http://doi.org/10.24867/JPE-2022-01-043

Journal of Production Engineering
Vol.25 No.1

JPE (2022) Vol.25 (1) Original Scientific Paper
Ranisavljev, M., Štrbac, B., Janković, P., Lanc, Z., Matin, I., Hadžistević, M.

THE IMPORTANCE OF MEASURING SYSTEM ANALYSIS IN PROCESS CAPABILITY ASSESSMENT

Received: 05 April 2021 / Accepted: 15 August 2021

Abstract: *The implementation of statistical methods in the product development phases has become an unavoidable part of engineering practice. Monitoring of the condition of the process or production equipment is performed using established methodologies, which include the analysis of process capabilities. This analysis involves identifying the need to evaluate the production process or system, data collection, analysis, and interpretation of data. Data acquisition is performed using a measuring system, which with its characteristics in terms of accuracy and precision must meet certain criteria. This paper aims to determine the capability of the process, calculating the capability indices C_p and C_{pk}, with special reference to the measurement system. Before using the data in the analysis of abilities, an analysis of the measurement system was previously performed to determine its variation in the total variation of the study. The variation of the measuring system proved to be acceptable, which gave the author a sufficient reason to further exploit that measuring system. The process capability study was conducted on a sample of 125 parts, where it was concluded that the observed process is within the statistical control limits and can produce most of the workpieces within the specification limits.*
Key words: *Measurement system analysis, bias, GR&R, process capability.*

Značaj analize mernog sistema u proceni sposobnosti procesa. *Primena statističkih metoda u fazama razvoja proizvoda postala je nezaobilazan deo inženjerske prakse. Praćenje stanja procesa ili proizvodne opreme vrši se primenom utvrđenih metodologija koje obuhvataju analizu mogućnosti procesa. Ova analiza uključuje identifikaciju potrebe za evaluacijom proizvodnog procesa ili sistema, prikupljanje podataka, analizu i interpretaciju podataka. Prikupljanje podataka vrši se korišćenjem mernog sistema, koji svojim karakteristikama u pogledu tačnosti i preciznosti mora da ispunjava određene kriterijume. Ovaj rad ima za cilj da utvrdi sposobnost procesa, izračunavajući indekse sposobnosti C_p i C_{pk}, sa posebnim osvrtom na merni sistem. Pre upotrebe podataka u analizi sposobnosti, prethodno je izvršena analiza mernog sistema da bi se utvrdila njegova varijacija u ukupnoj varijaciji studije. Varijacija mernog sistema se pokazala prihvatljivom, što je autoru dalo dovoljan razlog za dalje korišćenje tog mernog sistema. Studija sposobnosti procesa sprovedena je na uzorku od 125 delova, gde je konstatovano da je posmatrani proces u granicama statističke kontrole i da može proizvesti većinu obradaka u granicama specifikacije.*
Ključne reči: *Analiza mernog sistema, pristrasnost, GR&R, sposobnost procesa.*

1. INTRODUCTION

Statistical monitoring of processes in engineering activities is the basis for achieving the quality of the production process, reducing the number of defective products, and maximizing profits [1]. Each production process has its imperfections that are the cause of variations in the quality characteristics of workpieces. Sometimes it is difficult to identify and quantify all the causes of variation, but it is necessary to determine their impact on the observed process. Insight into the state of the process is obtained by measuring the quality characteristics of the workpiece with a certain measuring system. If the measuring system does not give reliable results, the interpretation of the data and the state of the process will lead to inaccurate conclusions [2].

The process capability analysis study is a statistical tool that uses the normal distribution curve and control charts to determine the extent to which the observed process meets the requirements set by the specification. According to Kotz and Montgomery, several key assumptions need to be tested before assessing process capability: the process must be in a state of statistical control; the quality characteristic must have a normal distribution; in case the specification has a lower and upper limit; the mean value of the process must be in the middle between the limits of the specification; observations must be random and independent.

