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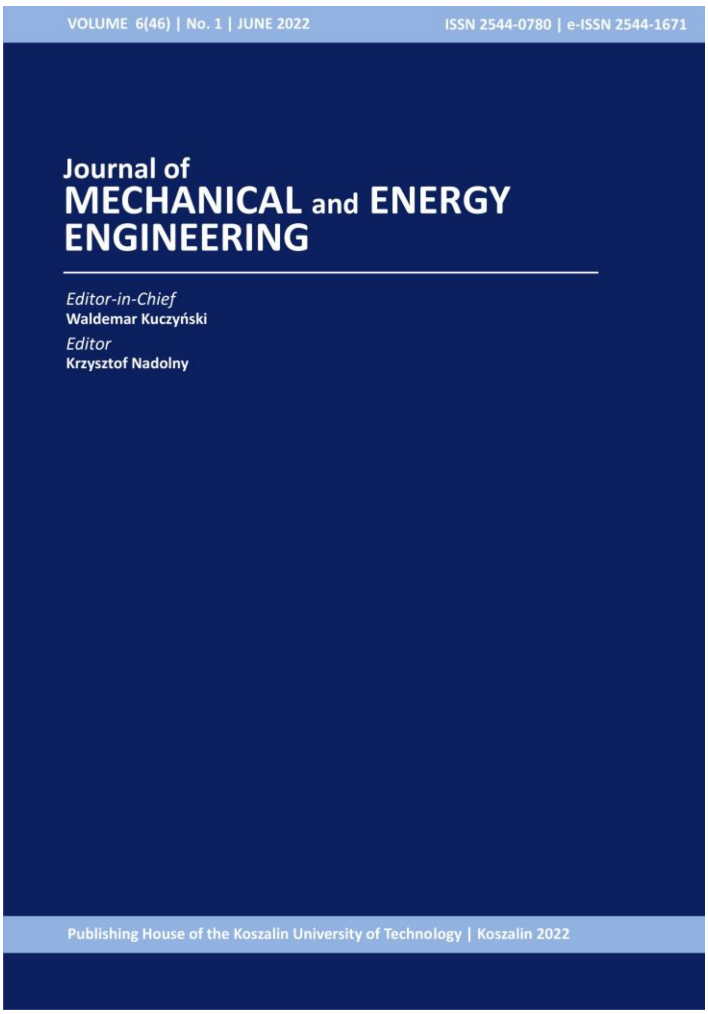

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STUDY OF PROCESS STABILITY IN INJECTION MOLDING BASED ON PRODUCT WEIGHT

Tomasz CHACIŃSKI[1*], Piotr JASKÓLSKI[2], Michał PAŁUBICKI[2]

[1*] Faculty of Mechanical Engineering, Department of Production Engineering, Koszalin University of Technology, Raclawicka 15-17, 75-620 Koszalin, Poland, e-mail: tomasz.chacinski@tu.koszalin.pl
[2] Faculty of Mechanical Engineering, Department of Production Engineering, Koszalin University of Technology, Raclawicka 15-17, 75-620 Koszalin, Poland

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Abstract: This paper describes a stability study of a plastic injection molding process. There is a need - underpinned by economic considerations - to continuously improve and lead to a maximum reduction in the level of deficiencies in production processes. One of the methods that can help to improve the process is SPC (Statistical Process Control). One of the SPC tools are process capability indicators (*Cp*, *Cpk*) or performance indicators, such as *Pp*, *Ppk*. In this paper, on a mass measuring station, a study was conducted on three types of products manufactured in a company, and the measurements concerned each piece of the product manufactured during one work shift. The data collected were used to calculate the process capability and to evaluate these processes.

