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Statistical control of the production process of rolled products

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Abstract
The article presents the results of the use of SPC tools, i.e. control charts and indicators of the qualitative capability to assess the stability and capability of the production process of rolled products - I-sections. Statistical analysis of the collected data regarding the selected feature of the analysed product - the width of the foot, and the normality of the distribution were done, which showed that the obtained distribution of measurement results is not a normal distribution. As a result, appropriate SPC procedures for non-normal distribution were used. The Pareto-Lorenzo diagram and FMEA method were also used to obtain information about the structure of non-conformities of the analysed product and the level of risk associated with them. This information was used to propose corrective actions and improve the production process of rolled products.

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1. Introduction

Each process requires inspection, supervision and control in order to ensure the highest quality of offered products or services. Statistical Process Control (SPC) is the most important set of tools used in quality assurance systems (Hryniewicz, 2000). The SPC covers various activities aimed at stabilising the production process and ensuring its capacity, which allows to standardise the quality of manufactured products and reduce their level of defectiveness (Greber, 2005). In the implementation of SPC, two phases can be distinguished: achieving and improving control (engineering phase), and maintaining control (operational phase) (Amaral, 2012). One of the basic tools of SPC are control charts (Fouad, Mukattash, 2010). The control charts enable constant supervision of the process and enable its on-line control thanks to the provision of information on its progress. Application of c.ch. allows to “early sight” when the given process starts to behave in a “non-standard” manner and, if needed, to react quickly (Ignaszak, Sika, 2012).

One of the most important goals pursued by a manufacturing company is the ability of the process to meet customer requirements (specifications) (Iwaniec, 2006). This ability can be assessed using another SPC tool - capabiity indicators (Cp, Cpk, Pp, Ppk) (Hamrol, 2017).

Each modern production plant that wants to improve the quality of its products, optimize production processes and minimize the costs of poor quality should implement a program of SPC of the production process. SPC is an effective and powerful methodology for analysing, monitoring, managing, and improving process performance (Uçurum, Çolak, Çınar, Dışpınar, 2016.). If the SPC is performed properly (understanding of the nature of the statistical stability), and the process is assumed to adequate qualitative capability, the risk of producing product incompatible - due to the controlled characteristic - it is kept to a minimum (Hamrol, 2017). It should be noted that in order for SPC's to show its full potential, it need to be properly implemented and applied, respecting certain principles and assumptions which ensure that SPC tools provide accurate information on the state of the process (Greber, 2009). As Deming claimed, "*the use and understanding of control cards (SPC tools) by management is more important than their use by linear workers*" (Wheeler, 2000).

The aim of the article is to present the results of the use of SPC tools: control charts and capability indicators to assess the stability and capacity of the production process of rolled products in a metallurgical enterprise. The SPC analysis was supported by the analysis of qualitative data on nonconformities in order to propose corrective actions and improve the rolling process.

2. Experimental

The examined object is a company from the metallurgical industry located in the Silesian Voivodeship in Poland (it is one of the branches of this company in Poland). The tests were carried out on the “Large Rolling Mill” (one of the departments) in relation to the production process of wide alloy sections, type HE 400, hot-rolled, which is one of the products in the range. The assortment of manufactured products is very wide, it consists of 15 different types of products, which will be available in different varieties, versions (from 4 to even 49 versions within a given assortment group). The tested product is a the I-section wide beam of HE 400 type. The basic dimensions, which required inspection (in accordance with PN-EN 10034:1996) are shown in Fig. 1.