Several papers have addressed the issue of process capability analysis based on measured quality characteristics. Pawar et al. [3] used this to monitor and improve its processes in the automotive industry by changing process parameters for boring operations and conducting and comparing results from both sets of experiments. They conclude that after changing machine parameters such as spindle speed, feed rate, and depth of cut and analyzing process capability, they can achieve comparatively better process performances. Research in the field of additive technologies has been improved by the methodology of statistical process control, especially in the application of new composite materials in the Fused Deposition Modeling method. Sharma et al. performed multi-response optimization and process capability analysis for surface properties of 3D printed functional prototypes of polyvinyl chloride

Note: The manuscript was presented at the 14. International Scientific Conference MMA held in Novi Sad, Serbia, 23.-25. September, 2021.

(PVC) reinforced with polypropylene (PP) and hydroxyapatite (HAp) for possible bio-sensing applications. process capability indices (C_p and C_{pk}) were calculated to ensure the statistical nature of the process [4]. Ketan and Nassir improved the process of extrusion of aluminum profiles through the DMAIC methodology and calculations and interpretation of process capability indices. In that manner, they are able to accomplish decrease in the dispersion of the production process, and as a result, a significant reduction in the number of bad pieces was achieved, resulting in increased earnings from 127,000 monetary units per 1000 kg of product to 223,000 monetary units [5].

Measurement data are used more often and, in more ways, than ever before. For instance, the decision to adjust a manufacturing process is now commonly based on measurement data. The input data for conducting any type of process analysis are the measured data obtained by a measuring system. The quality of measurement data is defined by the statistical properties of multiple measurements obtained from a measurement system operating under stable conditions.

The statistical properties most used to characterize the quality of data are the bias and variance of the measurement system. The property called bias refers to the location of the data relative to a reference (master) value, and the property called variance refers to the spread of the data. The test procedure which should be used to understand a measurement system and to quantify its variability depends on the sources of variation which may affect the measurement system. In many situations, the major sources of variation are due to the instrument (gage/equipment), person (appraiser), and method (measurement procedure) [6]. The prevalence of this methodology is most pronounced in the automotive industry, where are parts like ball bearings frequently inspected.

The crucial piece of measuring equipment such as for measuring the performances of ball bearings is submitted to verification through measurement system analysis. Measurement system analysis (MSA) was used to assess the vibration measurement system of rolling bearings [7]. This methodology is so important that could be, in some case, supplement to the various standards, such as VDI / DGQ 3442 standard for the assessment of the accuracy of numerical machine tools [8].

In this paper, attention was paid to the measurement system and its impact on the obtained results, so that before the analysis of the process capability, the analysis of the measurement system was performed using Gage Repeatability and Reproducibility Study (GR&R).

The Gage Repeatability and Reproducibility of measuring instruments breaks down the total variation in the study into variation due to workpieces (processes) and variation due to the measuring system. The results from GR&R study should be evaluated to determine if the measurement device is acceptable for its intended application. A measurement system should be stable before any additional analysis is valid.

2. EXPERIMENTAL RESEARCH

To better understand the observed production process in a real production environment, there is a need to investigate how well that process can meet customer requirements and how well the measuring system can describe the process through the evaluation of the quality characteristics. Knowing this information can help engineers to optimize and upgrade any given process, thus reducing the costs of production many times over.

First, we must look carefully at the measuring system. All measurement processes conducted in this paper were performed with a flat measuring plate micrometer with $50 \div 75$ mm measuring range, and 0.01 mm resolution.

To check the bias of the measurement results, a block gauge with a length of 50 mm was measured, Figure 1.

Fig. 1. Checking the bias of the measuring device by measuring the gauge block

Fig. 2. Acquisition of measurement data for process capability analysis

The gage block was measured 25 times under the same conditions. Bias is calculated from the following equations [10]:

$$\text{bias}_i = x_i - \text{reference value} \tag{2.1}$$

$$\text{avg bias} = \frac{\sum_{i=1}^{n} \text{bias}_i}{n} \tag{2.2}$$

From the available sample, it is calculated that the Bias has the average value of 0.002 mm, where the reference value is 50 mm from gage block, and the x_i values are results of the measurement obtained by micrometer.

Following the guidelines in literature [13], for the study of process capability, 125 samples were randomly selected. The quality characteristic being measured (Fig. 2.) is the simple distance between two parallel planes on the workpiece. Parallel planes on the workpiece were machined on the vertical milling machine. The dimension stated by technical documentation is $50 \pm 0{,}1$ mm.