Keywords: injection molding, quality control, statistical process control, process capability indicators

1. INTRODUCTION

Plastic articles have become an important and integral part of modern life; they are used to make parts and machines that we use every day, they owe their popularity to their low manufacturing costs compared to other materials [1]. However, due to the growing awareness and environmental responsibility of society and enterprises, it is necessary to eliminate waste and minimize the production of defects in every industrial sector, especially in the production of plastics. According to this philosophy, by means of the SPC method and tools of process capability indicators, the capability of selected processes in a production company was assessed. With the help of the mentioned indicators the processes were evaluated, and this evaluation can form a basis for indicating the direction of process improvements. An improvement of production processes selected by SPC potentially leads to minimizing the production of non-conforming products, thus reducing the production of defects.

The application of SPC therefore involves continuous improvement of the company's operations, The organization must ensure that any product that does not meet product standards is detected and regulated so that it is not used or delivered in an undesired manner. Controls, as well as corresponding responsibilities and permissions for dealing with nonconforming products, must be recorded [4].

The use of these methods allows management and operators to focus on the fact that a given process can start to develop flaws if suitable rectification operations are not carried out [4].

Using these methods also allows one to take care of quality and, nowadays, in a market economy, the quality of products and services is critical in determining the competitiveness of the enterprise as a whole, and of products and services in particular [9].

2. MATERIALS AND METHODS

2.1. Objects of the study

Three production processes were selected for the study, each implemented on a separate production nest. The parameter under study was the mass of the product, which can be related to the quality of the product [2]. The processes were selected for the study because of:

- variety of products in terms of size (large, medium and small),
- variety of products in terms of complexity (simple, more complex, and complicated),
- variety of products in terms of weight (heavy, lighter and light)

The product features are summarized in Table 1 [3].

Tab. 1. Summary of the characteristics of the products tested

Specimen type	Size of the specimen	Complexity	Part mass, g
I	Big	simple geometry, openwork, no other elements	429
II	Medium	simple geometry, complex openwork on walls, required accuracy due to cover assembly	501
III	Small	complicated geometry, multi-part product, latches and hinges	250

2.2. Process evaluation criteria

Due to the possibility of conducting research on a large sample and the fact that the process is not in developmentm stage indicators C_p and C_{pk} were used [5]. The mentioned indicators can be used when [6]:

– data has normal distribution,
– process is under statistical quality control,
– process mean is centered between lower control limit and upper control limit.

Each manufacturing process will be evaluated under the criteria described below.

1. The potential process capability index calculated from the following Formula (1):

$$C_p = \frac{S_u - S_l}{6\delta}, \tag{1}$$

where: S_u – upper control limit; S_l – lower control limit; δ – standard deviation.

2. The actual process capability index calculated from the following Formula (2):

$$C_{pk} = \min\{C_{pku}, C_{pkl}\}, \tag{2}$$

where: $C_{pku} = \frac{X_{sr} - S_l}{3\delta}$; $C_{pkl} = \frac{S_u - X_{sr}}{3\delta}$; X_{sr} – process average value; S_u – upper control limit; S_l – lower control limit; δ – standard deviation.

According to Kaya and Kahraman [7], quality conditions and C_p values are as shown in Table 2. According to Rezaie *et al.* [8], C_{pk} is the distance between the mean of the process and the closest specification limit. Rezaie *et al.* demonstrate that process with C_p value 2 can be expected to have no more than 0.002 out of spec. boundaries PPM.

2.3. Test bench

An AXIS B6M industrial platform scale was selected for the measurements (Fig. 1). Table 3 shows the technical parameters of the indicated measuring device.

Fig. 1. AXIS B6M scale used as test bench [10]

Tab. 2. Quality conditions and C_p values [7]

Quality condition	C_p value
Super excellent	$2.00 \leqslant C_p$
Excellent	$1.67 \leqslant C_p \leqslant 2.00$
Satisfactory	$1.33 \leqslant C_p \leqslant 1.67$
Capable	$1.00 \leqslant C_p \leqslant 1.33$
Inadequate	$0.67 \leqslant C_p \leqslant 1.00$
Poor	$C_p < 0.67$

Tab. 3. Technical parameters of used AXIS B6M scale [11]

Parameter	Value
Maximum load	6 kg
Minimum load	4 g
Scale interval	0.2 g
Verification scale interval	2 g
Operating temperature	0°C – 40°C
Measuring time	< 4 s
Weighing pan dimensions	300 × 300 mm

The technical parameters of the selected device meet the conditions of use for the selected group of products.

