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Quality characteristics analysis for the assembly of the elements from the construction of a mechanism for adjusting the seats in the automotive industry

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Abstract. Statistical control of a technological process is a method that is based on a series of tools that allow documentation, understanding, monitoring and supervising of the entire process, in order to ensure quality finished products. When the technological process is complex, statistical methods contribute to an early identification of systematic deviations, so that the quality characteristics are within the allowable tolerance limits. Thus, statistical control is a preventive method of quality management. The analysis of the capability of a production process is mainly used to determine the capability of the process to ensure compliant products, by analyzing certain monitored data that are representative of that process. The paper presents a study on the statistical control of some pieces from the construction of electric motors used to adjust the seats of vehicles. For each piece, 8 measurements were made, the volume of each measurement having 50 elements and the results were interpreted through a software application developed for this purpose and made in the Java language. The software analyzes a database consisting of the values of the dimensions of the measured pieces and identifies whether these values have a statistically normal distribution and falls within the permissible tolerance limits.

Keywords: Statistical Control, Capability, Automotive Industry.

1 Introduction

Even in the conditions where a technological process is of high complexity, its quality characteristics must be within the specified tolerance limits [1], [2]. Early identification of systematic deviations can be achieved through statistical models, as preventive methods of quality management [3], [4], [5]. Basically, the statistical control of a technological process is based on a collection of tools that allow the documentation, comprehension, monitoring and control of the process itself [6].

The state of statistical stability, in which the parameters of a system may vary within admissible limits, highlights the concept of statistical control state as a necessary condition for the approval of any technological process. The process is defined as a set of means and activities in a reciprocal relationship, which transforms the initial characteristics into results [6]. The approval of technological processes can include both the state of statistical control of the process and a certain convenient value of the process capability index [7], [8].

If the state of statistical control of the process is based on the comparison of previous data with current ones, the purpose not being to identify errors, but to highlight them in order to eliminate as many nonconforming parts, the calculation of the process capability index is performed in real production conditions in order to observe if the process is controllable in time and if it ensures the necessary quality [9], [10].

Quantitative assessment of the performance of a technological manufacturing process is achieved by studying performance indices, among the most important being the process capability. Basically, the capability of the process represents its ability to perform technical functions to obtain measurable results, which fall within specific tolerance limits, based on previous performance [11], [12].

The capability of a process, C_p, is influenced by the position and width of the distribution in relation to the tolerance limits: *USL* - Upper Specification Limit; *LSL* - Lower Specification Limit, which can be symmetrical or asymmetrical in relation to the nominal value, Figure 1. For a correct quantitative definition of a process capability, the process capability index is calculated:

$$C_p = \frac{USL - LSL}{6\sigma} \tag{1}$$

If the value of characteristic X is between the two limits, $LSL<X<USL$, then the product is acceptable in terms of quality and is classified as a compliant product, otherwise the product is classified as non-compliant.

To study the position of the spreading field in relation to the tolerance limits, the C_{pk} index is used - the process capability index, which shows the position of the average value in relation to the middle of the tolerance field:

$$C_{pk} = \min(C_{pk\,sx}, C_{pk\,dx}) \tag{2}$$

where:

$C_{pk\,sx}$ – higher process capability index (upper specification limit);

$C_{pk\,dx}$ – lower process capability index (lower specification limit).

The upper and lower specification limits define two values, which show the difference between the process average and the upper and lower specification limits, Figure 2.

$$C_{pk\,sx} = \frac{LSL - \overline{X}}{3\sigma}; \quad C_{pk\,dx} = \frac{USL - \overline{X}}{3\sigma}. \tag{3}$$

The general process C_{pk} is the lower value of $C_{pk\,sx}$ and $C_{pk\,dx}$. If $C_{pk} \leq 1$, it means that at least one of the tolerance limits will be exceeded.

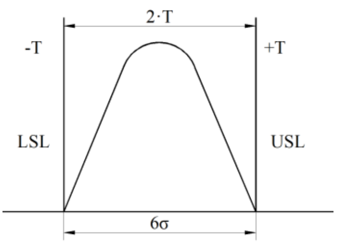

Fig. 1. Capability process: *6σ* - spreading degree; *σ* - standard deviation; *T* - tolerance [13].