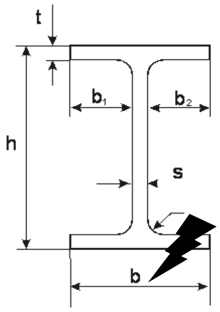

Fig. 1. The controlled dimensions of the I-section European wide beam, in accordance with PN-EN 10034:1996. Dimension *b* - width of the foot - the subject of the research

The dimension used in the SPC research was the width of the foot - "*b*". The "foot" was taken into account, which was shorter. The dimension was selected because of the differences depending on the place of the band from which the sample is taken. The width of the foot is also significantly influenced by the temperature factor, and therefore, along with the change in temperature, the dimension *b* also changes. For the other dimensions, except for the weight of the current meter of the band, the rolling temperature does not affect so much. Other factors also influence dimension *b*, such as incorrect adjustment of settings, hydraulic, mechanical or electrical malfunctions on the rolling stands or operator error.

The permissible dimensional deviations and deviations in shape and mass for hot-rolled parallel wall of I sections of structural steel with medium wide feet (I) and wide feet (H) are given in PN-EN 10034:1996. PN-EN 10034:1996 (Structural steel I and H sections - Tolerances on shape and dimensions). This standard requires that the target width for this type of I-beam section (variety A) should be 300 mm with a tolerance of ± 4,0 mm.

During sixteen hours of production of the analysed products (during two shifts of work), samples were taken from twenty bands, 4 samples from each band. Individual samples were taken as follows: 1 - beginning of the band, 2, 3 - middle of the band, 4 - end of the band.

3. Results and discussion

Firstly, the collected data on the width of profile rates (80 measurement results) were subjected to statistical analysis using basic statistical parameters such as: mean, range, standard deviation, coefficient of variation, skewness and kurtosis (Knop, Borkowski, Czaja, 2008). The results of the analysis are shown in Table 1.

Table 1. Basic statistical parameters of the foot width dataset

Variable	Descriptive statistics Mean	Minimum	Maximum	Range	Standard deviation	Coefficient of variation	Skewness	Kurtosis
Foot width	300,3800	296,0000	303,8000	7,8	2,052240	0,683225	-0,216860	-1,06887

The analysis shows that the average width of the profiles' feet was 300.376 mm, with an average variation of the results of ± 2.05 mm, the minimum width is 296 mm, while the maximum is 303.8 mm, hence the range of results was 7.8 mm. 68% of the average value is a standard deviation. Negative skewness and its value indicate that the distribution of results is slightly asymmetrical on the left (the numbers focus on high values of features), negative value of kurtosis and its value means that the distribution is more flattened than normal.

A box plot of the median-quartile-range type was used to analyse the distribution of data by these statistics (Fig. 2).

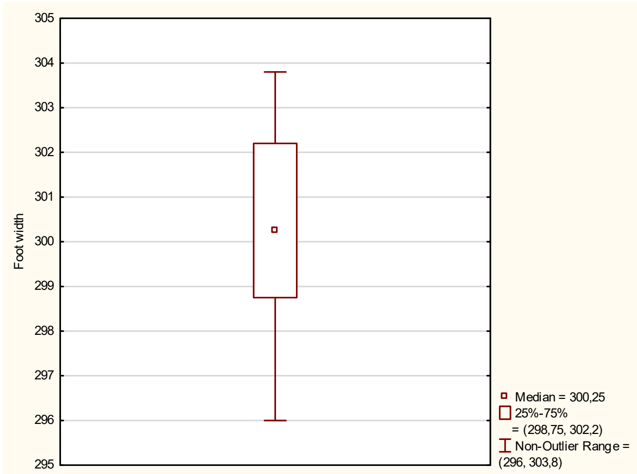

Fig. 2. Box plot of the widths of the foots.

The median is equal to 300.25, which means that the width of the feet in 50% of profiles is at most 300.25 mm. The bottom quartile is 298.75, which means that in 25% of profiles the width is at most 298.75 mm, while the upper quartile is 302.2, i.e. in 75% of profiles, the width is at most 302.2 mm. The shorter upper than lower whisker confirms the left-sided asymmetry of the entire data set, while the location of the median inside the box indicates the symmetry of the distribution of 50% of the middle results.