After the preparation of the measuring station, a repeatability test of the measurements was performed with the sample.

2.4. Methods

A methodology has been developed for research conducted within selected production cells. It is assumed that the implemented research:

– will apply to each unit of the selected product manufactured during one work shift,
– will concern the measurement of the weight of each piece of the selected product produced in one repetition,
– includes a record of each measurement for further analysis,
– enables an evaluation of the production process.

Each sample will be weighed during the production process, directly at the production station. The collected results will be analyzed, and indicators will be calculated.

3. RESULTS AND DISCUSSION

3.1. Results for specimen type I

Table 4 shows an excerpt of the results of the product mass tests conducted on the test for specimen type I.

Tab. 4. Excerpt of the study results for type I specimen

No.	Value, g
261.	426.0
262.	427.2
263.	429.4
264.	426.6
265.	428.4
266.	425.5
267.	427.6
268.	429.4
269.	429.0
270.	427.0

During the test at this bench, 460 measurements were recorded. Defective samples are defined as those that fall outside the imposed deviations (from 425.4 g to 430.2 g). Figure 2 shows a histogram of the recorded measurement values.

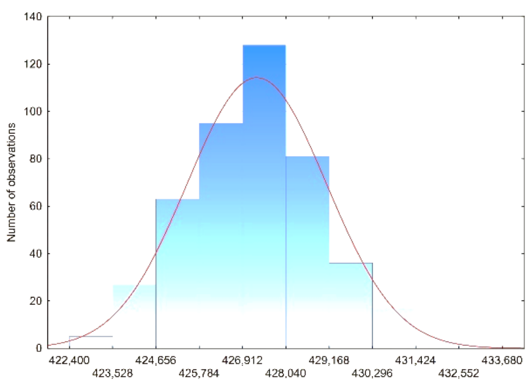

Fig. 2. Distribution of recorded measurement values for the specimen type I

The indicator values for the process are calculated below:

$$C_p = \frac{430.2-425.4}{6\times1.8114} = 0.4416, \quad (3)$$

$$C_{pku} = \frac{430.2-427.26}{3\times1.8114} = 0.5418, \quad (4)$$

$$C_{pkl} = \frac{427.26-425.4}{3\times1.8114} = 0.3415, \quad (5)$$

$$C_{pk} = \min\{C_{pku}, C_{pkl}\} = 0.3415. \quad (6)$$

The indices C_p (3) and C_{pk} (6) took the value of 0.44 and 0.34 respectively. Such values of the indices indicate that the process is well centered but with a large scatter.

3.2. Results for specimen type II

Table 5 shows an excerpt of the results of the product mass tests conducted on the test for specimen type II.

Tab. 5. Excerpt of the study results for type II specimen

No.	Value, g
124.	505.9
125.	507.7
126.	506.5
127.	505.9
128.	505.7
129.	505.9
130.	505.2
131.	506.5
132.	500.0
133.	506.6

During the test at this bench, 250 measurements were recorded. Defective samples are defined as those that fall outside the imposed deviations (from 498.0 g to 517.8 g). Figure 3 shows a histogram of the recorded measurement values.

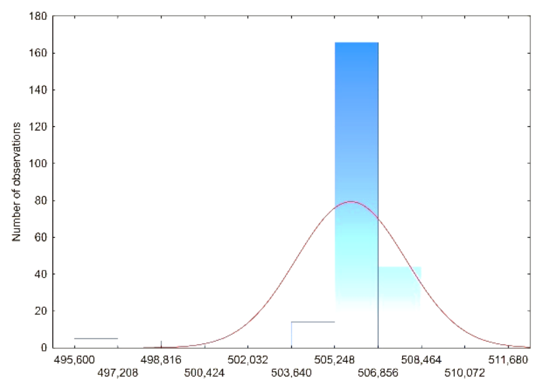

Fig. 3. Distribution of recorded measurement values for the specimen type II

The indicator values for the process are calculated below:

