D. NOSKIEVIČOVÁ, B. WOSKA

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DESIGN OF METHODOLOGY FOR APPLICATION OF STATISTICAL CONTROL ON SHORT RUN PROCESSES IN METALLURGY

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So called short run manufacturing environment is now typical for many industrial branches including metallurgy. To be applicable in such nonstandard conditions classical control charts and capability indices must be modified. In this paper the design of the methodology for the complex application of the statistical control on the metallurgical short run processes is presented and verified in conditions of the bars rolling.

Key words: metallurgy, bars rolling, short run processes, control charts, capability indices

INTRODUCTION

So called short run (SR) environment is nowadays typical for many industrial branches including metallurgy. SR processes are characterized by quite a wide variety of mixed products with relatively smaller lot or batch sizes. These conditions have resulted from the growing product customization, higher and higher production flexibility and larger stress on the high quality and low costs. The changing economic and production conditions in metallurgy are discussed in the wider context for instance in the papers [1] and [2]. In such conditions the conventional methods of statistical process control (SPC) and the capability analysis do not work. Some aspects of the application of SPC and the capability studies in metallurgy were discussed in the paper [3]. To be able to offer some meaningful information about the process stability and its capability the SPC and the process capability analysis must be modified for the SR processes. The design of the methodology for the complex SPC application in the conditions of the metallurgical SR processes is the main output of this paper. It is based on the critical analysis of the available control charts and the capability indices for the SR processes. This analysis forms the main contents of the analytical part of the research. The proposal of the methodology is based on the idea that SPC must be applied in a complex way where the capability analysis is an integral part of it. In the experimental part this design was applied in the conditions of the profile bars rolling. Such combined analysis and application of SPC including the capability study for the SR processes in metallurgy has not yet been found in the professional literature.

D. Noskievičová, Faculty of Metallurgy and Materials Engineering, VŠB-TU Ostrava, B. Woska, Viadrus, a.s., Ostrava, Czech Republic

ANALYTICAL PART

The analytical part was focused on the following aspects:

- SR SPC methods with special stress on the methods for variables**;**
- methods for evaluation of the variation representativeness;
- capability indices for SR environment including confidence intervals of capability indices.

Many proposals for applying the control charts in special conditions of a SR production have been offered up to now by many authors (for instance [4 - 9]). The most exhaustive review of the SPC methods for the SR conditions is offered by P. F. Tang [10]. In the analytical part different control charting methods have been evaluated using the factors such as the rate of maturity, practical usability, relative simplicity, predominance of the advantages compared with the disadvantages, the rate of the maturity. The result of this analysis is the decision tree (see Figure 1).

When selecting suitable SR control charts the assumption that the process standard deviation is approximately the same for all the parts must be tested in some cases (the target control charts). In the professional literature several methods for evaluating the process variance homogeneity can be found: the chart for mean ranges (R-bar) [7], the range test, [5], the F-test [5], the Bartlett test, the Levene test, the Brown-Forsyth test, the Cochran test, the Hartley test. These methods were analysed considering their complexity, precision, sensitivity to particular assumptions and their availability in the common SW products. The advantages and the disadvantages of the selected methods were then defined to offer users a simple methodology for their application in connection with the selection of a suitable SR control chart (see Table 1).