Next, the consistency of the collected data with the normal distribution was evaluated using the histogram shape analysis, statistical tests of Shapiro-Wilk and Lillifors as well as normality graph (Stanisz, 2007). The results of this analysis are shown in Figure 3.

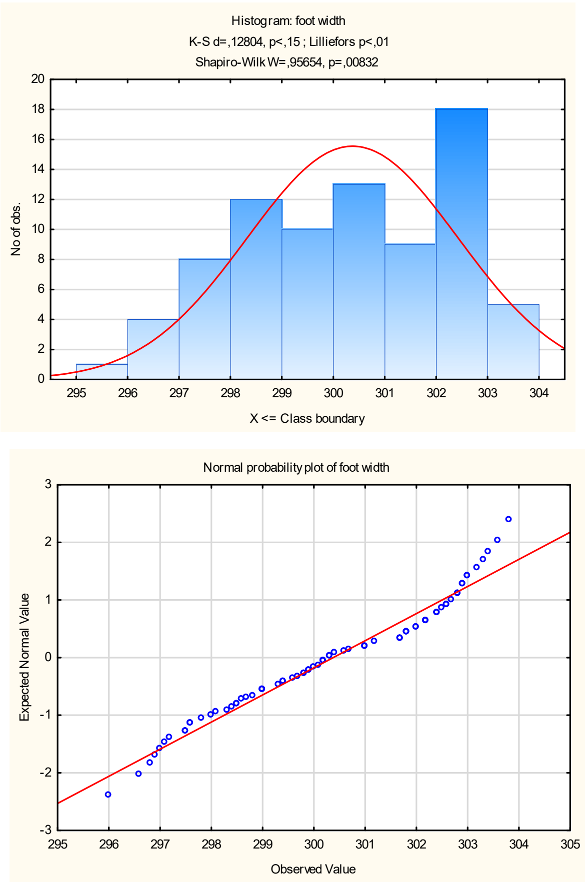

Fig. 3. Histogram with the results of statistical tests and a normality plot as a tool for assessing the conformity of the distribution with the normal distribution

The analysed characteristic does not have a distribution consistent with the normal distribution. This has been proven by all normality tests and normality graph. The characteristic has an asymmetric distribution - negative (left-sided), multi-modal.

Due to the lack of conformity of the distribution with the normal distribution in order to assess the stability of the process, the $\bar{x}$ and R chart was used, in which control limits were calculated based on so-called Johnson curves, based on skewness and kurtosis (Montgomery, 2012). The results of the construction of the $\bar{x}$ and R chart are shown in Figure 4.

By analyzing the control card $\bar{x}$, you can see that the process is unstable. The results obtained from the first and sixth samples are outside the lower control limit. If in the case of the first sample this is normal (setting the profile after rebuilding), then in the case of the sixth sample it is the so-called "red light" for the employee and the process should be stopped at this point. Although there are no trends, the runs tests (Table 2) indicated 8 points outside the C zone (from 6 samples to 13). This test indicates that the samples taken are influenced by two different factors with a binomial distribution. This is a different, additional signal about the process deregulation. The process should be stopped in order to identify the causes of the disturbances and to take appropriate corrective actions. Analyzing the R chart it can be assumed that the process is stable from the point of view of variability. The results obtained from twenty consecutive samples are between the upper and lower control limits.

Table 2. Runs tests

A/B/C Zone: 3,000/2,000/1,000 *Sigma Runs tests	**Foot widht; Runs tests X-Bar chart** from sample	to sample
9 points in Zone C or beyond (on one side of central line)	**OK**	**OK**
6 points in a row steadily increasing or decreasing	**OK**	**OK**
14 points in a row alternating up and down	**OK**	**OK**
2 out of 3 points in a row in Zone A or beyond	**OK**	**OK**
4 out of 5 points in a row in Zone B or beyond	**OK**	**OK**
15 points in a row in Zone C (above and below the center line)	**OK**	**OK**
8 points in a row in Zone B, A, or beyond, on either side of the center line (without points in Zone C)	**6**	**13**

