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THE EVALUATION OF PRODUCTION LINE MEASUREMENT PROCESS QUALITY

Key words

Measurement process, repeatability and reproducibility analysis, MSA, production process.

Abstract

In production control processes, many decisions are made based on measurements conducted during the production itself. Therefore, the product quality, the equipment operating conditions, and the course of production process are all influenced by the quality of measurement system in use. Repeatability and Reproducibility Analysis (R&R), which is one of the methods of Measurement System Analysis (MSA), can be used in order to evaluate the measurement system's precision.

This article presents an evaluation of a measurement system, transferred directly from a Control Department to a Production Line in one of the enterprises in Podlaskie region. For the calculation, the author used the results of a measurement experiment in the surveyed enterprise carried out in the STATISTICA software. There was also an analysis conducted of cause-and-effect in relation to measurement processes of bad quality.

Introduction

A measurement system can be defined by reference to a process approach used within some organizations. In that case, both the measurement system and measurement process can be described in an analogy to a production system and production process. This approach enables one to use concepts and instruments that have already been proven useful in statistics-based manufacturing process control and measurement control. The main purpose of the defined process is to obtain a numeral output generated during its execution. It can be assumed that a measurement process is a special case of a technological process [1].

MSA (Measurement System Analysis) method, which examines the credibility and correctness of the measurements, is used in measurement systems evaluation. This approach has been developed by automotive companies in cooperation with ASOQ and AIAG as guidelines for their own production systems and subcontractors.

Among many methods that evaluate the usability of measurement systems suggested within the MSA, the Repeatability and Reproducibility (R&R) analysis is the most widely used. R&R analysis is a procedure especially helpful in business, because it allows analysis of the impact of particular components of the measurement system on the variability of the results of measurements. This tool also enables a researcher to make a valid assessment of the extent to which the variability of the measurement results distorts the observed variability of the examined manufacturing process. Moreover, it can be used to determine what part of the measurement results is caused by the measuring equipment applied and what results from the carelessness of the operator. This information, which is essential to the process of quality control, determined the universal application of the R&R analysis with certainty [2].

This article presents an evaluation of a measurement system, transferred directly from a Control Department to a Production Line in one of the enterprises in Podlaskie region. For the calculation, the author used the results of a measurement experiment in the surveyed enterprise, carried out in the STATISTICA software. An analysis of cause-and-effect was also carried out in relation to measurement processes of bad quality.

1. The essence of the R&R analysis

The variability of the measurement system is affected by such factors as the operator (e.g. training), the product (e.g. purity), the method (e.g. differences between methods), the measuring instrument (e.g. wear), and the environment (e.g. temperature).

In practice, the following control procedures are mainly used for the analysis of the ability of the control measures [3, 4]:

- Procedure 1, used in determining the measurement uncertainty and capacity indicators C_g (dispersion measurement system), C_{gk} (centring of the measuring system);
- Procedure 2, which leads to the calculation of repeatability, reproducibility, and the total dispersion, the so-called R&R method with user impact; and,
- Procedure 3, used to determine the reproducibility and the total dispersion (without user impact).

The most popular, because of its versatility, is the Procedure 2, wherein the input data are the results of repeated measurements (2 to 3) of a small sample of product (ca. 10) done by a number of operators. In the course of calculations carried out using the average range method, there are estimated components (standard deviation) of the observed Total Variation (TV) i.e. R&R – standard uncertainty (including Repeatability EV – Equipment Variation, Reproducibility AV – Appraiser Variation and the magnitude of the process PV (Process Variation)). In case of application for analysis of variance (ANOVA) calculations, there is an additional total variation (TV) component in the form of the interaction between operators and measured products. By comparing the components of variation among themselves or with a tolerance of the measured characteristics, there are indicators determined to assess the measurement system [5]. The detailed procedures of the indicators calculations are thoroughly discussed in many references on this topic [4, 6, 7]. The typical ranges of instrument capacity for the repeatability and reproducibility indicator, which are the basis of evaluating the measuring system, are shown in Table 1.