3. RESULTS AND DISCUSSION

After performing the bias test on the selected gage, the gage repeatability and reproducibility study is conducted. Repeatability is described as variation in measurements obtained with one measuring instrument when used several times by an appraiser while measuring the identical characteristic on the same part. It is commonly referred to as E.V. – Equipment Variation. Reproducibility is described as variation in the average of the measurements made by different appraisers using the same gage when measuring a characteristic on one part. It is commonly referred to as A.V. – Appraiser Variation. Method used to calculate variations in measurement system and in manufacturing process is Analysis of variance (ANOVA). Analysis of variance is a standard statistical technique and can be used to analyze the measurement error and other sources of variability of data in a measurement systems study. In the analysis of variance, the variance can be decomposed into four categories: parts, appraisers (operator), interaction between parts and appraisers, and replication error due to the gage [10].

Goal of the Gage R&R study is to show that E.V. or Equipment Variation does not play a significant role in overall variation. Most of the total variation must be attributed to process variation (part-to-part variation) [4]. MINITAB® statistical software is used for all calculations and graphical displays. Results according to ANOVA method are given in Table 1 and Table 2. and graphical representation in Fig. 3.

Gage R&R Study – ANOVA Method					
Two-way ANOVA table with interaction					
Source	DF	SS	MS	F	P
Part	9	0,0166900	0,0018544	172,655	0,000
Operator	2	0,0000067	0,0000033	0,310	0,737
Part * Operator	18	0,0001933	0,0000107	1,074	0,399
Repeata-bility	60	0,0006000	0,0000100		
Total	89	0,0174900			
α to remove interaction term = 0,05					

Table 1. Gage R&R Study – ANOVA Method

Source	VarCo.	%Con. of VarCo.	SD	Study Var (6 x SD)	%Stud. Var (%SV)
Total GRR	0,0000102	4,73	0,0031892	0,0191351	21,75
Repeat.	0,0000102	4,73	0,0031892	0,0191351	21,75
Repr.	0,0000000	0,00	0,0000000	0,0000000	0.00
Operat-or	0,0000000	0,00	0,0000000	0,0000000	0.00
Part-to-part	0,0002049	95,27	0,0143150	0,0858900	97,61
Total var.	0,0002151	100,00	0,0146660	0,0879957	100,00
Number of Distinct Categories = 6					

Table 2. Gage R&R Study

According to ANOVA, workpieces have statistical significance (p-value = 0.000 <α = 0.05), while operators and the interaction of operators with workpieces do not have statistical significance.

The contribution of the variation of the measurement system in the study is 4.73%, while the contribution of the variation between workpieces in the overall study is significant and amounts to 95.27%. The histogram of the variation components shows that most of the variations in the study can be attributed to variation due to the manufacturing process (workpieces). Metrologists have achieved satisfactory repeatability and reproducibility. On the range map and *X*bar map, most points go beyond the control limits, which in this case is good, the measuring instrument is chosen correctly. The measuring system recognized 6 different categories of workpieces, which is a satisfactory case (NDC should be 5 or more). Since the variation of the measuring system is 27.75%<30% in the %StudyVar column and based on the criteria given in the literature [10], we can conclude that the selected measuring system is conditionally acceptable.

As for the study of process capability, the observed process has an upper (USL) and lower (LSL) limit of the specification. The values of the specification limit are 50.1 mm, while the value of the lower limit is 49.9 mm. Based on that, ideally, the mean value of the measured result should be in the middle between the upper and lower limit of the specification. Analysis of the obtained results shows a minuscule difference between the index C_p = 2.67 and C_{pk} = 2.59 (in Fig. 4. Pp and Ppk). The difference between these two indices confirms that the observed process is not centered. The values of both capability indices exceed the value of 1.33, considered the limit below which these indices should not have values. The observed process has a small scatter of results, which is shown by the index C_p.

