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EFFECTIVE APPLICATION OF STATISTICAL PROCESS CONTROL (SPC) ON THE LENGTHWISE TONSURE ROLLED PLATES PROCESS

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This paper deals with the effective application of SPC on the lengthwise tonsure rolled plates process on double side scissors. After explanation of the SPC fundamentals, goals and mistakes during the SPC implementation, the methodical framework for the effective SPC application is defined. In the next part of the paper the description of practical application of SPC and its analysis from the point of view of this framework is accomplished.

Key words: Statistical process control, complex application, effective application, problem solving process, SPC cycle

Djelotvorna primjena statističke kontrole procesa (SKP) rezanja uzdužno namotanih limova na škarama. Ovaj članak opisuje djelotvornu primjenu SKP na proces rezanja uzdužno namotanih limova na škarama s dvostrukom oštricom. Nakon objašnjenja osnova SKP, ciljeva i grešaka kod primjene SKP, metodski okvir za efektivnu primjenu SKP je definiran. Sljedi opis praktične primjene SKP i njegove analiza sa stajališta da je opisani okvir primjene kompletan.

Ključne riječi: Statistička kontrola procesa, kompleksna primjena, djelotvorna primjena, proces rješavanja problema, SKP ciklus

INTRODUCTION

Statistical process control (SPC) is an approach to process control that has been widely used in many industrial and non-industrial fields. SPC is based on the so called Shewhart´s conception of the process variability. This conception distinguishes variability caused by obviously effecting common causes (the process is considered to be statistically stable) from variability caused by abnormal assignable causes (the process is considered not to be statistically stable) [1].

The main function of SPC is to reduce variation in an output characteristic by detecting the change of a process input [2]. Meeting this goal is affected by various technical, statistical, organizational methodical and economical factors [3], [4]. But in practice there are many factors mentioned above that are not considered when implementing and applying SPC. It often led to ineffective and failure applications and to de-motivation of users [3]. The SPC utilization is often predominantly aimed at plotting points in the control chart without analysis of the process variation [2], [5]. Kelly & Drury [3] state that a battle between reaction to non-stability signals and ability to meet production plans result in de-evolution of SPC.

Only the process monitoring is not sufficient for meeting the main function of SPC. SPC must be built as the problem-solving process and the sequence of subprocesses "Out-of control signal revelation – Root cause identification – Corrective or improvement action acceptance – Verification of action" must be the axis of every SPC application. All other factors must support these activities.

To meet the goals of SPC and to keep off the imperfections defined above, the SPC application must be complex and effective and SPC must be realized as a problem-solving process.

The main contributions of this paper are:

- defining the methodical frame for the complex and effective application of SPC based on not only statistical factors
- four-phases cycle where outputs of the previous phase are inputs for the consecutive phase and the phases are repeated whenever it is needed for
- problem-solving that runs through all phases
- incorporation of the measurement system analysis and capability analysis as integral parts
- openness toward various other statistical, technical and economical analyses as tools of searching for corrective actions and improvements and for verification of their effectiveness
- demonstration of all mentioned features of the proposed methodology on the practical application in metallurgy which has brought practical results in the form of measurement system improvements;
- design of the instrument for objectification and standardization of the process of assessing the size of the rolled plate width allowance
- optimized algorithm for setting the scissors;
    - economical savings;
    - revelation of other improvement potentials.

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METHODICAL FRAMEWORK

Defining complex and effective application of SPC

Complex application of SPC is such application that is realized considering the whole complex of technical, statistical, methodical, organizational and economical factors and that is implemented in the frame of the following four phases as a problem-solving process.

Preparatory phase: The presented concept of the complex and effective application of SPC sees the measurement system analysis (MSA) as one of the obligatory and integral parts of SPC. Theoretically capable measurement system is presumed. But in practice it is very often forgotten to verify and eventually ensure high quality data before their processing and interpretation. Specification of possible causes of the process variability based on the knowledge and analysis of the process and definition of the rules for the process instability evaluation are the next key parts of the preparatory phase that are often missing or realized incorrectly.

Phase of verification and ensuring process statistical stability: This phase is realized through the data collection, construction and interpretation of control charts and eventual application of corrective actions or improvements. Statistical stability is a precondition for the next phase.