Table 1. The measurement system capability presented as a function of R&R value

Parameter value	The evaluation of the measurement system
%R&R < 20%	suitable for use
20 % < %R&R < 30%	must be improved (can be used conditionally)
%R&R > 30%	not acceptable (corrective measures necessary)

The final acceptance of the measurement system should not be based solely on the analysis of one set of indicators. Long-term efficiency of the system should also be verified using graphical analysis in time.

2. Measuring experiment

In the analysed production company in the Podlaskie region, all tests and measurements are performed in a research and measurement laboratory by the quality assurance department staff. Due to the appearance of new projects, it was decided to attempt to transfer a part of simple measurements, and well-known details, on setters of the injection process. For this purpose, a number of trainings have been conducted and selected employees have been familiarized with their new responsibilities. Due to significant impact of the measurement system on the quality of the measurement results and directly related analyses, prior to final deployment of the measurement task on the division of injection, there was a verification of the effectiveness of organized prior training by analysing the repeatability and reproducibility [8].

There were selected three types of elements manufactured in the plant, and then samples of 10 pieces of parts each were taken from the production line, representing the variability of the manufacturing process under consideration. Thus, prepared parts were transferred to the appropriate part of the study, which was attended by 16 setters of the injection process (4 from each shift). The task of the selected employees was to take measurements three times, using callipers, each of the selected items, and provide the person supervising the test with the obtained results, which were written in the appropriate form. After the experiment, the collected data was subjected to R&R analysis, using the procedure available in the Industrial Statistics & Six Sigma module of STATISTICA 10 program.

The following selected details of the production line were used for measurements:

- The lid – measuring a diameter of 111.80 mm nominal dimension and tolerance +/- 0.2. (External dimension);
- The ON/OFF button (switch rocker) – testing the distance between the faulting located within the mandrels serving attachment, in a device of nominal dimension 23.50 mm with a tolerance of +/- 0.15 (external dimension); and,
- The steam guide – measuring the dimension at the upper edges of ‘ribs’, whose nominal value is 20.00 mm with a tolerance of 0.15 mm +/- (internal dimension).

For each tested element, there were obtained 480 measurements, which were used for further analysis.

The first step was to develop a histogram of the distribution of measurements of each of the tested details together with defining the lower control line (LCL), the upper control line (UCL), and nominal value (NOM). The histogram is a useful tool to check whether the collected data were not pre-selected (cut histogram) or if products of different machines or processes were not mixed (bimodal histogram) or if there was any measuring instrument error (the gap in the histogram) [9]. The prepared histograms are shown in Figs. 1, 2, and Fig. 3.

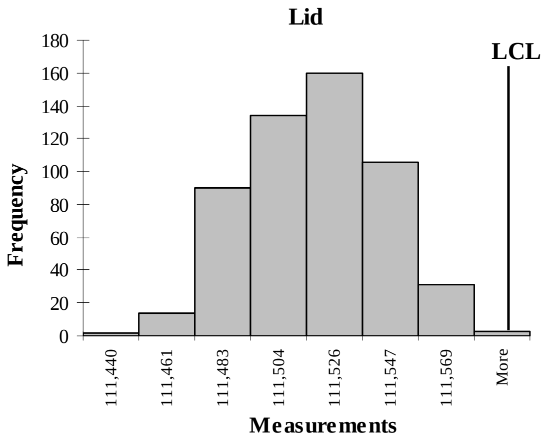

Fig. 1. Histogram of the lid measurement results

The analysis of obtained lid measurement histogram (Fig. 1) indicates that all measurements are below the specified lower limit of the specification (LCL). The comparison of the results with the nominal value of the cover (111.80 mm) shows either there has been an error in the selection of parts involved in the study or some irregularities with the setting of the injection machine.