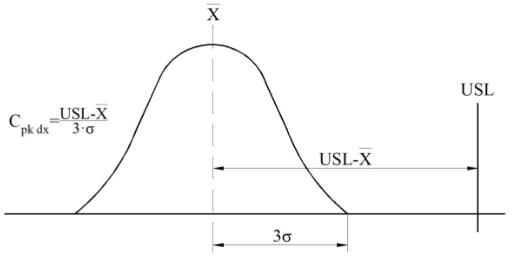

Fig. 2. Lower process capacity index, $C_{pk\ dx}$, X - average of measurements [13].

Increasing the value of the C_{pk} index can be possible by centering the process so that the average value and the average specification match. Sometimes the C_{pk} index is used when there is only one limit of specification, upper or lower, which cannot be defined in the case of C_p.

Depending on the values of the C_{pk} index, the confidence level of the process capability can be defined: C_{pk} <1 - non-compliant process results; C_{pk} = 1 - any change in the process setting will lead to the appearance of undetected non-compliant results; C_{pk} = 1.33 - it is difficult to predict the occurrence of non-compliant results through process control diagrams; C_{pk} = 1.5 - control diagrams are not very useful because the chances of detecting non-compliant results are still too low; C_{pk} = 1.6 - there is a high chance that non-compliant products will be detected using control diagrams; C_{pk} = 2 - there is a very high chance that non-compliant products will be detected using control diagrams, the level of confidence being very high.

Therefore, it can be stated that the results obtained from a statistical control are distributed around a value, usually variable, regardless of the manufacturing or measuring process [14], [15].

2 Characteristics of the mechanism for adjusting the seats in the automotive industry

In the paper, a study on statistical control over some parts from the construction of electric micromotors used to adjust the seats of vehicles is presented. Electrical micromotors are provided with housings that protect them completely and are generally made of aluminum, Figure 3.

Regardless of the type of micromotor, it is built of two component parts: stator and rotor. The stator is the fixed part of the micromotor, generally external, which includes the housing, the supply terminals, the stator ferromagnetic armature and the stator envelope. The rotor is the moving part of the engine, usually placed inside. It consists of a shaft and a rotor armature that supports the rotor envelope. Between the stator and the rotor there is a portion of air called the air gap that allows the rotor to move in relation to the stator. The thickness of the air gap is an important indicator of micromotor performance.

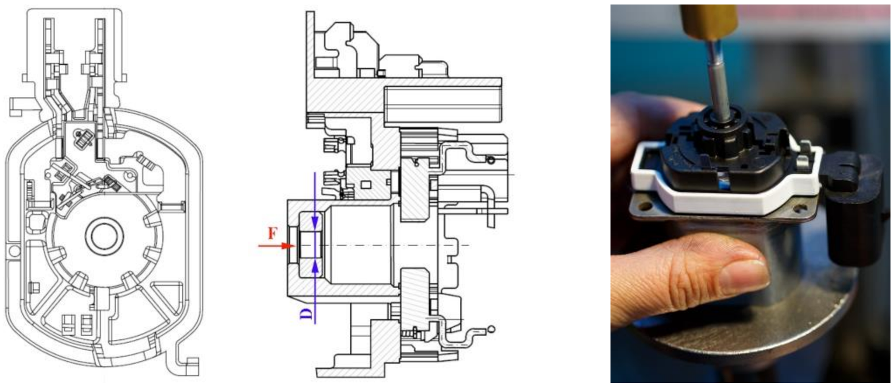

Fig. 3. Assembled micromotor.

A rotor is an electromagnet made by wrapping a very thin wire around two or more poles of a metal core. The rotor has a shaft and the switch is attached to it, Figure 4.

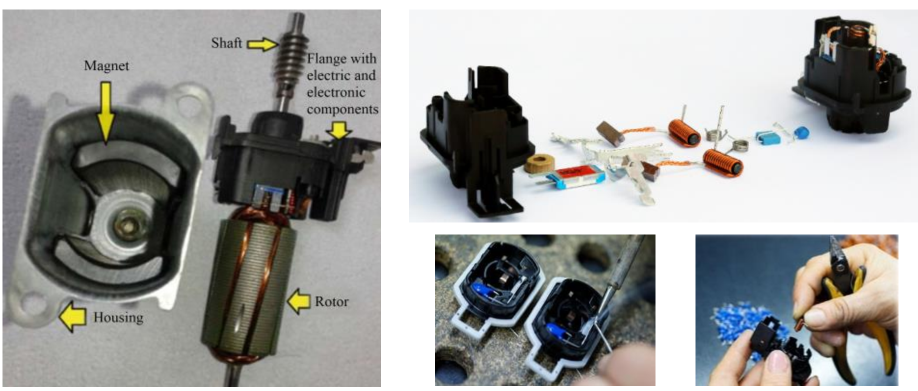

Fig. 4. Disassembled micromotor.