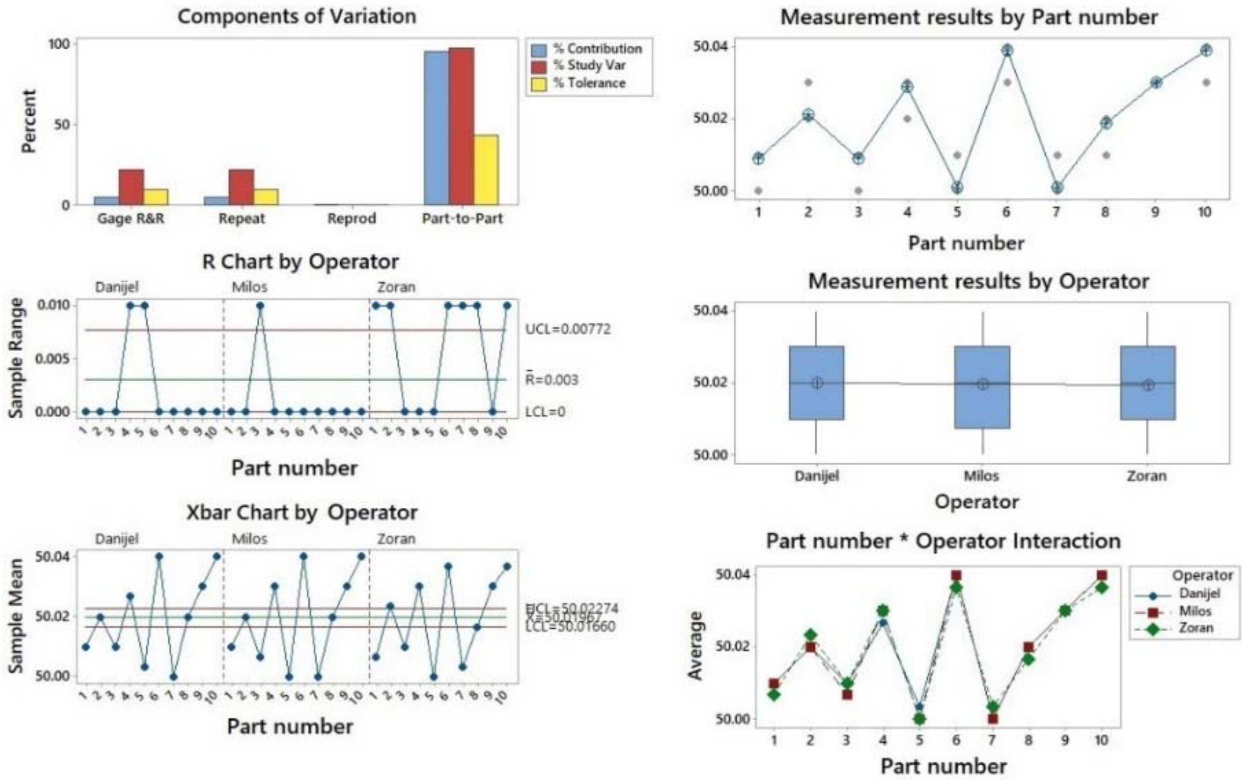

Fig. 3. Graphical representation of the results of the ANOVA method

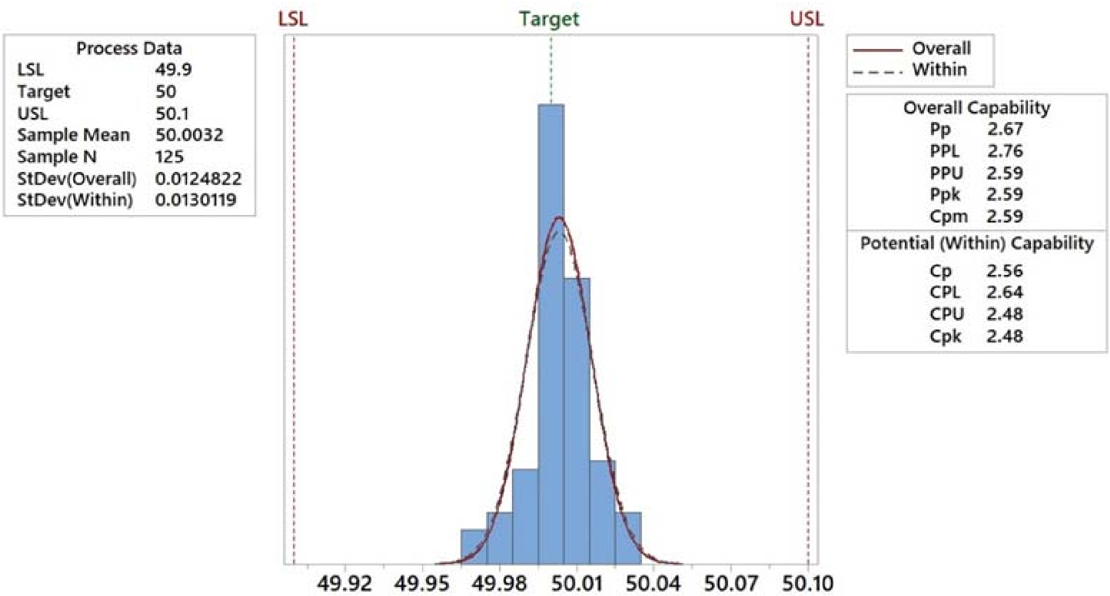

Fig. 4. Process capability analysis for measured results

The number of defective parts per million produced, an in this case, is equal to 0, i.e., the PPM index (Parts per million = 0.00).

4. CONCLUSION

The conducted study shows the importance of the analysis of process capabilities as a statistical tool for monitoring and quality assurance of manufactured workpieces that will meet the prescribed specifications. Reducing variations from the set value (target T) affects the reduction of losses in the production process. This is the desired goal according to today's modern theories of quality improvement. Before conducting the process capability study, special attention was paid to the measurement system, as an essential link in the measurement process chain. A crossed study of repeatability and reproducibility of measuring instruments was conducted to determine the variation of the measuring system. The reference standard (gauge block) used in the study has a nominal length of 50 mm. The analysis of the measuring system showed that the observed measuring device has all the necessary features to be used with certainty for data acquisition in the process capability study. The analysis of the obtained results from the process capability study showed that the observed process has good stability, i.e., the range of 6σ is within the specification limits, and good centricity because the value of the C_{pk} index is approximately equal to the C_p index value. Based on this, the estimated number of workpieces that do not meet the specification, presented as a PPM index, is minimized.

5. REFERENCES

[1] Stepenhurst, T.: Mastering statistical process control A Handbook for Performance Improvement Using Cases, Elsevier Butterworth-Heinemann, 2005.

[2] Saikaew. C.: An implementation of measurement system analysis for assessment of machine and part variations in turning operation, Measurement, 118, 2018