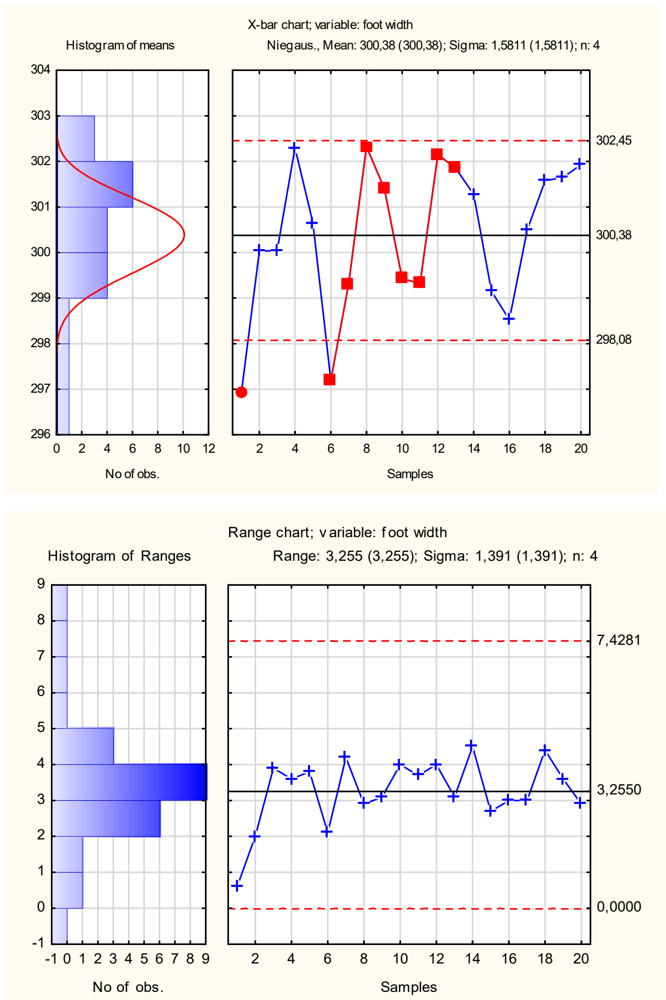

Fig. 4. The $\bar{x}$ and R chart for data regarding to the analysed characteristic - the width of the profile's feet

The EMWA chart was used to quickly detect small changes in averages and trends (to check whether there was a shift in the average process). This card is less sensitive to data that is not normally distributed (Sałaciński, 2009), which is its advantage in this particular case. The result of the application is shown in Figure 5.

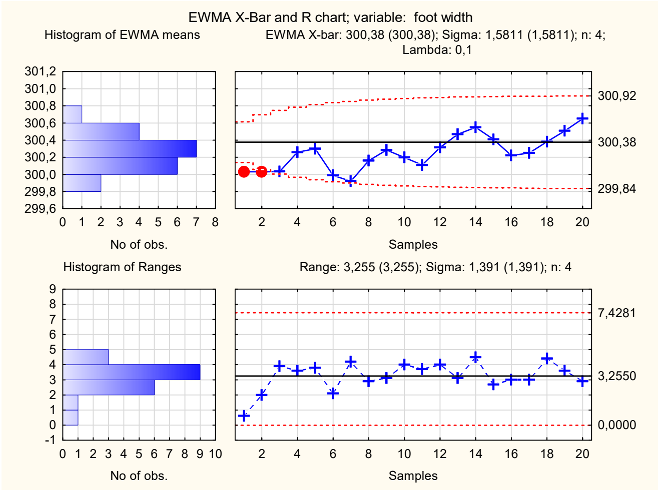

Fig. 5. The EWMA chart as a supplement to the $\overline{x}$-R card for data concerning the analysed characteristic - the width of the profile's feet

The chart showed two signals of deregulation (for samples 1 and 2). Subsequent samples show alternating upward and downward trends, as well as a shift of the average of the samples obtained towards higher values. This relationship can be seen even better if we construct the CUSUM chart (Figure 6) for individual observations (not samples). On the CUSUM chart, you can see a lot of different trends - the average takes values larger or smaller than the target, a large number of samples also goes beyond the control limits, which proves and confirms the fact that the process is unregulated.