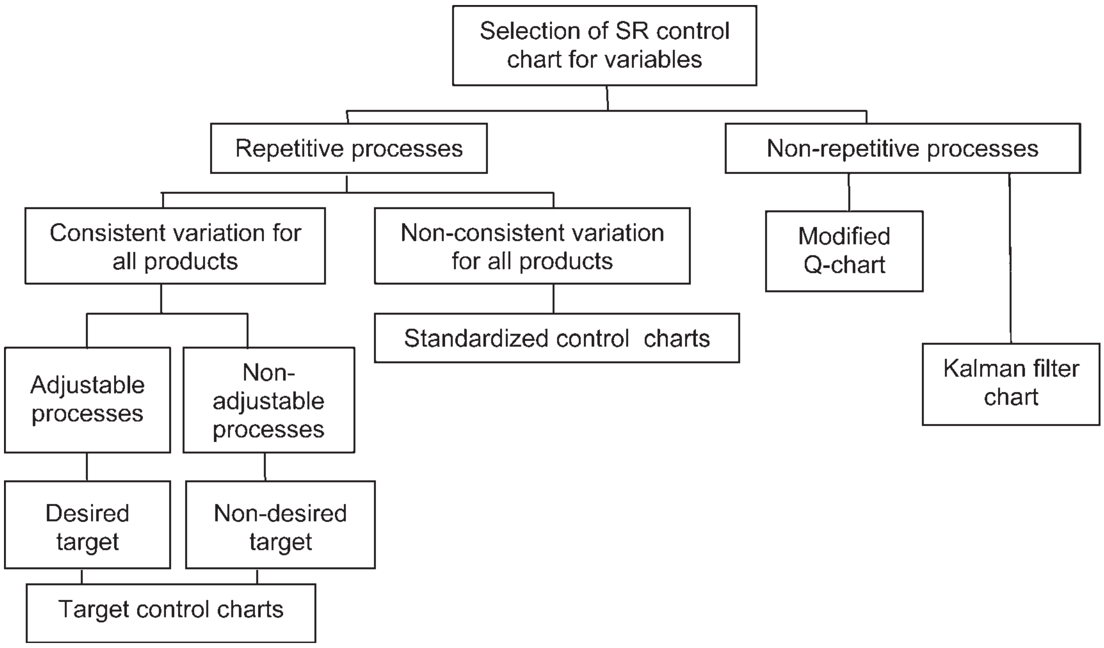

Figure 1 Decision tree for selection of the SR charting method [10]

As compared to the amount of papers and other professional literature dealing with the various control charts for SR manufacturing there are only several authors solving the problem of the capability analysis for the SR conditions in detail (for instance [11, 12]). After analysing the different approaches to the SR capability indices the authors of this paper divided the SR capability indices into 5 groups:

- Type A capability indices C_p, C_{pk} for the processes with consistent variation for all products computed from the transformed data (deviations from the target value).
- Type B capability indices C_p, C_{pk} for the processes with consistent variation for all products computed from the original measurements.
- Type C capability indices C_p, C_{pk} for the processes with non-consistent variation of all products. These estimations are not often based on the sufficient data amount. For that reason the capability indices of type C are not very precise.
- Type D capability indices C_p, C_{pk}, using unification of the different tolerances based on

the linear transformation of the measured values. The unified tolerances can lead to the situation when highly capable product will hide the non-capable products and vice versa. For that reason the so called diagrams ($\bar{y}$, s) should be added [11].

Type E capability indices C_{pm} and capability run chart [12].

Table 1 **Methods for evaluation of the variation representativeness [5, 7]**

Method	Advantages	Disadvantages
Chart for mean ranges (R-bar)	Graphical display of all evaluated products Clear and quick answer Simply programmed	Less precise measure of variation
Range test	Simple Clear decision rule	Less precise
F-test	More precise than methods above Simple Standard part of the majority of SW products	Suitable for comparison of only 2 samples Sensitive to departures from normality
Bartlett test	Suitable for *k* samples Test with high power	More complicated Sensitive to departures from normality
Levene test	Suitable for *k* samples More robust test	more complicated less powered
Brown-Forsyth test	Suitable for *k* samples Most robust test	not standard part of every statistical SW product
Cochran test	Suitable for *k* subgroups More simple	Suitable only for samples of the same size Sensitive to departures from normality Not standard part of every statistical SW product
Hartley test	More simple method For *k* samples of the same size	Less powered Sensitive to departures from normality Not standard part of every SW product

METHODOLOGY DESIGN

Based on the main idea of the authors´ research and on the conclusions of its analytical part, the proposal for a practical complex implementation of SPC including the capability assessment in the conditions of the repetitive SR processes was proposed (see Figure 2).