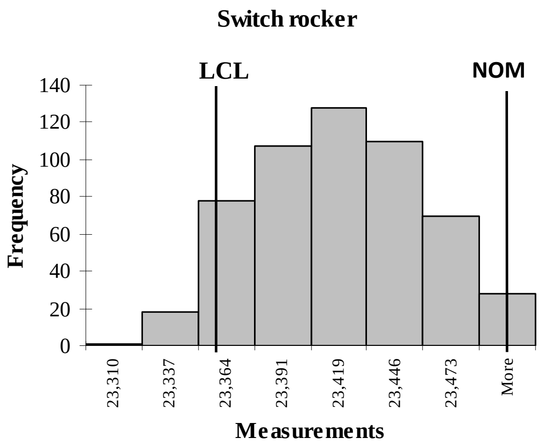

Fig. 2. Histogram of the switch rocker measurement results

The results of switch rocker histogram (Fig. 2) analysis are only slightly better. In this case, most of the observed measurements are located between the lower control line of the specification (LCL) and the desired value (NOM).

What is disturbing is the fact that only 18 of 480 collected measurements reach the nominal value, while more than 60 results are outside the acceptable limit.

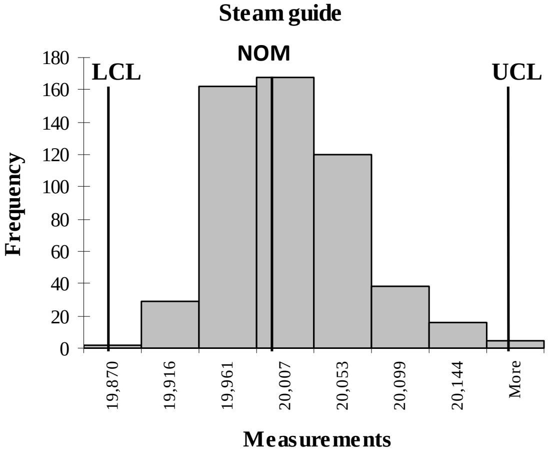

Fig. 3. Histogram of the stream guide measurement results

Steam guide was the last of tested parts, and the histogram of results is shown in Fig. 3. This situation is considerably more favourable than in the previous cases, since almost all of the results are within a specified tolerance range that is between the upper (UCL) and lower control line (LCL). In addition, it is worth noting that more than 160 measurements reach the nominal value, which is a very good result.

3. Research-based R&R analysis

After collecting the measurement results, all the data were put into the STATISTICA program and further divided into three groups according to tested parts. The procedure for the R&R analysis in the program allows the calculation of indicators with the range method and the analysis of variance. In the program, there are many possibilities for graphical presentation of the results of the experiment. The most important of these is the general results variability diagram showing grouped values of deviation from the obtained average for each result. The results of each of the employees surveyed were placed in separate frames, and the height of the point indicates the value of the variation of the corresponding operator. The line placed in a central location of each frame represents the average deviation from the average measurements of the same part for all tested. When interpreting graphs, a lot of attention must be paid to the length of the lines connecting the results of measurements of one sample.

The high length of this section indicates, just as the length of the frame, the poor reproducibility (high volatility) of the operator when measuring the same part. R&R analysis charts for particular parts are shown in Figs. 4, 5 and 6.