The key characteristics of electric micromotors for adjusting the seats of the vehicles are: reliability, low noise, magnetic field generated by permanent magnets, flexibility and high level of automatization, 12V or 24V supply voltage. Motor torque varies from 0.2 Nm to 0.35 Nm without gear and from 8 Nm to 12 Nm with gear. It is also important to increase the nominal power from 8.7W to 8.8W, ensuring the micromotor a higher driving power, but also resistance. By using intelligent statistical control solutions, created to maximize efficiency and increase productivity, companies must remain competitive in terms of ensuring compliant products, without much nonconforming parts, quality control of these products being essential and the high level of repeatable accuracy that these technologies provides allows providers to respect the increasingly high standards imposed by original equipment manufacturers.

3 Quality characteristics of the mechanism for adjusting the seats in the automotive industry

Capability is the ability of a system or process to make a product that will meet the requirements for making it. The method is frequently used to verify the dynamic stability of a process and involves repeated control at regular intervals. Thus, it was considered 1 part (bushing) from the construction of a micromotor for adjusting the seats of an Audi car. 50 samples were taken from the assembly line, each bushing was measured at 8 workstations and the results were interpreted through a software application developed for this purpose and made in Java. In order to establish the capability for the part from the construction of electric motors used to adjust the seats of Audi vehicles, certain limits set out in Table 1 were imposed.

Table 1. Limits set for the inner diameter (*D* – Figure 3) of the bushing (mounting dimension) from the construction of electric micromotors used to adjust the seats of an Audi vehicle.

Nr. sample elements / Nr. workstation	50/1	50/2	50/3	50/4	50/5	50/6	50/7	50/8
Specific lower limit	9.80	9.80	9.80	9.80	9.80	9.80	9.80	9.80
Specific average	9.98	9.98	9.98	9.98	9.98	9.98	9.98	9.98
Specific upper limit	10.15	10.15	10.15	10.15	10.15	10.15	10.15	10.15
Specific tolerance	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Minimum detected	9.94	9.95	9.91	9.94	9.95	9.90	9.95	9.94
Average - 3σ	9.89	9.88	9.88	9.90	9.89	9.89	9.89	9.89
Detected average	9.99	10.00	9.99	10.00	10.00	10.00	10.01	10.00
Detected average + 3σ	10.10	10.12	10.11	10.102	10.103	10.108	10.12	10.11
Maximum detected	10.10	10.10	10.10	10.09	10.09	10.08	10.09	10.10
Max - Min. detected	0.14	0.15	0.20	0.15	0.14	0.18	0.14	0.16
Standard deviation	0.04	0.04	0.04	0.03	0.04	0.04	0.04	0.04
Natural tolerance (6σ)	0.21	0.24	0.23	0.21	0.21	0.22	0.23	0.23
C_p	1.64	1.48	1.55	1.70	1.67	1.57	1.56	1.53
$C_{pk\ sx}$	1.83	1.69	1.71	1.93	1.89	1.77	1.83	1.74
$C_{pk\ dx}$	1.44	1.27	1.39	1.47	1.45	1.38	1.29	1.31

Basically, in order to assess the capability, it started from the probability of obtaining conforming parts to an assembly operation. The procedure involves going through several stages: establishing the characteristics of the parts; measuring a characteristic on each part; determining the statistical parameters, checking the obtained data to see if they comply with the normal distribution and calculating the probability of performing a correct assembly operation. Figures 5 ÷ 12 show the specific values for C_p, C_{pk}, $C_{pk\ sx}$, $C_{pk\ dx}$, respectively the position of the spreading field in relation to the tolerance limits, for the specific values taken into account: minimum specific value - 9.800, maximum specific value - 10.150, average value: 9.975, values valid for the dimension defining the inner diameter (*D* – Figure 3) of the bushing (mounting dimension), measured with a comparator.