EXPERIMENTAL PART

The proposed methodology was verified in the conditions of the profile bars rolling. This production has typical features of a repetitive short run process. The first two steps of the proposed methodology (see Figure 2) can be described as follows:

- *Selected process*: profile bars rolling;
- *Product family*: hot rolled steel L bars;
- *Products:* 3 products of one type different in dimensions with tolerances 20 ± 1 mm, 30 ± 1 mm, 40 ± 1 mm;
- *Quality characteristics*: the arm width / mm.

The homogeneity of the process variation was verified using the control chart for *R*-bars (see Table 1). It was selected due to its simplicity and its graphical output. Based on the results of this analysis and on the definition of the sample size $n = 4$ (randomly selected from the bunch), the SR target *x*-bar and range control charts were selected (see Figure 1). The control interval was defined as every 2nd bunch. The capability indices of type A were applied including the computation of the confidence intervals.

RESULTS AND DISCUSSION

The quality characteristics was selected on the base of the analysis of rework and the claims in the bar rolling process as well as the customer requirements. The product family (hot rolled steel L bars) was created on the base of the analysis of the orders repeatability, the volume of the particular orders and the technological similarity.

The applied measurement system analysis MSA led to the sufficient result: the complex index of the measurement system capability *GRR* = 22,18 % (for more information about the evaluation of these indicator see [3]).

The measurement system then could be considered acceptable for the following statistical analysis. In spite of this result it was decided to improve the capability of this measurement system by implementing the working instruction for the data collection and record.

The chart for the *R*-bar (see Table 1) showed that the variation of the rolling process can be considered homogenous for all the analysed products.

The target range control chart, where the range *R* for every sample was depicted, confirmed the results of the previous process homogeneity analysis. The SR target *x*-bar control chart, where the difference $(\bar{x}-T)$ between the average and the target value for every sample was depicted, showed that the stability with regard to the process level is influenced by the same cause irrespective of the particular products. It was revealed that it was an influence of tampering the process by the operators.