$$C_p = \frac{517.8-498}{6\times2.0214} = 1.6325, \quad (7)$$

$$C_{pku} = \frac{517.8-505.79}{3\times2.0214} = 1.9802, \quad (8)$$

$$C_{pkl} = \frac{505.79-498}{3\times2.0214} = 1.2848, \quad (9)$$

$$C_{pk} = \min\{C_{pku}, C_{pkl}\} = 1.2848. \quad (10)$$

The indices C_p (7) and C_{pk} (10) took the value of 1.63 and 1.28 respectively. Such values of the indices indicate that the process is moderately capable and well centered.

3.3. Results for specimen type III

Table 6 shows an excerpt of the results of the product mass tests conducted on the test for specimen type III.

Tab. 6. Excerpt of the study results for type III specimen

No.	Value, g
124.	249.1
125.	249.2
126.	250.7
127.	249.8
128.	247.9
129.	250.7
130.	248.9
131.	249.2
132.	248.8
133.	250.3

During the test at this bench, 380 measurements were recorded. Defective samples are defined as those that fall outside the imposed deviations (from 246.0 g to 270.7 g). Figure 3 shows a histogram of the recorded measurement values.

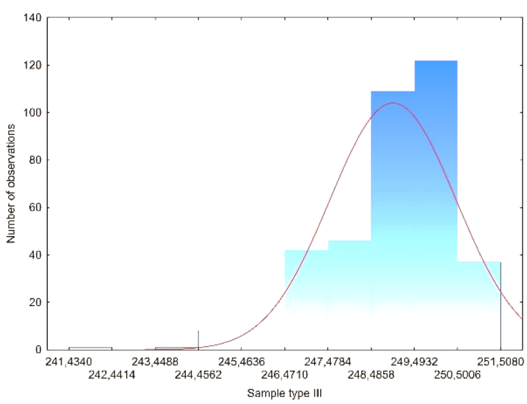

Fig. 4. Distribution of recorded measurement values for the specimen type III

The indicator values for the process are calculated below:

$$C_p = \frac{270.7-246}{6\times1.4701} = 2.8002, \quad (11)$$

$$C_{pku} = \frac{270.7-248.96}{3\times1.4701} = 4.9302, \quad (12)$$

$$C_{pkl} = \frac{248.96-246}{3\times1.4701} = 0.6703, \quad (13)$$

$$C_{pk} = \min\{C_{pku}, C_{pkl}\} = 0.6703. \quad (14)$$

The indicators C_p (11) and C_{pk} (14) were 2.8 and 0.67 respectively. These values indicate that the process has an excellent potential but it is poorly centered.

3.4. Discussion

The values of the calculated indicators suggest that one should aim for:

– a reduction of the scatter for the first type of sample,
– an increase of the alignment for sample type three.

In the case of the type of the two specimens, the index values are considered satisfactory.

4. CONCLUSIONS AND DISCUSSION

After conducting research and analyzing the results in the form of an evaluation of individual production processes by means of the adopted indicators, it was possible to come up with the following conclusions.

1. After the analysis of the evaluation of the production processes, it was deduced that the production process of type one product is, among the three studied, the production process that obtains the worst evaluation indexes. Since the indices C_p (3) and C_{pk} (6) took the values of 0.44 and 0.34 respectively, this process is considered insufficiently stable.
2. For the sample type II, the indices C_p (7) and C_{pk} (10) took the value of 1.63 and 1.28 respectively. Of the three processes examined, only this one remains at a satisfactory level. The process is characterized by a good potential and centering.
3. For the sample type III, the indicators C_p (11) and C_{pk} (14) were 2.8 and 0.67 respectively. These values indicate that the process needs to be more centered, however the scatter is at satisfactory level.

Of the three products examined, it is product type one that proves to be a product whose manufacturing process is insufficiently stable.