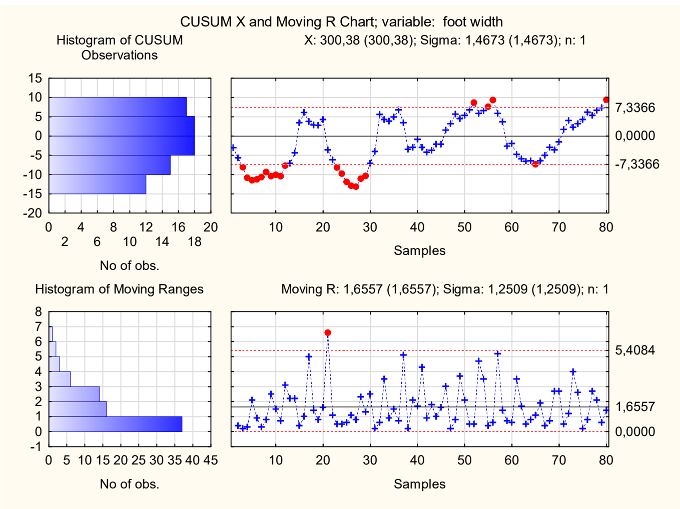

Fig. 6. The CUSUM chart together with a Moving Range chart for data regarding to the analysed characteristic - width of the profile's feet

In order to assess the process's ability to meet the requirements, Cp, Cpk capability indicators for non-normal distribution were used (Ryan, 2011). The results are shown in Figure 7.

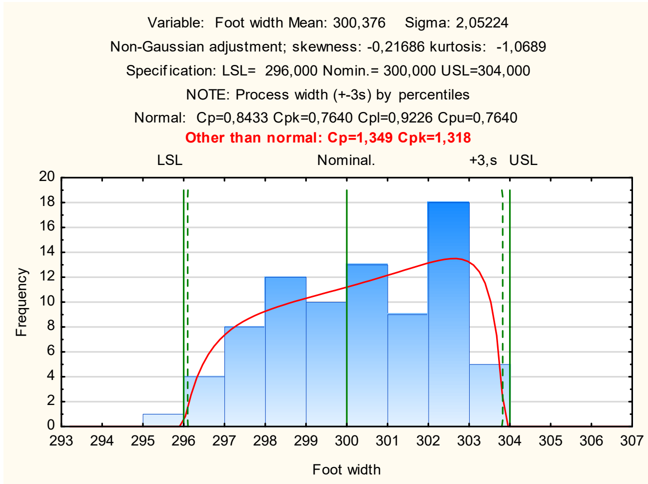

Fig. 7. Analysis of process capability for non-normal data distribution using Cp, Cpk indicators

While assessing the process using Cp, Cpk indicators, it can be concluded that the process has the ability to meet customer requirements, while the level of this ability should be considered relatively good. None of the individual observations went beyond the specification. More values of the width of the profiles are greater than or equal to the nominal value (55 out of 80, 68.75%). One should strive in the process to further reduce the dispersion of obtained values and to improve the process's centering.

The problem of the examined enterprise are nonconformities related to the analysed product. It was decided to analyse this problem using the Pareto-Lorenzo diagram and the FMEA method (Knop, 2017, Hamrol, 2018).