Sample 50/1			
Min.	***9.940***	Max.	***10.080***
Average	***9.996***	6σ	***0.214***
Total error:	***0.00%***	Estimated error:	***0.00%***
C_p	***1.636***	C_{pk}	***1.444***
$C_{pk\ sx}$	***1.828***	$C_{pk\ dx}$	***1.444***

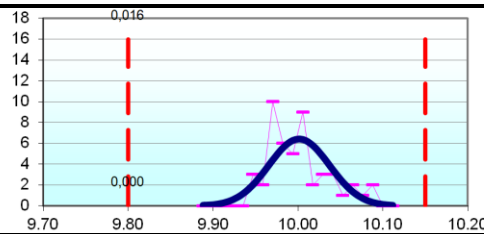

Fig. 5. Specific values C_p, C_{pk}, $C_{pk\ sx}$, $C_{pk\ dx}$ and position of the tolerance field – Sample 50/1

Sample 50/2			
Min.	***9.950***	Max.	***10.100***
Average	***10.000***	6σ	***0.237***
Total error:	***0.00%***	Estimated error:	***0.01%***
C_p	***1.480***	C_{pk}	***1.268***
$C_{pk\ sx}$	***1.691***	$C_{pk\ dx}$	***1.268***

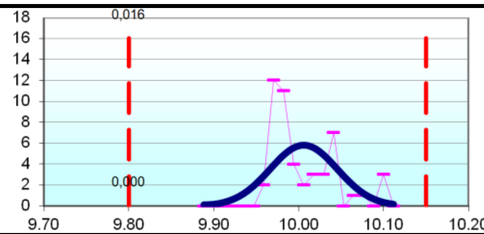

Fig. 6. Specific values C_p, C_{pk}, $C_{pk\ sx}$, $C_{pk\ dx}$ and position of the tolerance field – Sample 50/2

Sample 50/3			
Min.	***9.910***	Max.	***10.070***
Average	***9.993***	6σ	***0.226***
Total error:	***0.00%***	Estimated error:	***0.00%***
C_p	***1.549***	C_{pk}	***1.387***
$C_{pk\ sx}$	***1.711***	$C_{pk\ dx}$	***1.387***

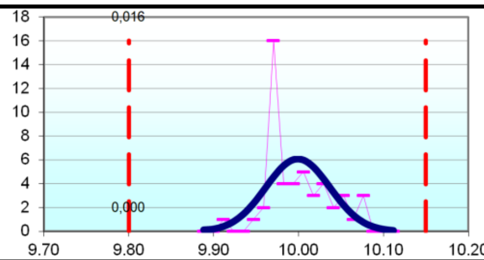

Fig. 7. Specific values C_p, C_{pk}, $C_{pk\ sx}$, $C_{pk\ dx}$ and position of the tolerance field – Sample 50/3

Sample 50/4			
Min.	***9.940***	Max.	***10.090***
Average	***9.999***	6σ	***0.206***
Total error:	***0.00%***	Estimated error:	***0.00%***
C_p	***1.701***	C_{pk}	***1.469***
$C_{pk\ sx}$	***1.933***	$C_{pk\ dx}$	***1.469***

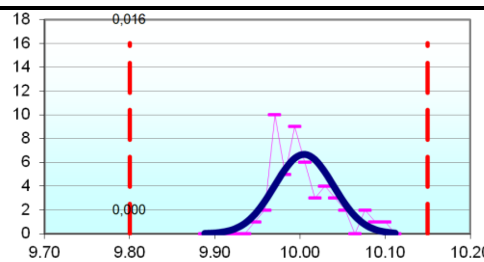

Fig. 8. Specific values C_p, C_{pk}, $C_{pk\ sx}$, $C_{pk\ dx}$ and position of the tolerance field – Sample 50/4

Sample 50/5			
Min.	***9.950***	Max.	***10.090***
Average	***9.998***	6σ	***0.210***
Total error:	***0.00%***	Estimated error:	***0.00%***
C_p	***1.669***	C_{pk}	***1.446***
$C_{pk\ sx}$	***1.891***	$C_{pk\ dx}$	***1.446***

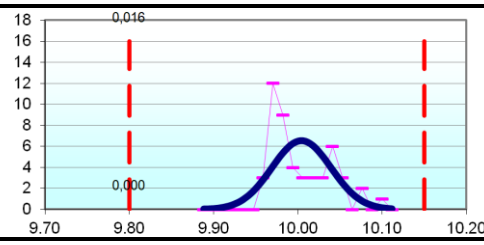

Fig. 9. Specific values C_p, C_{pk}, $C_{pk\ sx}$, $C_{pk\ dx}$ and position of the tolerance field – Sample 50/5

Sample 50/6			
Min.	***9.900***	Max.	***10.080***
Average	***9.997***	6σ	***0.222***
Total error:	***0.00%***	Estimated error:	***0.00%***
C_p	***1.574***	C_{pk}	***1.381***
$C_{pk\ sx}$	***1.768***	$C_{pk\ dx}$	***1.381***