The implementation of SPC solutions, e.g. in the form of a dynamic platform industrial scales into the transport chain of the product at the machine operator's stand, would allow for early detection of product defects and minimization of products not complying with the product specification.

Nomenclature

Symbols

C_p – Potential process capability index
C_{pk} – Actual process capability index
P_p – Potential process performance index
P_{pk} – Actual process performance index
X_{sr} – Process average value
δ – Standard deviation

Acronyms

SPC – Statistical Process Control
PPM – Parts Per Million

References

1. Chaciński T., Sutowski P. 2021, Common defects in injection molding of plastic products and their influence on product quality, Journal of Mechanical and Energy Engineering, 5(1), pp. 7-14. doi: 10.30464/10.30464/jmee.2021.5.1.7.
2. Elsheikhi S. A., Mulvaney-Johnson L. Campean F. Gough T. Coates P., 2010, Reprocessing of polypropylene material through injection moulding: investigation of part quality, physical properties, processing properties and mechanical properties, *26th Annual Meeting of The Polymer Processing Society*.
3. Chaciński T., 2021, Projekt usprawnienia procesu kontroli jakości w produkcji artykułów z tworzyw sztucznych [...], Politechnika Koszalińska. (in Polish).
4. Dudek-Burlikowska M., 2005, Quality estimation of process with usage control charts type X-R and quality capability of process Cp, Cpk, *Journal of Materials Processing Technology*, Vol. 736-743, ISSN 0924-0136, https://doi.org/10.1016/j.jmatprotec.2005.02.210
5. Karale C. K., 2017, Process Capability and Capability Index (Cp and Cpk). 10.13140/RG.2.2.14000.25608.
6. Keskin G., Çolak M., Güngör B. 2019, Application of Statistical Process Control in Production Process: A Case Study in Cleaning Products Sector. *Conference: 11th International Statistics Congress*.
7. Kaya I., Kahraman C. 2011, Process capability analyses based on fuzzy measurements and fuzzy control charts, *Expert Systems with Applications*, Volume 38, Issue 4, 2011, pp. 3172-3184, ISSN 0957-4174, https://doi.org/10.1016/j.eswa.2010.09.004.
8. Rezaie K., Osadi B., Taghizadeh M.R. 2006, Measuring Process Capability Indices, Conference: *The 36th International Conference on Computers & Industrial Engineering*.
9. Temasova G N, Leonov O A, Shkaruba N Zh, Vergazova Yu G, Petrovskiy D I, 2021, Application of statistical methods for quality control of agro-industrial production processes, *IOP Conf. Series: Earth and Environmental Science* 839 (2021) 022026, doi:10.1088/1755-1315/839/2/022026
   https://elektrowag.pl/pl/p/WAGA-przemyslowa%2C-UDZWIG-WAGI-DO-WYBORU-OD-MAX-3-KG-DO-MAX-15-KG/161
10. https://www.axis.pl/uploads/1240225718R-BM-049-02-09%20B-41_9%20PL%20v11.pdf

Biographical notes

Tomasz Chaciński defended his Bachelor of Engineering thesis in July 2021. He is an employee of the Faculty of Mechanical Engineering at the Department of Production Engineering, the Technical University of Koszalin. His interests include solving problems in production processes organization, improvement of production systems through automation of their processes and application of dynamic quality control methods.

Piotr Jaskólski defended his major thesis with honours in 2020 at the Faculty of Mechanical Engineering of the Koszalin University of Technology, majoring in Mechanical Engineering. He is a leader of a team of students performing a physical model of a modular didactic production system. Currently, he is an employee of the Koszalin University of Technology at the Faculty of Mechanical Engineering. His scientific interests include issues related to an automation of manufacturing processes, CNC machining and modern technologies in production engineering.

Michał Pałubicki is a student of Mechanical Engineering at the Faculty of Mechanical Engineering, the Technical University of Koszalin. He is currently preparing to defend his Bachelor of Engineering thesis. His interests include issues related to rapid prototyping, CAD software, and production process improvement.