Phase of verification and ensuring process capability: Verification of the process capability and eventual process analysis to reveal the opportunities for the process improvement and its realization are the main goals of this phase.

Phase of the ongoing statistical process control: In this phase standardized utilization of the accepted improvements and maintenance of the new reached level of the process variability using control charts have to be realized. It must be supported by the delegation of new responsibilities and authorities.

Effective application of SPC is such complex application which results in the process improvement, i.e. reduction of the process variability and reveals the potential for the next improvements.

SPC as a problem-solving process

SPC must be built as a problem solving process that runs through all four phases defined above. During the step of the SPC design general structure of the problem-solving process must be respected. It means realization of the following steps: Problem identification; Problem causes detection; Generation of solution alternatives; Choice of alternative; Implementation of choice alternative; Evaluation of the choice alternative effectiveness and relevant revision.

COMPLEX AND EFFECTIVE SPC APPLICATION IN PRACTICE

The methodology defined in the previous chapter was applied on the lengthwise tonsure rolled plates process with the goals to produce rolled plates with the allowance for width as small as possible (minimization of the production cost) and to reduce the probability of the defective plate occurrence.

I. Preparatory phase

During the preparatory phase the oncoming activities were realized:

- Process definition: Lengthwise tonsure rolled plates process was selected due to its potential for improvements with indispensable economical benefits.
- Defining the controlled quality characteristic: Allowance for the rolled plate width on the under surface is crucial for the meeting the plate width specifications. Thanks to the technology of lengthwise tonsure the under surface width is less than the upper one.
- Specification of the key possible causes of the process variability: Based on the knowledge of the process and statistical analysis of some factors the wearing and resetting of the scissors, the measurement system capability, the plates temperature before tonsuring and the way of the operator judgement of the plate width allowance were set as the main potential causes of the process variability.
- Realization of MSA: Due to the revealed non-capability of the applied measurement system during the initial MSA the analysis had to be repeated to verify the effectiveness of accepted corrections and improvements of the measurement system.
- Control interval setting: On the basis of knowledge of the process (slow change of assortment (rolling campaigns), slow wear of scissors, automatic resetting of scissors) 4-hours control interval was set as optimal.
- Subgroup size setting: Due to the long control interval it was decided to make subgroups of 1 piece of the plate.
- Target value of the controlled quality characteristics. On the basis of the knowledge of the process and economical consequences it was set 3 mm. This value is a compromise between economically motivated production as close as possible to the lower specification and minimization of the probability of the defective plate occurrence. Control charts selection: Based on the subgroup size the charts for individuals and moving ranges were selected.

Definition of the rules for the process instability evaluation: It was decided to apply two rules:

- Any single point outside the control limit;
- 6 points in a row trending up or down.

II. Phase of verification and ensuring the process statistical stability

Using selected control charts for individuals and moving ranges and applying the selected instability tests the process statistical stability was verified. Because no point was out of the control limits (LCL or UCL) and no trend was detected in these control charts the process could be considered to be statistically stable. The results of this phase are discussed in more detail in the next chapter.

III. Phase of verification and ensuring the process capability

Capability indices C_p and C_{pk} were computed and compared with the minimal target value 1,33. Due to the value of C_{pk} the process could not be treated as capable. An analysis of the causes of this situation using Ishikawa diagram was then realized and the key cause was set. To despatch this problem improvement action was designed, implemented and verification of the process statistical stability and capability were repeated. The results of this phase are discussed in more detail in the next chapter.

IV. Phase of the ongoing SPC

Because during the former phase the process statistical stability and capability were ensured it was possible to incorporate the proposed SPC system into the standard control system of the production unit. The improvement remedy (the implemental excel sheet) has been currently applied by operators and statistical stability has been monitored using control charts. The new responsibilities and authorities were delegated to the quality managers and operators.

RESULTS AND DISCUSSION

The initial MSA showed that the measurement system was not acceptable (the complex index of measurement system capability % GRR is 36,1 % and another indicator ndc = 4).

