Analysis of Production Equipment in a Production Organization

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Abstract: *In the present paper we dealt with the issue of quality improvement in the production organization ZVS – Armory. According to the developed methodology, we investigated the capability of the production equipment. In the first measurement, all values were within the tolerance range, but they were not subject to normal distribution and were mainly in the upper tolerance range. Corrective measures had to be taken. The corrective measures were a change in production technology. On the next measurement, the measured values were in order, and it was possible to proceed to the calculation of the capability indices of the production equipment. The calculated values of the capability indices of the production equipment were Cm = 5,900 and Cmk = 5,869.*

Keywords: *quality improvement, measuring equipment capability, manufacturing equipment capability, manufacturing process capability*

INTRODUCTION

In today's highly competitive era, organizations must withstand pressures and threats in both national and international markets. The successful operation of each of them, to a large extent, depends on the speed and ability to adapt to the demands of the market. Demands for product features from customers are becoming increasingly important. One of the most important characteristics of an organisation, therefore, is the ability to adapt to and meet the wishes and requirements of individual customers. (Bujna et al., 2019

To maintain and improve quality, organisations need to know and use appropriate quality tools. By using effective tools, they can improve their market position, increase their competitiveness, productivity and, most importantly, reduce production costs. At the same time, the rapid development of technology makes it difficult for organisations to maintain quality at an appropriate level. The quality management process must therefore be carried out throughout the entire production process. Quality management is the way in which organisations will significantly increase customer satisfaction and also their market share. (Hučka, 2017)

MATERIALS AND METHODS

Nowadays, every organization needs to produce quality products, so the emphasis is on quality monitoring and quality improvement. By implementing various statistical methods, organisations can monitor and evaluate production processes and thus provide customers with proof that their requirements are being met. It is also important to improve the quality of production processes already in place and to introduce measures that can improve these processes. (Paulová, 2013)

The aim was to propose suitable quality management tools that will ensure quality improvement in the production process in the ZVS – Armory organization. The proposed methods were implemented in the production process of CNC machining of the selected part - extractor on the dimension $6{,}95{+}^{0,}$ ^mm.

The component being tracked is the extractor, which is part of the extractor system, a semi-automatic submachine gun. The dimension to be monitored is the width of the component (Fig. 1) $6{,}95^{+0{,}050}_{-0{,}050}\,mm$, with a customer request for a tighter tolerance $6{,}95^{+0{,}030}_{-0{,}030}\,mm$.

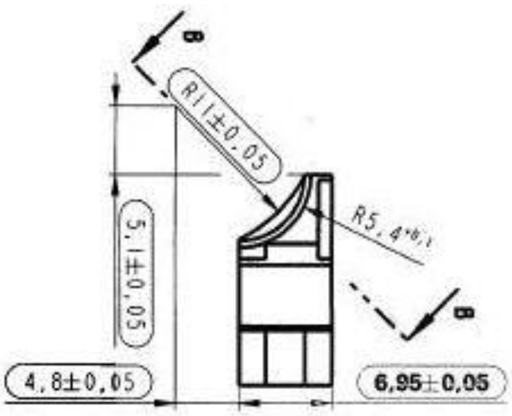


Fig. 1 Cutaway of the manufacturing drawing of the extractor component

Capability of production equipment Characteristics of the production facility

When detecting the fitness of a production machine, the CNC Feeler VMP 30A, it is necessary to select a control character. The control characteristic will be the width of the part of the extractor 6.95+0.03. It is also necessary to determine the boundary conditions viz:

- data of the production facility,
- process data,
- details of where the production facility is located.

The boundary conditions will be documented in the measurement record table.

Data acquisition

In the case of sampling, the production equipment shall be adjusted so that the measured values are in the centre of the tolerance field. Fifty samples shall be taken from the production process for testing. The samples shall be taken consecutively and shall be marked in order. The measured values shall be entered in the evaluation sheet, table, in the order in which they were taken from the plant. The individual values will then be plotted on a single value chart (Hrubec, 2016).