[3] H. U. Pawar, S. K. Bagga, and D. K. Dubey: Investigation of production parameters for process capability analysis: A case study, Mater. Today Proc., vol. 43, pp. 196–202, 2021.

[4] R. Sharma, R. Singh, and A. Batish.: On multi response optimization and process capability analysis for surface properties of 3D printed functional prototypes of PVC reinforced with PP and HAp, Mater. Today Proc., vol. 28, pp. 1115–1122, 2019.

[5] Ketan, H., Nassir, M.: Aluminium hot extrusion process capability improvement using Six Sigma, Adv. Prod. Eng. Manag., vol. 11, no. 1, pp. 59–69, 2016.

[6] Down, M., et al.: Measurement system analysis reference manual, Chrysler Group LLC, Ford Motor Company, General Motors Corporation, 2010.

[7] M. Wrzochal and S. Adamczak.: Application of a Gage R&R study in evaluation of rolling bearing measurement system accuracy, Transp. Res. Procedia, vol. 40, pp. 934–939

[8] Štrbac, B., et al: Supplement to the Standard VDI/DGQ 3442 with Gage R&R Study, New Technologies, Development and Application IV, Sarajevo, 2021.

ACKNOWLEDGMENT

The results presenzed imn this paper are obtained in the framework of the project entitled “Innovative scientific and artistic research from FTS (activity) domain” funded by the Ministry of Education, Sciences and Technological Development of Republic of Serbia”

Authors: **B.Sc. Miloš Ranisavljev, Assist. Prof. Branko Štrbac, M.Sc. Zorana Lanc, PhD Matin Ivan Full Prof. Miodrag Hadžistević,** University of Novi Sad, Faculty of Technical Sciences, Department of Production Engineering, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia, Phone.: +381 21 485-23-24.

E-mail: ranisavljev@uns.ac.rs;
strbacb@uns.ac.rs;
zoranalanc@uns.ac.rs;
matini@uns.ac.rs;
miodrags@uns.ac.rs

Full Prof. Predrag Janković, Faculty of Mechanical Engineering in Niš, University of Niš, Aleksandra Medvedeva 14, 18106 Niš, Serbia

E-mail: predrag.jankovic@masfak.ni.ac.rs