The rules of thumb for acceptance of the measurement system are: % GRR ≤ 30 %, ndc ≥ 5. More detailed rules for % GRR used in the analysed application are in the following table.

Tablica 1 **Rules for the measurement system capability evaluation**

% GRR	Conclusions
< 10 %	Measurement system is acceptable.
10 % - 30 %	Measurement system may be acceptable based on the application (contingent upon its importance in application, cost of its replacement or its repair).
> 30 %	Measurement system needs improvement (sources of excess variation must be identified and system must be improved).

During the team-made analysis of the causes of the measurement system non-capability four root causes were set using Ishikawa diagram and Pareto analysis:

- Low measurement scale of the tape line
- Unsuitable location of the halogen lamp
- Violation of rectangularity of the tape line location
- High temperature of the measured plate.

As a result of the former analysis the following actions were set and realized:

- Application of the new tape line with higher and more marked scale;
- Implementation of the instruction for operators to keep urgently the rectangularity of the tape line location;
- Change of the lighting location;
- Implementation of instruction to minimize time for apposition of the tape line and for making measurement.

MSA was repeated in the new conditions and the measurement system improvement was shown (the complex index of the measurement system capability % GRR equals 22,8 %, ndc = 6). All possibilities to improve the measurement system still better and cost consequences of it were analysed. It was concluded that further improvements currently were not possible. After the cost analysis of the present measurement system replacement it was concluded that after improvements described above the existing measurement system could be considered to be acceptable and the following data analysis could be regarded as reliable enough.

After the process and data analysis correctly selected control charts (Figure 1 and 2) were applied to verify the process statistical stability.

The rules for the process instability evaluation defined in the preparatory phase were applied. Because no point has been out of the control limits (LCL or UCL) and no trend was identified the process could be considered to be statistically stable.

The key condition for the next phase was confirmed and verification and ensuring the process capability could follow.

The capability indices C_p and C_{pk} were computed. C_p is 3,09 and C_{pk} equals 0,98 (1640 nonconforming products per one million products). Because the target value for capability indices was set 1,33 it means that the process could not be considered to be capable. The analysis of the causes of this situation using Ishikawa diagram and statistical analysis were then realized. High variability in the allowance for the width on the upper surface of the plate before cooling of the plate leading to the high variability in the actual width on the under surface of cooled plates was identified as a key cause. The reason was that values of the allowance for the width on the upper surface of the plate before cooling were based on operators´ own subjective judgement. Every operator had to take into account the temperature, thickness and width of the plate and the previous measurements of the actual plate