Evaluation of measured values

In the next evaluation procedure, it will be necessary to see if the measured values plotted on the individual value card are not arranged in a chaotic way or if these values show any trend. Should either of these possibilities occur, the process will have to be declared incompetent. Should the process be incapacitated, corrective action will need to be taken and the measurement will need to be repeated. Should neither of the possibilities be demonstrated and the measured values visually follow a normal distribution, the process may continue

Determination of the stability of measured values

From the measured values, artificial subgroups of the range n = 5. For each subgroup, the average value is calculated X_i and the standard deviation s_i (Hrubec, 2016).

Average character value X_i in a subgroup is calculated according to the equation:

$$\bar{X}_i = \frac{1}{n}\sum_{j=1}^{k} X_{ij} \qquad (1)$$

for i = 1, 2, ... k and for j = 1, 2, ... n,
where: i – serial number of a subgroup,
j – serial number of a measured value in a subgroup,
k – number of subgroups,
n – extent of subgroup,
X_{ij} – measured value in i-th subgroup.

Standard deviation in the subgroup:

$$s_i = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}\left(X_{ij} - \bar{X}_i\right)^2} \qquad (2)$$

Calculated values $\bar{X}_i$ and s_i are plotted on the diagram on $\bar{X} - card$ and $s - card$ obtain appropriate scales for both types of diagrams. The outliers must first be calculated $\bar{X}_{max}$, $\bar{X}_{min}$, s_{max}

The overall average value is then calculated $\bar{\bar{X}}$ according to the equation:

$$\bar{\bar{X}} = \frac{1}{k}\sum_{i=1}^{k}\bar{X}_i \qquad (3)$$

and the average standard deviation $\bar{s}$:

$$\bar{s} = \frac{1}{k}\sum_{i=1}^{k} s_i \qquad (4)$$

Determination of cut-off values for the mean and standard deviation

The mean position of the process under study can be considered stable if the individual values of $\bar{X}$ do not exceed the upper limit of the intervention $HMZ_{\bar{X}}$, to be calculated:

$$HMZ_{\bar{X}} = \bar{\bar{X}} + 1{,}3.\bar{s} \geq \bar{X}_{max} \qquad (5)$$

or lower limit of intervention $DMZ_{\bar{X}}$ to be calculated:

$$DMZ_{\bar{X}} = \bar{\bar{X}} - 1{,}3.\bar{s} \leq \bar{X}_{min} \qquad (6)$$

If the largest observed standard deviation of the groups of five s_{max} less than *2,1. s*, then the standard deviation can be considered stable.

$$HMZ_s = 2{,}1.\bar{s} \geq s_{max} \qquad (7)$$

Stability tests are performed to ensure that there are no disturbing elements affecting the process. If the means and standard deviations lie within the limiting poly, statistical evaluation can begin. If the values are outside the field, the cause must be found, eliminated and the measurement repeated

Calculation of the capability indices of production equipment C_m a C_{mk}

To determine the capability index of a production facility C_m and the corrected index of capability C_{mk} the average of all measured values must be calculated $\bar{X}_N$ and determine the standard deviation of all measured values σ_{N-1}. The average value $\bar{X}_N$ shall be calculated:

$$\bar{X}_N = \frac{1}{N}\sum_{i=1}^{N} X_i \qquad (8)$$

Where: **i** = 1,2, …N,
X_i - **i**-th value of the measured character

Standard deviation σ_{N-1} is calculated:

$$\sigma_{N-1} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(X_i - \bar{X}_N)^2} \qquad (9)$$

Where: **N** – the total number of measured values

Capability index of the production facility C_m is then calculated:

$$C_m = \frac{USL - LSL}{6.\sigma_{N-1}} = \frac{T}{6.\sigma_{N-1}} \qquad (10)$$

Where: **T** – tolerance,
USL, **LSL** – upper and lower tolerance values

The minimum requirement for the capability index of a production facility shall be $C_m \geq 1{,}66$.