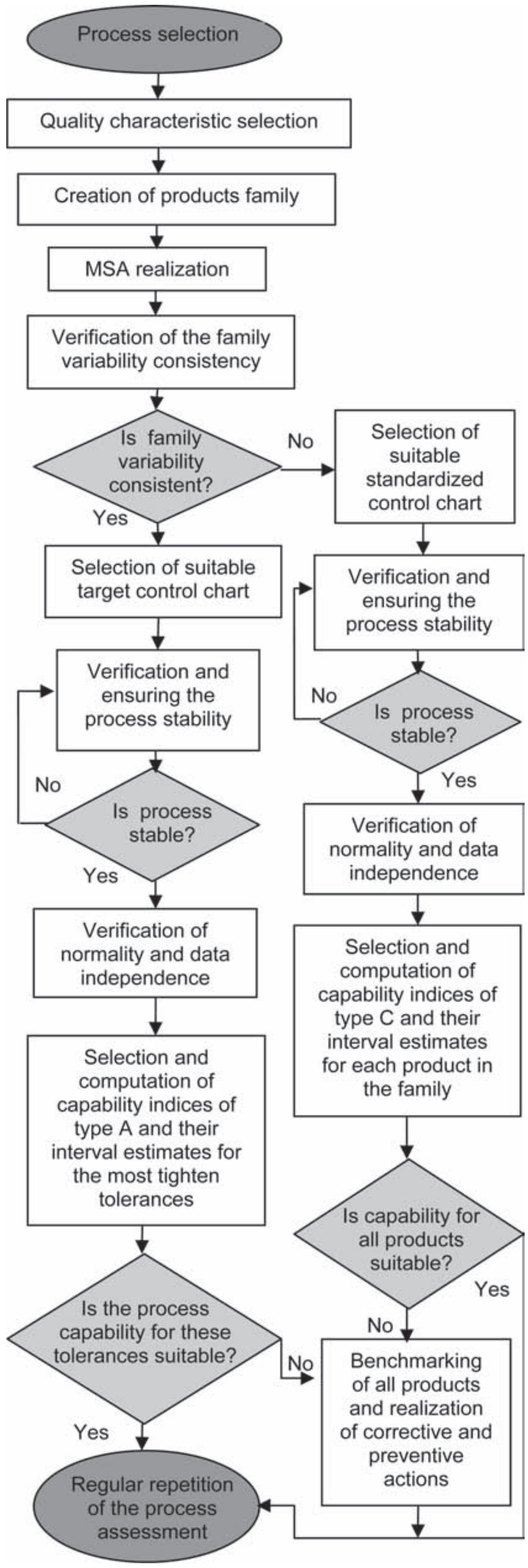

Figure 2 Steps of the designed methodology

The data normality and the data independence for every product were verified using suitable statistical tests (the Shapiro – Wilk test, the test for the sample skewness and kurtosis, the test for randomness) and graphical tools. The results of this analysis showed that the data could be considered normally distributed and independent.

The capability analysis was done using the capability indices of type A with the confidence intervals as the best solution with regard to the applied control charting method. The values of the indices and the confidence intervals are the same for all products due to the fact that all three analysed products had the same width (see Table 2).

Table 2 **Capability indices**

C_p / - 1,2,3	C_{pk} / - 1,2,3	Confidence interval limits for C_p / -		Confidence interval limits for C_{pk} / -	
		Lower	Upper	Lower	Upper
1,46	1,45	1,2775	1,6425	1,276	1,624

It was clear that the process had to be improved to reduce the risk of the true value of C_{pk} being less than the obvious target value of 1,33.

During two months after the first analysis, SPC was applied on a regular basis and the operators started to decide about the process adjustment according to the information from the control charts. It led to the reduction of the process variation (see Figures 3 and 4) and to the reduction of the scrap by 14,2 t per these two months.

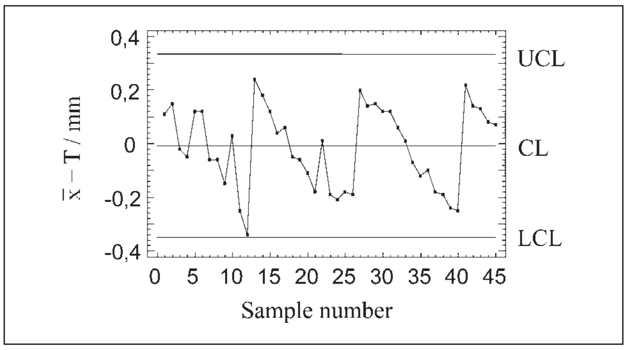

Figure 3 Process variation at the beginning of the SPC implementation (Target x-bar control chart)

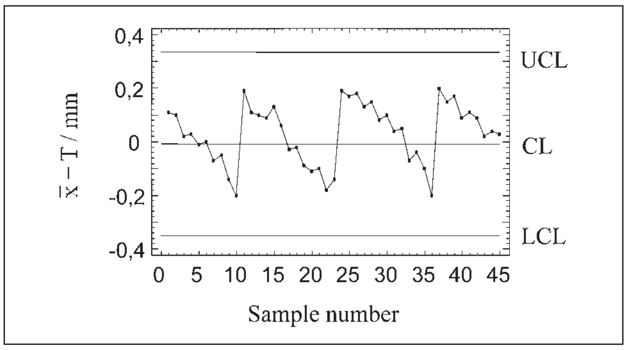

Figure 4 Reduction of the process variability after two months (Target x-bar control chart)

CONCLUSIONS

The main output of this paper was the original design of the methodology for the complex SPC application in the conditions of the SR processes. It was based on the critical analysis of the available control charting methods and the capability indices for the SR processes conditions. In the end, this proposal has been applied in the real conditions of the profile bars rolling. The gained results showed that the proposal was applicable and led to the reduction of the process variability and to the significant scrap reduction.

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Legend of symbols

R	range / mm
R-bar	mean range / mm
x-bar	mean / mm
C_p	process capability index / -
C_{pk}	critical process capability index / -
C_{pm}	Taguchi´s capability index / -
$\bar{x}-T$	difference between the mean and target value / mm
n	sample size
GRR	index of gage reproducibility and repeatability / %

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Note: The responsible for English language is: Otilia Drottnerová, Department of Foreign Languages, VŠB-TU Ostrava, Czech Republic