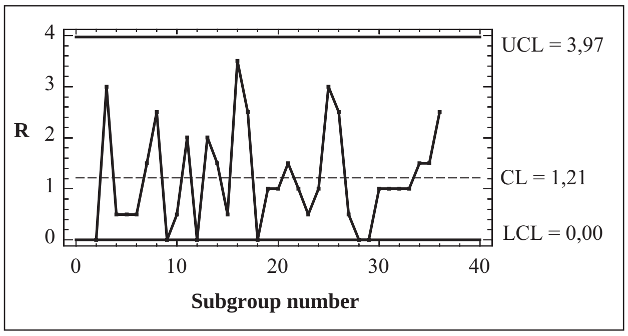

Figure 1 Control chart for moving ranges

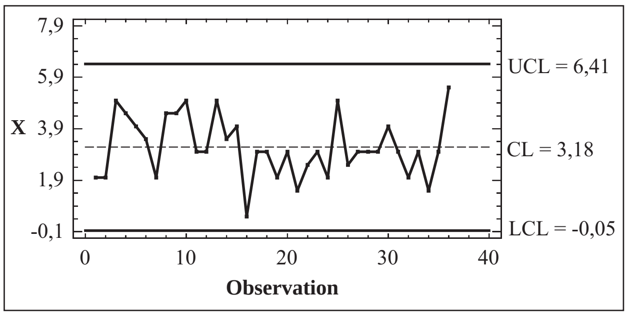

Figure 2 Control chart for individuals

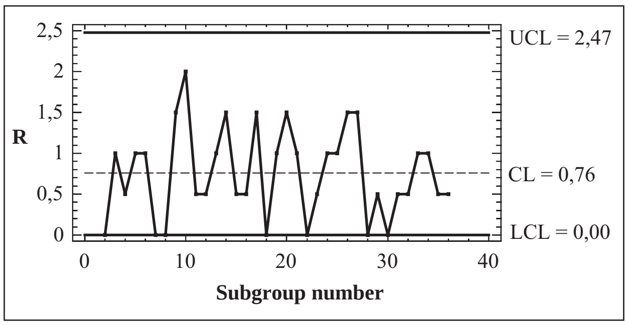

Figure 3 Control chart for moving ranges after improvement

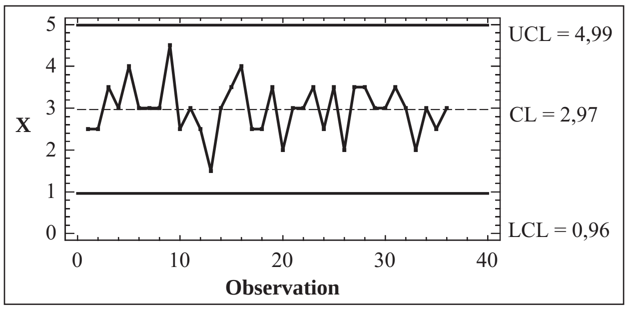

Figure 4 Control chart for individuals after improvement

width over wide assortment of the plates. To despatch this problem an instrument for objectification and standardization of the procedure for this judgment was proposed. The implemental sheet called "Monitoring of the width allowance" for more objective judgment of the plate width and for optimal setting of scissors was designed. After insertion of nominal value of thickness and width and actual temperature of the plate this excel application immediately offers to operator information about the suitable width allowance to reach for the optimal value of the width allowance on the under surface (3 mm) after cooling to 20˚C**.** The design of the implemental sheet allows for two important factors that have significant influence on the final plate width after cooling: material temperature expansivity and dependability of the difference between the upper surface and under surface width on the plate thickness. The mathematical description of this dependability is based on the regression analysis resulting in the following relation:

$$\Delta b = 0{,}359168+0{,}0865762\ .\ c, \qquad (1)$$

where:

Δb - difference of widths,

c - thickness of plate.

This analysis confirmed the operators´ experience that the algorithm of the present computer control system for setting the scissors gap had not been exact.

Verification of the correctness and efficiency of the proposed implemental sheet is based on the hypothesis that standard deviation of values of the allowance of the rolled plate width on the under surface is less than before application of the sheet and mean of these values is more closely to the optimal value of 3 mm. Before the confirmation of the hypothesis by the repeated capability analysis the new evaluation of the process stability using again control charts for individuals and moving ranges was realized (see Figures 3 and 4). Because the analysis of the control charts did not reveal any point out of control limit nor any trends the process after application of the "Implemental sheet" could be considered to be statistically stable. Then the capability indices were computed: C_p equals 4,96 and C_{pk} equals 1,47. The both indices are greater than 1,33. It means that the process could be considered to be capable. The increase of the capability results from the reduction of standard deviation and from mean lying more closely to the optimal value. It is an evidence of the process improvement.

The economical effect of this improvement is equal to the cost savings in an amount of nearly 2 M CZK / year. This results from the fact that with smaller width allowance the producer gives to the consumer "gratis" less material that stays at him and could be used as a quality melting charge.

The proposed SPC system was incorporated into the standard control system of the scissors. The implemental excel sheet has been currently applied by operators to support their more precise assessment of the plate width and statistical stability has been monitored using control charts. The new responsibilities and authorities were delegated to the quality managers and operators.

CONCLUSION

The analysis of the application of SPC on the lengthwise tonsure rolled plates process showed that it had been implemented in a complex and effective way. It was realized in all four phases considering many organizational, methodical, technical, statistical and economical factors. SPC was also realized as a problem-solving process. Owing to cost savings this application can be viewed to be effective, too. During this implementation of SPC there were revealed next potentials for the future improvement and for another cost savings: change of the gauge for measuring width of plates, incorporation of the algorithm contained in the implemental sheet "Monitoring of the width allowance" into the automatic control system of the scissors and automatic reading of the plate temperature.

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