The Pareto-Lorenz diagram was used to analyse the structure of nonconformities occurring during rolling of sections during one year. 14 non-conformances resulted in the creation of 4726,3 tons of scrap. For each nonconformity the symbol was assigned and a ton was adopted as the unit of measure. For individual nonconformities, the percentage and cumulative share were calculated and the results are presented in the form of the Pareto-Lorenz diagram (Figure 8). On the X axis, the nonconformities in the descending order are marked, on the Y-axis on the left the number of defective products expressed in tons, and on the right-hand side the cumulative frequency of occurrences expressed in percent. The nonconformities analysed are: ŁP – Flakes and cracks steelmaking N – Non-rolling, F – Wavy finish, ND – Inadequate length, UM – Mechanical damage, K – Curves, Z – Cold shut, AŚ – Web asymmetry, PS – Foot gradient, RW – Separation, SW – Sprains, twist, NW – Not filling, PP – Longitudinal cracks, R – Abrasion marks.

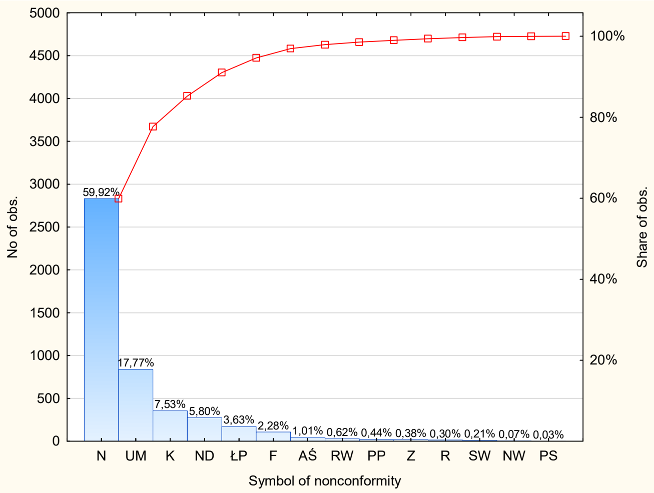

Fig. 8. Pareto-Lorenz (P-L) diagram to capture the structure of nonconformity in the rolling process.

Analyzing the P-L graph, it can be seen that two nonconformities are the cause of 77.7% of quality problems. These are non-rolling (N) and mechanical damage (UM). The remaining 12 nonconformities generate only 22.3% of qualitative problems. After the P-L analysis, it is known that the causes of non-rolling and mechanical damage should be searched for first and then eliminated or minimized.

Non-rolling is all the defects arising in the rolling process due to mechanical, electrical or technological reasons. They are continuously updated on the production report. In order to reduce their occurrences, it is necessary to increase the discipline of work and to ensure timely repairs.

Mechanical damage are nonconformities arising during the production process. They are detected most often during inspection at the finish section where such products are regenerated, reclassified or scrapped. Regeneration on a cold cut saw involves cutting out damaged pieces of material. Shorter lengths are then obtained, for which there are often no orders. If there is no customer for such a product within a certain time, it is scrapped. The view of mechanical damage is shown in Fig. 8. Mechanical damage also occurs frequently during material transport on grates, roller tables, trolleys or during material loading by an overhead crane. If the damage is small, it is difficult to detect it. This nonconformity is of great importance for the client. In order to improve the quality, it is necessary to introduce more frequent inspections of devices and to ensure timely re-pairs. The quality control staff should also be trained to improve the detection of this type of non-conformity.

The FMEA analysis was used to assess the degree of criticality of the nonconformities under investigation and to take corrective actions aimed at reducing the value of their risk. The result of the analysis is presented in Table 3.

The adopted criticality level (RPN = 120) was exceeded for 4 discrepancies: inadequate length, mechanical damage, cold shut and web asymmetry. For these nonconformities, corrective actions should be taken, which are, above all, employee training and repairs. These 4 nonconformities should be addressed first, but one should not forget about nonconformities that occur less frequently and are less important for the client.

Fig. 9. Mechanical damage of the foot.