Corrected index of production equipment C_{mk} which takes into account the position of the mean value $\bar{X}_N$ is calculated according to the equations:

$$C_{mk} = \frac{USL - \bar{X}_N}{3.\sigma_{N-1}} \quad (11)$$

$$C_{mk} = \frac{\bar{X}_N - LSL}{3.\sigma_{N-1}} \quad (12)$$

The smaller value of the two formulas is used for evaluation. The minimum requirement for the corrected capability index of a production facility shall be $C_{mk} > 1{,}61$

RESULTS

Monitoring, measurement and analysis

The organization has planned and implemented measurement, data collection and validation through a quality management system to ensure performance, to ensure the conformity of the manufactured parts to the customer's specific requirements. To ensure continuous improvement of the effectiveness of the quality management system, the organisation obtains information from customers and consumers of the final products.

Capability of production equipment Characteristics of the production facility

The manufacturing process of the investigated component was carried out on a CNC machine called Feeler VMP 30A (Fig. 2), which is shown in the figure. It is a vertical machining centre of the VMP series. The dimensions of the worktable are 890 x 420 mm; the maximum load of the work table is 300 kg. The maximum spindle speed is 10 000 min^{-1}. The width of the machine is 2100mm; the maximum height is 2370mm; the weight is 3300kg.

There are currently 4 such CNC machines in the company and they are used for the production of both simpler and more complex parts.

The production equipment is a Feeler VMP 30 A CNC milling machine, and the selected control feature was the width of the part to be monitored, the extractor. The boundary conditions were determined, which are given by in the table. (Jančichová, 2020)

Fig. 1 Vertical CNC machine Feeler VMP 30A

Data acquisition

The production process was sampled every 3 hours during the production process. The samples were numbered in the order in which they were taken. The measured values were entered in a table, which was also used to create a tab of the individual values

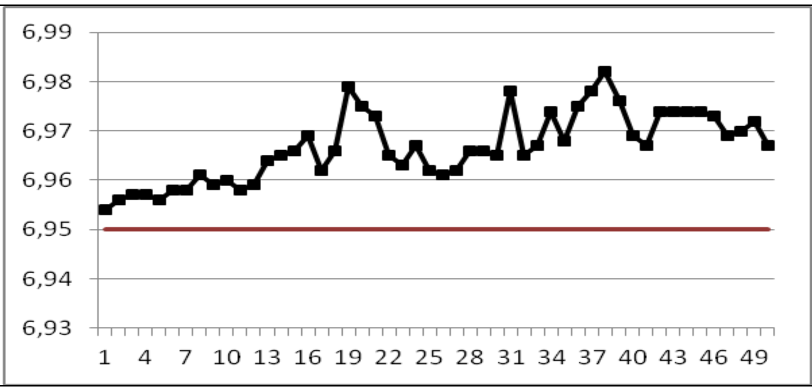
***Table 1** Form for evaluation of the suitability of a production equipment*

<table>
<tr><td>ZVS – Armory</td><td colspan="4">Form for evaluation of the suitability of a production equipment</td></tr>
<tr><td colspan="2">Part: Extractor</td><td colspan="3">Controlled dimension: $6.95^{+0.03}_{-0.03}$ mm</td></tr>
<tr><td rowspan="2">Machine:
Feeler VMP 30 A</td><td colspan="4">Marginal conditions</td></tr>
<tr><td>Performance:
7.5 kW</td><td>Voltage:
380 V</td><td>Noise:
68 – 70 dB</td><td>Tools: Automatic tools</td></tr>
<tr><td>Temperature: 24.5 ˚C</td><td rowspan="2">Speed:
10 000 min⁻</td><td rowspan="2">Shift:
3.6 mm.min⁻¹</td><td colspan="2" rowspan="2">Cooling emulsion:
Hydrol ZUBORA</td></tr>
<tr><td>Humidity: 50%</td></tr>
</table>

Measured values

No.	mm	No.	mm	No.	mm	No.	mm	No.	mm
1	6.954	11	6.958	21	6.973	31	6.978	41	6.967
2	6.956	12	6.959	22	6.965	32	6.965	42	6.974
3	6.957	13	6.964	23	6.963	33	6.967	43	6.974
4	6.957	14	6.965	24	6.967	34	6.974	44	6.974
5	6.956	15	6.966	25	6.962	35	6.968	45	6.974
6	6.958	16	6.969	26	6.961	36	6.975	46	6.973
7	6.958	17	6.962	27	6.962	37	6.978	47	6.969
8	6.961	18	6.966	28	6.966	38	6.982	48	6.97
9	6.959	19	6.979	29	6.966	39	6.976	49	6.972
10	6.96	20	6.975	30	6.965	40	6.969	50	6.967

Values measured card



Evaluation of measured values Investigating the regularity of measured values

From the table of individual values (Tab. 1), it was assessed that the measured values are chaotically arranged, located in the upper part of the tolerance field and do not follow a normal distribution. Therefore, after consultation, corrective action was taken and the measurements were repeated. The corrective measures were a change in the production technology of the component.