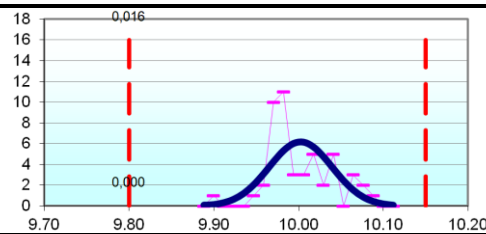

Fig. 10. Specific values C_p, C_{pk}, $C_{pk\ sx}$, $C_{pk\ dx}$ and position of the tolerance field – Sample 50/6

Sample 50/7			
Min.	***9.950***	Max.	***10.090***
Average	***10.005***	6σ	***0.225***
Total error:	***0.00%***	Estimated error:	***0.01%***
C_p	***1.559***	C_{pk}	***1.289***
$C_{pk\ sx}$	***1.829***	$C_{pk\ dx}$	***1.289***

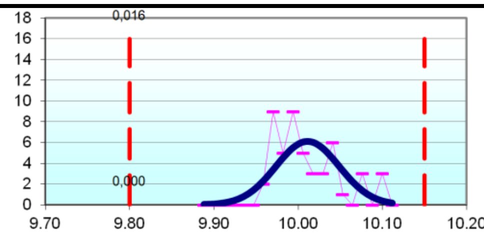

Fig. 11. Specific values C_p, C_{pk}, $C_{pk\ sx}$, $C_{pk\ dx}$ and position of the tolerance field – Sample 50/7

Sample 50/8			
Min.	***9.940***	Max.	***10.100***
Average	***10.000***	6σ	***0.229***
Total error:	***0.00%***	Estimated error:	***0.00%***
C_p	***1.528***	C_{pk}	***1.313***
$C_{pk\ sx}$	***1.742***	$C_{pk\ dx}$	***1.313***

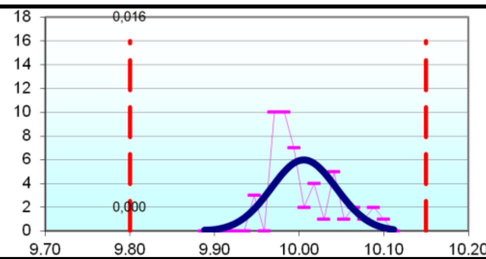

Fig. 12. Specific values C_p, C_{pk}, $C_{pk\ sx}$, $C_{pk\ dx}$ and position of the tolerance field – Sample 50/8

Also, in table 2, certain limits were imposed for the effective force (F) at the assembly of the bushing from the construction of electric micromotors used to adjust the seats of an Audi vehicle.

Table 2. Limits set for the effective force (F – Figure 3) at the assembly of the bushing from the construction of electric micromotors used to adjust the seats of an Audi vehicle.

Nr. sample elements / Nr. workstation	50/1	50/2	50/3	50/4	50/5	50/6	50/7	50/8
Specific lower limit	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
Specific average	34.50	34.50	34.50	34.50	34.50	34.50	34.50	34.50
Specific upper limit	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Specific tolerance	51.00	51.00	51.00	51.00	51.00	51.00	51.00	51.00
Minimum detected	22.60	23.70	21.60	25.20	25.50	23.20	21.20	25.80
Average - 3σ	18.49	18.47	17.84	18.34	18.64	17.66	17.29	18.34
Detected average	30.93	30.53	28.40	31.11	31.90	29.25	29.64	31.68
Detected average + 3σ	43.38	42.60	38.97	43.87	45.16	40.85	41.98	45.02
Maximum detected	41.00	43.00	37.40	44.60	44.10	41.40	40.20	44.30
Max - Min. detected	18.40	19.30	15.80	19.40	18.60	18.20	19.00	18.50
Standard deviation	4.15	4.02	3.52	4.26	4.42	3.86	4.12	4.45
Natural tolerance (6σ)	24.89	24.14	21.13	25.53	26.51	23.19	24.69	26.68
C_p	2.05	2.11	2.41	2.00	1.92	2.20	2.07	1.91
$C_{pk\ sx}$	1.76	1.78	1.84	1.73	1.73	1.75	1.67	1.70
$C_{pk\ dx}$	2.34	2.44	2.99	2.26	2.12	2.65	2.46	2.12

Figures 13 ÷ 20 show the specific values for C_p, C_{pk}, $C_{pk\ sx}$, $C_{pk\ dx}$, respectively the position of the spreading field in relation to the tolerance limits, for the specific values taken into account: minimum specific value – 9.000, maximum specific value – 60.000, average value: 34.500, values valid for the effective force at the mounting of the bushing, measured with a dynamometer.