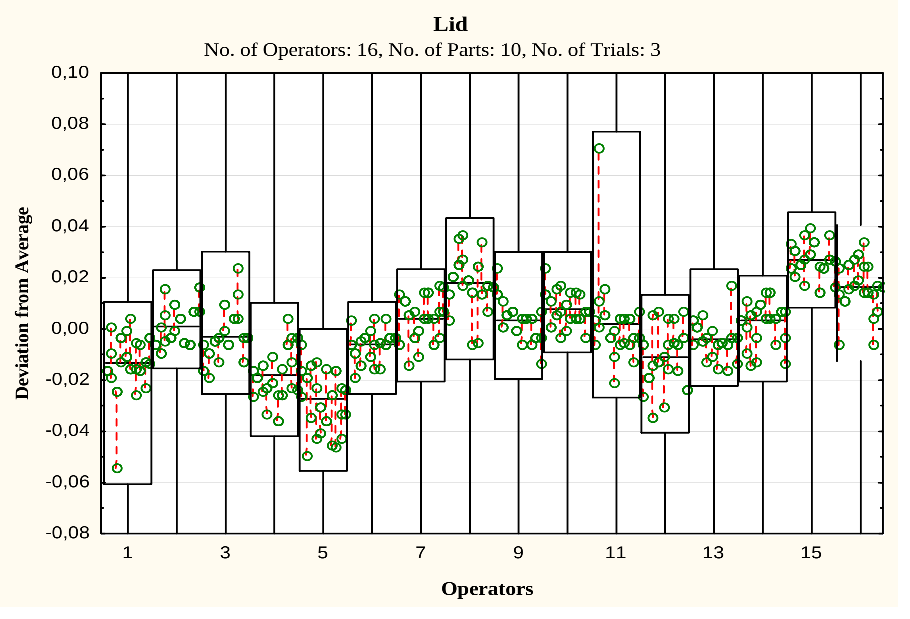

Fig. 4. Repeatability and reproducibility summary plot for the lid

From the graph shown in Fig. 4, it appears that the average results of most operators are comparable. The smallest measurement deviation from the average is recorded by operators with numbers 2, 9, and 11, which does not determine their skills, since the operator with number 11 also has the largest range (0.09) in the results. It may also be noted that the employees Numbers 2, 6, 10, and 15 proved to be the most repetitive.

Fig. 5 is a graph of the overall repeatability and reproducibility for the switch. It shows that the first five operators present the smallest reproducibility, as their average results are significantly deviated from the average of all measurements. The greatest difficulties with the repetition of their results were operators 1, 5, and 11. In terms of reproducibility of the results, the best skills were presented by the operators with numbers 3, 6, and 10.