Table 3. Simplified FMEA analysis

Type	**Effects of nonconformity**	**Causes**	**O**	**D**	**S**	**RPN**
ŁP	Defective product	Inadequate quality of the charge	5	3	7	**105**
SW	Defective product, regeneration	Improper setting of the rolling mill or straighteners	2	3	7	**42**
N	Scrap	Failures during the process	9	1	6	**54**
ND	Regeneration, scrap	Employee's incompetence	5	6	7	**210**
UM	Defective product, regeneration	Employee's incompetence, no repairs	6	4	7	**168**
K	Scrap, regeneration	Improper setting of the rolling mill or straighteners	7	2	7	**98**
Z	Scrap, regeneration	Improper setting of the rolling mill	4	5	8	**160**
AŚ	Defective product, regeneration	Bad fixture adjustment, no repairs	6	4	6	**144**
PS	Scrap, regeneration	Improper setting of the rolling mill or straighteners	2	6	7	**84**
RW	Scrap, regeneration	Inadequate quality of the charge	2	6	7	**84**
NW	Defective product, regeneration	Improper setting of the rolling mill	2	3	7	**42**
PP	Scrap, regeneration	Improper setting of the rolling mill, charge defect	2	2	9	**36**
F	Scrap, regeneration	Improper setting of the rolling mill	6	2	5	**60**
R	Regeneration	Bad fixture adjustment	7	3	5	**105**

4. Summary and conclusion

The evaluation of the I-section rolling process based on the stability and capacity analysis of this process, additionally supported by the analysis of the nonconformity structure and their risk, allowed to obtain a lot of valuable information useful for managers in improving this process.

Process evaluation using control charts showed that it is not stable. However, only one dimension (width of the foot) was included in the SPC analysis. The results from the $\overline{x}$ chart are a warning signal for process managers, despite the fact that all values were within tolerance. As a result, the process showed a good qualitative capability, this capability was determined based on the procedure for a non-normal distribution, because the process did not behave according to this distribution (the distribution of results was oblique, clearly flattened and multimodal). The cause of such a disturbance shall be indicated.

By analyzing the structure of nonconformities, the basic quality problems, i.e. non-rolling and mechanical damage, were identified. Corrective actions have been proposed which mainly consist in a better policy of repairing machinery and increasing the number and quality of training provided.

Summing up, it should be emphasized that the company under study invests all the time and strives for full automation of the process, which improves the quality. However, most of the rolling mill machinery and equipment is still obsolete, which means that in order to maintain the appropriate quality level, the steel mill is forced to incur higher maintenance costs. Effective repairs and trainings (their quality and quantity) are a critical element requiring improvement, which will increase the quality and repeatability of the obtained results from the rolling process.

SPC tools are an invaluable source of information about the rolling process and its results, which can be used to improve the process. By analyzing the behavior of the process over time, knowledge about the predictability of the process was obtained. The results were not satisfactory. The process is unpredictable and can give managers a headache. It is much easier and faster (and often cheaper) to eliminate the source of disruption than to remove its effects. The goal of the managers of the rolling process should be to minimize sources of process variability, which will be resulted in process improvement and cost reduction. It is really difficult to control the stability of the rolling process. What counts the most is above all the experience and high involvement of workers at each working stand (ULEWICZ, 2003).

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轧制产品生产过程的统计控制

關鍵詞
SPC
轧制产品
稳定性分析
能力分析
定性分析

摘要
本文介绍了使用SPC工具的结果，即控制图和评估轧制产品生产过程稳定性和能力的定性能力指标剖面图。对所分析产品的所选特征的收集数据进行统计分析足的宽度和分布的正态性，这表明所获得的测量结果的分布不是正态分布。结果，使用了适当的非正态分布SPC程序。
Pareto-Lorenzo 图和FMEA
方法也用于获取有关分析产品的不合格结构和与之相关的风险水平的信息。该信息用于提出纠正措施并改进轧制产品的生产过程。