Sample 50/1			
Min.	***22.600***	Max.	***41.000***
Average	***30.932***	6σ	***24.887***
Total error:	***0.00%***	Estimated error:	***0.00%***
C_p	***2.049***	C_{pk}	***1.763***
$C_{pk\ sx}$	***1.763***	$C_{pk\ dx}$	***2.336***

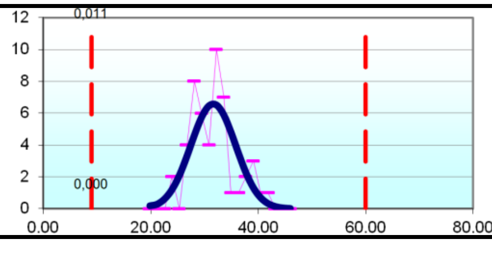

Fig. 13. Specific values C_p, C_{pk}, $C_{pk\ sx}$, $C_{pk\ dx}$ and position of the tolerance field – Sample 50/1

Sample 50/2			
Min.	***23.700***	Max.	***43.000***
Average	***30.534***	6σ	***24.138***
Total error:	***0.00%***	Estimated error:	***0.00%***
C_p	***2.113***	C_{pk}	***1.784***
$C_{pk\ sx}$	***1.784***	$C_{pk\ dx}$	***2.441***

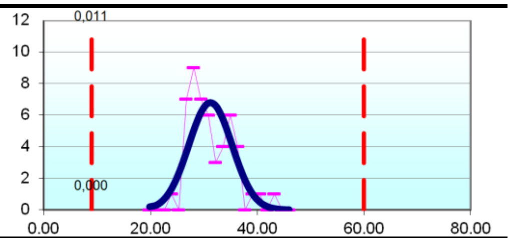

Fig. 14. Specific values C_p, C_{pk}, $C_{pk\ sx}$, $C_{pk\ dx}$ and position of the tolerance field – Sample 50/2

Sample 50/3			
Min.	***21.600***	Max.	***37.400***
Average	***28.402***	6σ	***21.132***
Total error:	***0.00%***	Estimated error:	***0.00%***
C_p	***2.413***	C_{pk}	***1.836***
$C_{pk\ sx}$	***1.836***	$C_{pk\ dx}$	***2.991***

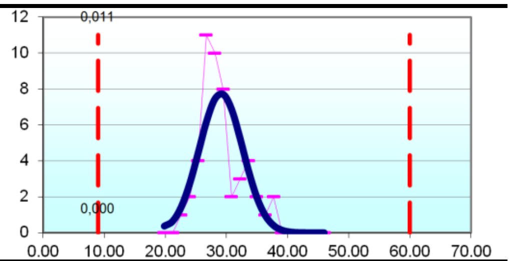

Fig. 15. Specific values C_p, C_{pk}, $C_{pk\ sx}$, $C_{pk\ dx}$ and position of the tolerance field – Sample 50/3

Sample 50/4			
Min.	***25.200***	Max.	***44.600***
Average	***31.112***	6σ	***25.533***
Total error:	***0.00%***	Estimated error:	***0.00%***
C_p	***1.997***	C_{pk}	***1.732***
$C_{pk\ sx}$	***1.732***	$C_{pk\ dx}$	***2.263***

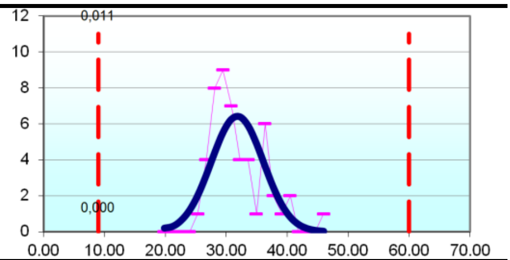

Fig. 16. Specific values C_p, C_{pk}, $C_{pk\ sx}$, $C_{pk\ dx}$ and position of the tolerance field – Sample 50/4

Sample 50/5			
Min.	***25.500***	Max.	***44.100***
Average	***31.898***	6σ	***26.514***
Total error:	***0.00%***	Estimated error:	***0.00%***
C_p	***1.924***	C_{pk}	***1.727***
$C_{pk\ sx}$	***1.727***	$C_{pk\ dx}$	***2.120***