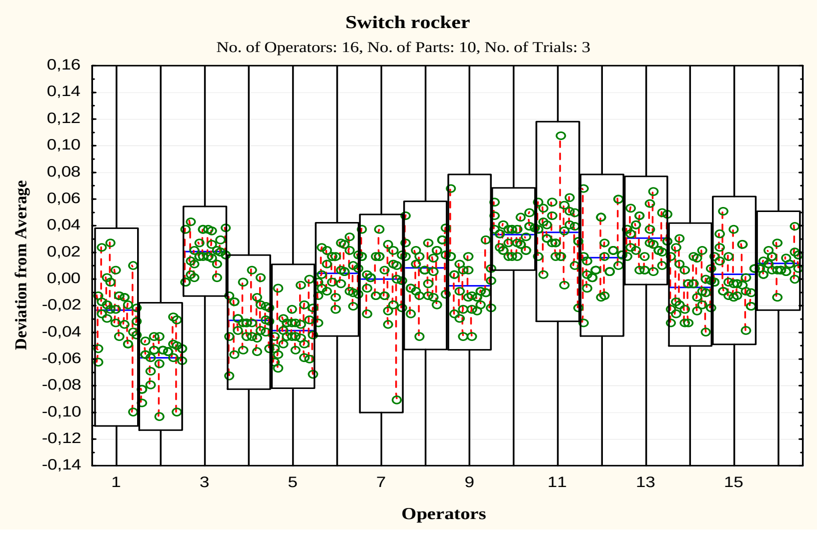

Fig. 5. Repeatability and reproducibility summary plot for the switch rocker

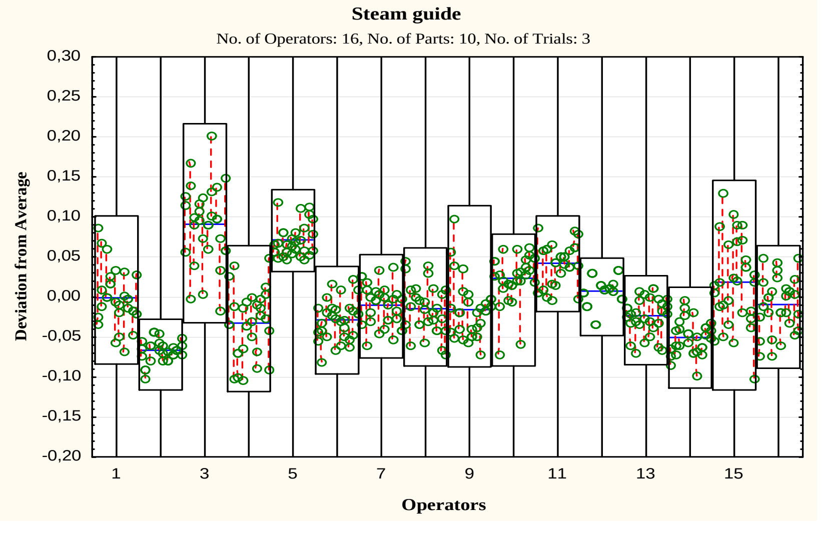

Fig. 6. Repeatability and reproducibility summary plot for the steam guide

The situation on the chart shown in Fig. 6 appears to be very similar to the previously described situation. It can be noted that the least reproducibility was shown by operators numbered 2, 3, 4, 5, and 11, whose deviation from the average range from -0.07 for the second setter up to 0.09 for the employee numbered 3. The results of these variations are not extreme solely within these five operators but stand out against the remaining values because of the indicator. The graph shows quite clearly that the operator numbered 12 has a nearly perfect reproducibility (lack of vertical lines). However, the analysis of earlier, not as good, results of that employee excludes the impact of measuring skills of the operator.

The next step was the use of the analysis of variance (ANOVA) for the calculation of the total %R&R indicator and the individual components of the measurement process (repeatability, reproducibility, process variation). The results are shown in Figs. 7, 8, and 9.

	Variance Components; Variable: Lid Mean=111,510 Std.Dv=,251E-1 Operators: 16 Parts: 10 Trials: 3					
Source (Expected MS)	Estimatd Sigma	,90 Lowr Conf.Lim	,90 Uppr Conf.Lim	Estimatd Variance	% of R & R	% of Total
Repeatability	0,007919	0,007438	0,008472	0,000063	22,744064	9,220000
Operator	0,013613	0,010216	0,019905	0,000185	67,214442	27,247425
Interaction (OP)	0,005262	0,004195	0,006422	0,000028	10,041494	4,070626
Part-to-Part	0,020110	0,014350	0,033386	0,000404		59,461949
Combined R & R	0,016605	0,014130	0,021873	0,000276	100,000000	40,538051
Total	0,026079			0,000680		100,000

Fig. 7. R&R analysis results with the use of analysis of variance for the lid

	Variance Components; Variable: Switch Rocker Mean=23,4057 Std.Dv=,408E-1 Operators: 16 Parts: 10 Trials: 3					
Source (Expected MS)	Estimatd Sigma	,90 Lowr Conf.Lim	,90 Uppr Conf.Lim	Estimatd Variance	% of R & R	% of Total
Repeatability	0,018985	0,017832	0,020312	0,000360	33,3646	20,3208
Operator	0,026505	0,019941	0,038688	0,000703	65,0349	39,6097
Interaction (OP)	0,004158	0,000000	0,007460	0,000017	1,6004	0,9748
Part-to-Part	0,026332	0,018746	0,043783	0,000693		39,0948
Combined R & R	0,032867	0,028174	0,042938	0,001080	100,0000	60,9052
Total	0,042115			0,001774		100,0000

Fig. 8. R&R analysis results with the use of analysis of variance for the switch rocker