Data recovery

After corrective action, a change in technology, 50 manufactured parts were taken out of the process again, at a time interval of 3 hours and the measurement was repeated. The measured values are shown in tab. 2.

Evaluation of measured values

It could be evaluated from the form of the individual measured values that the measured values are not subject to any trends, are not chaotically arranged and are subject to a normal distribution. It was possible to move on the determination of stability.

Determination of stability of measured values

From the measured values, subgroups of n = 5 were formed, and for each subgroup, the mean Xi and standard deviation Si were calculated according to Eq. The results are presented in the table.

Table 2 *Form for evaluation of the suitability of a production equipment*

ZVS – Armory	**Form for evaluation of the suitability of a production equipment**			
Part: Extractor		Controlled dimension: $6.95^{+0.03}_{-0.03}$ mm		
Machine: Feeler VMP 30 A	Marginal conditions			
	Power: *7.5 kW*	Voltage: *380 V*	Noise: *68 – 70 dB*	Tools: Automatic tool
Temperature: 24.5 ˚C / Humidity: 50%	Speed: 10 000 min^{-1}	Shift: *3.6mm.min^{-1}*	Cooling emulsion: Hydrol ZUBORA	

Measured values

No..	mm	No.	mm	No.	mm	No.	mm	No.	mm
1	6.952	11	6.947	21	6.952	31	6.952	41	6.953
2	6.949	12	6.949	22	6.951	32	6.952	42	6.951
3	6.951	13	6.950	23	6.947	33	6.947	43	6.949
4	6.95	14	6.952	24	6.953	34	6.949	44	6.948
5	6.948	15	6.951	25	6.950	35	6.953	45	6.951
6	6.95	16	6.951	26	6.948	36	6.952	46	6.950
7	6.949	17	6.949	27	6.953	37	6.948	47	6.948
8	6.95	18	6.948	28	6.949	38	6.949	48	6.95
9	6.949	19	6.951	29	6.95	39	6.952	49	6.952
10	6.951	20	6.95	30	6.951	40	6.952	50	6.949