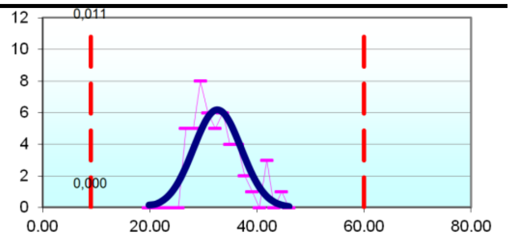

Fig. 17. Specific values C_p, C_{pk}, $C_{pk\ sx}$, $C_{pk\ dx}$ and position of the tolerance field – Sample 50/5

Sample 50/6			
Min.	*23.200*	Max.	*41.400*
Average	*29.252*	6σ	*23.186*
Total error:	*0.00%*	Estimated error:	*0.00%*
C_p	*2.200*	C_{pk}	*1.747*
$C_{pk\ sx}$	*1.747*	$C_{pk\ dx}$	*2.652*

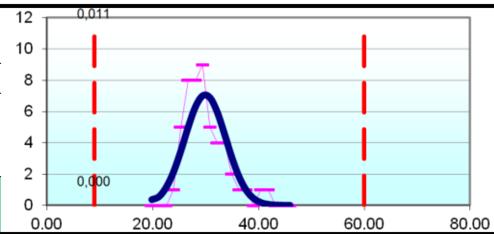

Fig. 18. Specific values C_p, C_{pk}, $C_{pk\ sx}$, $C_{pk\ dx}$ and position of the tolerance field – Sample 50/6

Sample 50/7			
Min.	*21.200*	Max.	*40.200*
Average	*29.636*	6σ	*24.692*
Total error:	*0.00%*	Estimated error:	*0.00%*
C_p	*2.065*	C_{pk}	*1.671*
$C_{pk\ sx}$	*1.671*	$C_{pk\ dx}$	*2.459*

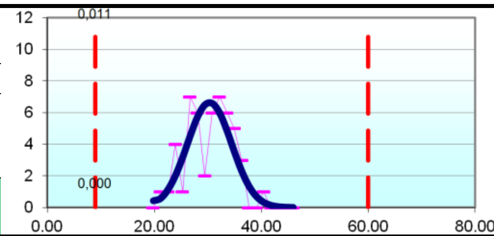

Fig. 19. Specific values C_p, C_{pk}, $C_{pk\ sx}$, $C_{pk\ dx}$ and position of the tolerance field – Sample 50/7

Sample 50/8			
Min.	*25.800*	Max.	*44.300*
Average	*31.680*	6σ	*26.675*
Total error:	*0.00%*	Estimated error:	*0.00%*
C_p	*1.912*	C_{pk}	*1.700*
$C_{pk\ sx}$	*1.700*	$C_{pk\ dx}$	*2.123*

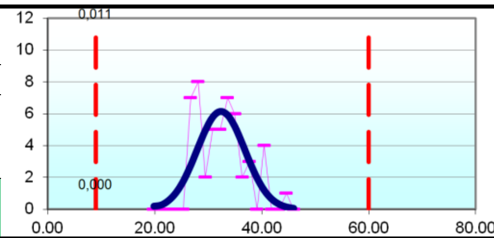

Fig. 20. Specific values C_p, C_{pk}, $C_{pk\ sx}$, $C_{pk\ dx}$ and position of the tolerance field – Sample 50/8

4 Interpretation of results and conclusions

To specify that the process is statistically controllable, the values of the upper and lower specification limits are analyzed in terms of $C_{pk\ sx}$ upper process capability indices and $C_{pk\ dx}$ lower process capability indices, respectively, for both nominal diameter control of the bushing, as well as for the specific mounting force, Table 3 and Table 4.

In order to visualize the evolution trends of the statistical parameters, control sheets are used in practice, which include the diagrams of the evolution of the average and amplitude for the followed characteristic.

The curves obtained by representing the values of the average and amplitude, calculated for each extracted sample, serve to verify the dynamic stability of the process: the approach of the control limits of the average value or amplitude are signals for initiating measures to reduce the values of the statistical parameters between the control limits.