	Variance Components; Variable: Steam Guide Mean=19,9931 Std.Dv=,547E-1 Operators: 16 Parts: 10 Trials: 3					
Source (Expected MS)	Estimatd Sigma	,90 Lowr Conf.Lim	,90 Uppr Conf.Lim	Estimatd Variance	% of R & R	% of Total
Repeatability	0,031570	0,029653	0,033777	0,000997	35,7920	31,8616
Operator	0,041229	0,030959	0,060260	0,001700	61,0451	54,3416
Interaction (OP)	0,009385	0,000911	0,014331	0,000088	3,1629	2,8155
Part-to-Part	0,018534	0,012782	0,031433	0,000344		10,9813
Combined R & R	0,052769	0,045695	0,068126	0,002785	100,0000	89,0187
Total	0,055930			0,003128		100,0000

Fig. 9. R&R analysis results with the use of analysis of variance for the steam guide

The last column of presented tables shows the obtained relative share of variability from various sources, which allowed the determination of the impact of specified factors on measurement results. In the first case (Fig. 7), repeatability of measurements represents 9.22% of the total variability, reproducibility (different operators) – 27.25%, while the variation between the parts contributes to the total variability of the process up to even 59.46%. Thus, most of the variability comes from variability between parts, which can be seen as positive information, but taking into account the overall level of R&R, which is 40,54%, the assessment of the measurement system is negative. The results of a further analysis of the measured parts look even worse (Fig. 8). In this case, the operators, by poor reproducibility of the results, brought up 40.74% of the variation, and the impact of variability between parts was 38.45%, while the low reproducibility of results added 19.25%. The overall level of R&R, which is considerably more than half of the total variability, reaches as much as 61.55% and disqualifies the measuring system from use. The analysis performed based on measurements of the steam guide (Fig. 9) also disqualifies the tested measurement system. Most of the variability in this case comes from the variability of operators – 54.34%, and only slightly less is brought by low reproducibility of operators – 31.86%, which is an unsatisfactory result. The ratio obtained after adding both of these values constitutes 89.02% of the variation and is more than three times the value of the last determined levels of the acceptance of the system. The impact of variability between parts, which adds less than 11% of the total variability of the system, is a confirmation of this alarming information.

Since none of the three examined measurement systems did receive the required quality, it was decided to examine the reasons for such a situation. For this purpose, based on Ishikawa diagram, the most important types of causes were highlighted (measurement method, the environment, measurement and material, operators, management). In comparison with the previous course of the measurement process in the quality control department, the group of operators and elements of the management process have been changed. To assess the impact of specific factors, some data was collected from operators and supervisors' observations during the measurement experiment [8]. The analysis was performed using the Pareto-Lorenz diagram. It has allowed the systematization of reasons for a low repeatability and reproducibility of the measurements (Fig. 10). The Pareto chart clearly shows that the company would benefit the most from the elimination of the first four causes, which occurred most frequently. The factor affecting the operators the most strongly was stress, resulting from the insufficient understanding of the research. It is thus important to develop more accurate measurement instructions, because the current ones are quite ambiguous. Employees should be familiar with the procedures in force during the measurement process, and re-trained in their application. Otherwise, the lack of motivation for the job will be more and more noticeable, hence the reluctance to undertake additional tasks.

