hypothesis I is confirmed, it would justify the beginning of the process of improvement in the Electrolysis operation which is responsible for the production of pure copper cathodes. [6]

**Hypothesis 2**: On the basis of laboratory results the breakages are indisputable influenced, with the amounts of oxides, on the surface of wire.

The values achieved on the Copper Wire Plant, have exceeded the required limit value for abt. 2000 A, recommended on the basis of professional literature, even the value of 2400 A, as the boundary limit of the simulation results, is performed under laboratory conditions. Therefore, following the launching of the production and experimental confirmation of the existing status, the value of 2000 A is to be defined as the up limit of critical parameter of improvement - the amount of oxides on the wire surface. It is also necessary to continue with monitoring of the mentioned parameter and to define the limit of 2000 A, as a basis for measurement of the viability of the entire process [5].

**Hypothesis 3**: Parameter "turn to break" correlates with the number of tears, presumably caused by the oxides of copper.

The correlation analysis demonstrates no interdependence between the parameters, which means between "turn to tear" and the oxide contents and is unable to disprove it in a significant way. Ič was appropriate to verify this interdependence through experiments on samples with oxide layer amount less than 2000 A (Figure 4.).

**Hypothesis 4**: The increased contents of oxides in the Copper Wire Plant are linked with the repeated milling in the oxide layers, formerly subject of the removal process. The Hypothesis 4 forms the bas ic assumption, the validity of which could substantially improve the critical parameters, in terms of the quality of the wires manufactured in the given plant. The hypothesis is based on laboratory findings which main value was on the level of 2162.9 A. However, the variability is characterized by a standard deviation only on the level of 121.3 A. The samples obtained at laboratory experiments (Figure 5.) are characterized by a mean value of 2841.1 A. with variability determined by the standard deviation at the level of 475.3 A.

The apparent disproportion between the main value and the change in the variability shows, at similar differences of temperature, it is possible to assume further influencing factors that are, unlike the laboratory environment, still present in the manufacturing process. The results obtained directly from the manufacturing process, (Figure 6), are in compliance with the previous findings and indicate a possible cause to deterioration, i.e. "bandaging". If the higher surface oxide contents were

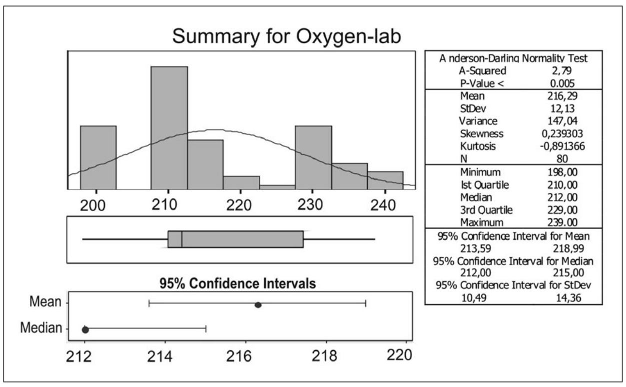


Figure 5. Oxides of the wire surface under laboratory conditionsbasic statistical characteristics

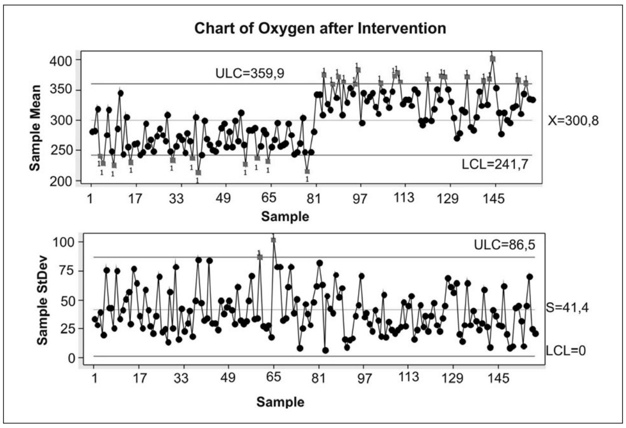


**Figure 6.** X-S Oxygen Chart - in the manufacturing process

caused by the continually acting of oxygen, then the variability of the individual measurements would be roughly the same, i.e. either of those acquired in the lab or those obtained under manufacturing conditions. This assumption was derived from the analogous nature of the random variable. If, however, the higher contents of oxides were caused by minute abt I mm size oxide scales (found in higher amounts by de-bandaging, at the same time forming part of the emulsion), then interpretation of all the contradictions should result into Hypothesis 4.

In case of proving Hypothesis 4, what we suggest is to ensure better purification of the emulsion and develop further technical measures that would minimize the possibility of repeated milling-in the already "peeled off" oxides back into the copper wire surface. With regard to the critical nature of the mentioned parameter, it would be possible, with all the previous hypotheses remaining valid, to expect Improvements at the customer in view of the dustiness present at tandem dragging machines but also in the light of potential tear.[8]

**Control -** this step within the DMAIC methodology, closing the cycle of improvement, is focused on controlling the concrete technical parameters verified during the previous steps as the critical steps of improvement. In case the Hypotheses 1-4 are held valid (it is about the presumptions to be verified in practice), as critical factor of improvements in the Copper Wire Plant of the given company is assigned to the parameter of oxidecontents along the wire surface. It is parameter which, on the basis of the QFD analysis, strongly correlates with the customer requirements and is measurable by described electrolytic method. There are indirect indications that the significant factor, which influencing the tears on the customer side, is also higher level of dustiness when pulling the wires on tandem dragging mechanisms.

## CONCLUSION

The implementation of the system of improvement, known as the Six Sigma, is rare. Within the cycle of improvement by DMAIC, which is the methodology of tool implementation tools within the Six Sigma System, there have been suggestions for modem statistical methods. Some of them are have been subjected to pass thorough modifications which will make them suitable for the concrete types of the parameters for the sub processes that occur in the course of copper wire milling.

Possibility and justification of applications of new, sophisticated statistical methods under the practical conditions in the manufacturing process has been presented as a synergic sequence of individual procedures, as part of the DMAIC techniques.

The results of one of the analyses were used as the input for the development of new approach and method. The decision-making on the particular steps were based on the facts and was making to create the all-round structure typical for the Six Sigma Methodology. It formed the basis for the development of a stochastic model, comprising the performance and efficiency parameters, to serve the process of continuous improvement.

The achievements lead to draft of the experimental plans which can help in setting the parameters representing the inputs to the individual stochastic models of real production.

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**Note:** The responsible for English language is the Author Z. Hajduová.