Table 3. Lower and upper process capability indices for the nominal diameter (*D*)

Cpk ”sx”	1.828	**Cpk ”dx”**	1.444
Cpk ”sx”	1.691	**Cpk ”dx”**	1.268
Cpk ”sx”	1.711	**Cpk ”dx”**	1.387
Cpk ”sx”	1.933	**Cpk ”dx”**	1.469
Cpk ”sx”	1.891	**Cpk ”dx”**	1.446
Cpk ”sx”	1.768	**Cpk ”dx”**	1.381
Cpk ”sx”	1.829	**Cpk ”dx”**	1.289
Cpk ”sx”	1.742	**Cpk ”dx”**	1.313

Table 4. Lower and upper process capability indices for the mounting force (*F*)

Cpk ”sx”	1.763	**Cpk ”dx”**	2.336
Cpk ”sx”	1.784	**Cpk ”dx”**	2.441
Cpk ”sx”	1.836	**Cpk ”dx”**	2.991
Cpk ”sx”	1.732	**Cpk ”dx”**	2.263
Cpk ”sx”	1.727	**Cpk ”dx”**	2.120
Cpk ”sx”	1.747	**Cpk ”dx”**	2.652
Cpk ”sx”	1.671	**Cpk ”dx”**	2.459
Cpk ”sx”	1.700	**Cpk ”dx”**	2.123

It is important to note that in the calculation of the total processing capacity of the indices, no matter how accurate they may seem, the results are always approximate. The objective of this control is to get as close as possible to the truth. There is always some variation due to sampling, so no process is fully under statistical control.

The analysis of the obtained results shows that the differences between the process average and the upper and lower specification limits at the mounting force parameter indicate high values for the C_{pk} index, over 1.6, which induces a stable process, with a small spread and a good centering of the average value. In other words, control diagrams can be used successfully in detecting non-compliant products.

Regarding the measurements for the dimension that defines the inner diameter of the bushing (mounting dimension), it is observed that the upper specification limit, defined by the upper process capability index $C_{pk\ sx}$, indicates values over 1.6, while the lower specification limit defined by the index of lower process capability $C_{pk\ dx}$, has values close to 1.33, so also C_{pk}, which indicates that the process control diagrams are not the best tools that can predict the appearance of non-compliant results.

References

1. Hallmann, M., Schleich, B., Wartzack, S.: From tolerance allocation to tolerance-cost optimization: a comprehensive literature review. The International Journal of Advanced Manufacturing Technology 107, 4859–4912 (2020).
2. Gheorghe, D., Georgescu, C., Baroiu, N.: Toleranţe şi control dimensional (Tolerances and dimensional control), Ed. Scorpion, Galaţi (2002).
3. Geppert, L., Ickstadt, K., Munteanu, A., Sohler, C.: Streaming statistical models via Merge & Reduce. International Journal of Data Science and Analytics 10, 331–347 (2020).
4. Juran, J., Godfrey, B.: Juran’s Quality Handbook. McGraw-Hill, New York (1998).
5. Mereuţă, E., Rus, M., Mereuţă, C.: Managementul calităţii (Quality management). Ed. Academica, Galaţi (2006).
6. *** EN ISO 9000:2000 - Quality management systems - Fundamentals and vocabulary.
7. Quality Management in the Bosch Group - Technical Statistics, Booklet No. 9 - Machine and Process Capability, Robert Bosch GmbH (2019).

8. Arcidiacono, G., Nuzzi, S.: A Review of the Fundamentals on process capability, process performance, and process Sigma, and an introduction to process Sigma Split. International Journal of Applied Engineering Research 12(14), 4556–4570 (2017).
9. Shinde, J.H., Katikar, R.S.: Importance of process capability and process performance indices in machine tool. International Journal of Research in Engineering & Applied Sciences 2, 1211–1217 (2012).
10. Bulgaru, M., Bolboacă, L.: Ingineria calităţii. Managementul calităţii, statistică şi control, măsurări în 3D (Quality engineering. Quality management, statistics and control, 3D measurements). Ed. Alma Mater, Cluj-Napoca (2001).
11. Montgomery, D., Runger, G.: Applied statistics and probability for engineers. Third Edition. Ed. John Wiley &Sons, New York (2002).
12. Baroiu, N., Teodor, V.G., Căpitănescu, V., Repeatability analysis of drill positioning to a CNC vertical machining center. Academic Journal of Manufacturing Engineering – AJME 1, 14–19, (2013).
13. Oakland, J.: Statistical process control. Fifth Edition. Butterworth Heinemann (2003).
14. Teodor, V.G., Păunoiu, V., Baroiu, N., Susac, F.: Optimization of the measurement path for the car body parts inspection. Measurement 146, 15–23 (2019).
15. Teodor, V.G., Păunoiu, V., Cărăușu, C., Baroiu, N., Costin, G.A.: Statistical control of forming process. IOP Conf. Series: Materials Science and Engineering 591(012071), 1–8 (2019).