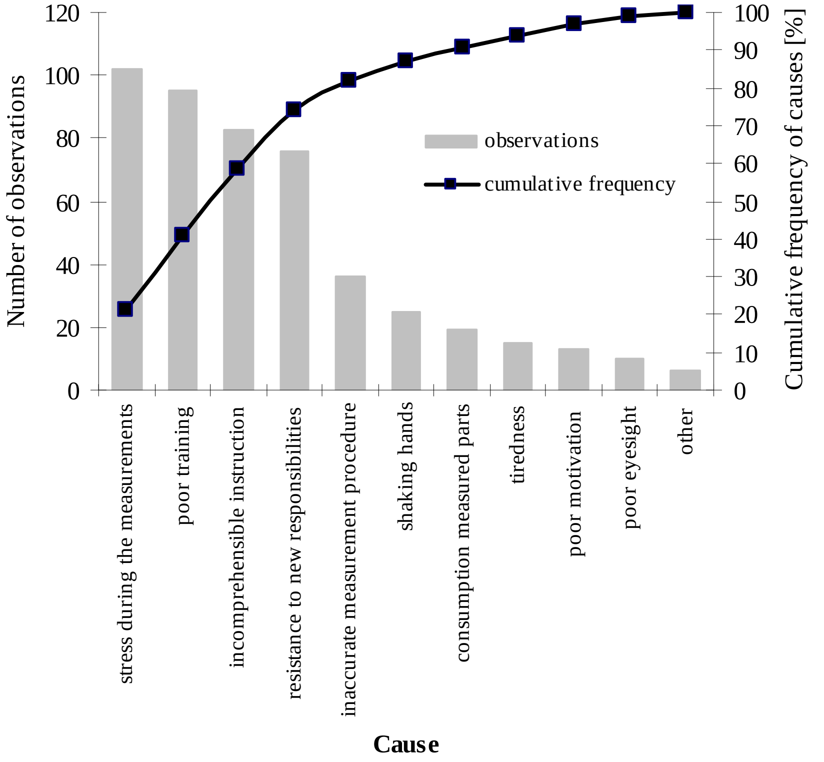

Fig. 10. Reasons for the low R&R values analysis

According to generally accepted criteria for quality measurement systems (Table 1), based on the analysis of R&R, all of the considered examples gave unambiguous information that the tested systems cannot be accepted in the production process. On the other hand, the idea of direct transfer of selected measurements from a research laboratory to the production line seems right, but it requires additional effort in the area of training and management.

Summary

The analysis of the repeatability and reproducibility of the measurements is extremely important due to the need to verify the accuracy of the measurement system, understood not only as a measuring device itself, but also as a combination of a measuring devices and operators that support them. These analyses can be easily performed using the increasingly wider range of computer applications relating to broadly defined production processes quality.

The main objective of the study presented in the article was to assess the quality of the measurement system implemented in the surveyed enterprise, which has been transferred from the quality control department directly on the production line. Conducted analysis of repeatability and reproducibility (R&R) indicated an inadequate level of measurement processes study. The main reasons for poor quality of processes result from human causes (operators). Measurements should be carried out by employees having technical skills in this area and after an appropriate training, which would increase their awareness of the relevance of collected data, which is necessary in the production process.

The analysis presented in this article has demonstrated the effectiveness of applying statistical methods in the research of the suitability of measuring systems.

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Ocena jakości procesu pomiarowego na linii produkcyjnej

Słowa kluczowe

Proces pomiarowy, analiza powtarzalności i odtwarzalności, analiza MSA, proces produkcyjny.

Streszczenie

W procesach sterowania produkcją wiele decyzji podejmowanych jest na podstawie przeprowadzonych w jej trakcie pomiarów. Jakość stosowanego procesu pomiarowego ma więc wpływ na jakość wyrobów, warunki eksploatacji maszyn, przebieg procesu produkcji. Do oceny poprawności systemu pomiarowego można wykorzystać analizę powtarzalności i odtwarzalności (R&R), która jest jedną z metod analizy MSA (Measurement System Analysis).

W artykule przedstawiono ocenę jakości systemu pomiarowego, który został przeniesiony z działu kontroli jakości bezpośrednio na linię produkcyjną w jednym z przedsiębiorstw w województwie podlaskim. Do obliczeń wykorzystano wyniki eksperymentu pomiarowego w badanym zakładzie opracowane przy użyciu aplikacji STATISTICA. Przeprowadzono również analizę przyczynowo-skutkową złej jakości procesów pomiarowych.