Values measured card

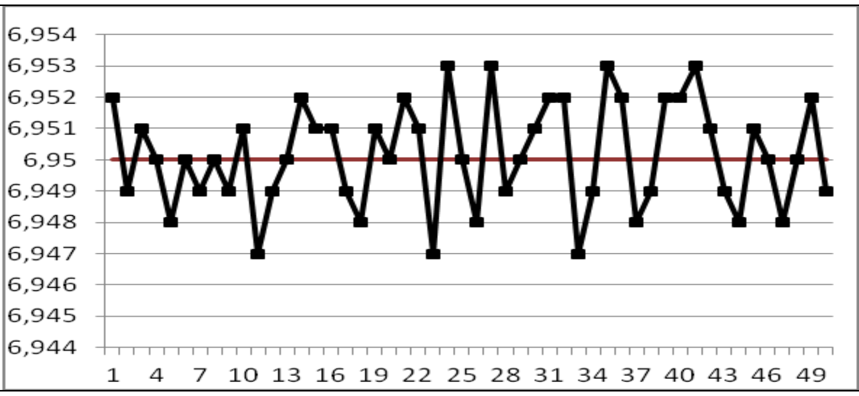


Table 3 *Measured values*

No.	Measured values, mm					$\bar{X}_i$ mm	s_i mm
	X_1	X_2	X_3	X_4	X_5		
1	6.952	6.949	6.951	6.95	6.948	**6.95**	**0.00045**
2	6.95	6.949	6.95	6.949	6.951	**6.9498**	**0.00024**
3	6.947	6.949	6.950	6.952	6.951	**6.9498**	**0.00055**
4	6.951	6.949	6.948	6.951	6.95	**6.9498**	**0.00037**
5	6.952	6.951	6.947	6.953	6.950	**6.9506**	**0.00066**
6	6.948	6.953	6.949	6.950	6.951	**6.9502**	**0.00055**
7	6.952	6.952	6.947	6.949	6.953	**6.9506**	**0.00072**
8	6.952	6.948	6.949	6.952	6.952	**6.9506**	**0.00056**
9	6.953	6.951	6.949	6.948	6.951	**6.9504**	**0.00056**
10	6.95	6.948	6.95	6.952	6.949	**6.9498**	**0.00042**

The overall average value was then calculated $\bar{\bar{X}}$:

$$\bar{\bar{X}} = \frac{1}{k}\sum_{i=1}^{k}\bar{X}_i = \frac{1}{10}\sum_{i=1}^{k} 6{,}95 + \cdots + 6{,}949 = \mathbf{6,9501}\ \boldsymbol{mm}$$

and the average standard deviation $\bar{s}$:

$$\bar{s} = \frac{1}{k}\sum_{i=1}^{k} s_i = \frac{1}{10}\sum_{i=1}^{k} 0{,}00045 + \cdots + 0{,}00042 = \mathbf{0,00051}$$

Determination of limit values for the average value $\bar{\boldsymbol{X}}_i$ and standard deviation $\boldsymbol{s}_i$

The values for the mean Xi were calculated – the upper limit:

$$HMZ_{\bar{X}} = \bar{\bar{X}} + 1{,}3.\bar{s} \geq \bar{X}_{max} \rightarrow \mathbf{6,9508} > 6{,}9506\ mm$$

and the lower limit:

$$DMZ_{\bar{X}} = \bar{\bar{X}} - 1{,}3.\bar{s} \leq \bar{X}_{min} \rightarrow \mathbf{6,9495} < 6{,}9498\ mm.$$

The calculated values of Xi and the limiting values of HMZx and DMZx for the average value of Xi are plotted on the X – diagram in the figure.

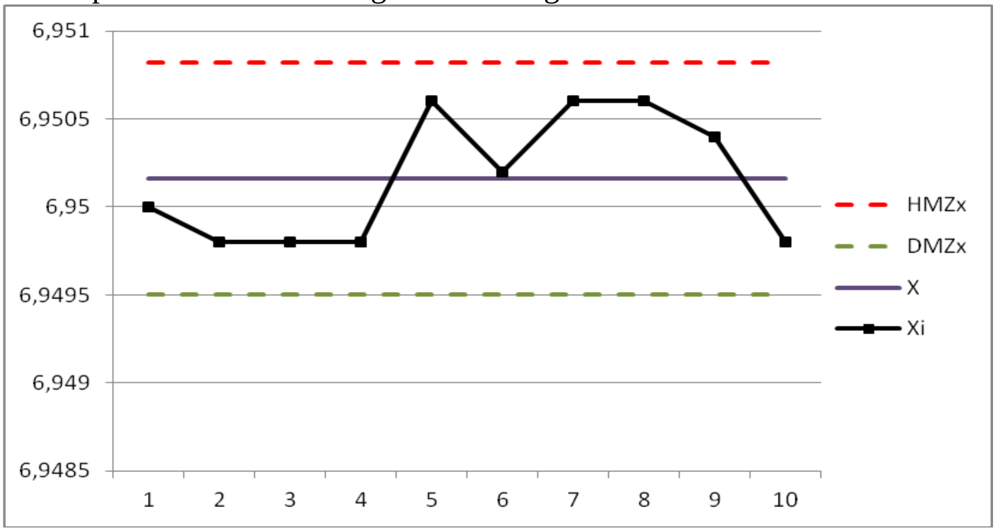


Fig. 3 X- card

Subsequently, the upper limit of the HMZs hit for the standard deviation si was calculated:

$$HMZ_s = 2{,}1.\bar{s} \geq s_{max} \rightarrow \mathbf{0,00107} \geq 0{,}00072\ mm.$$

The calculated values of the standard deviation si and the upper limit of the HMZs:

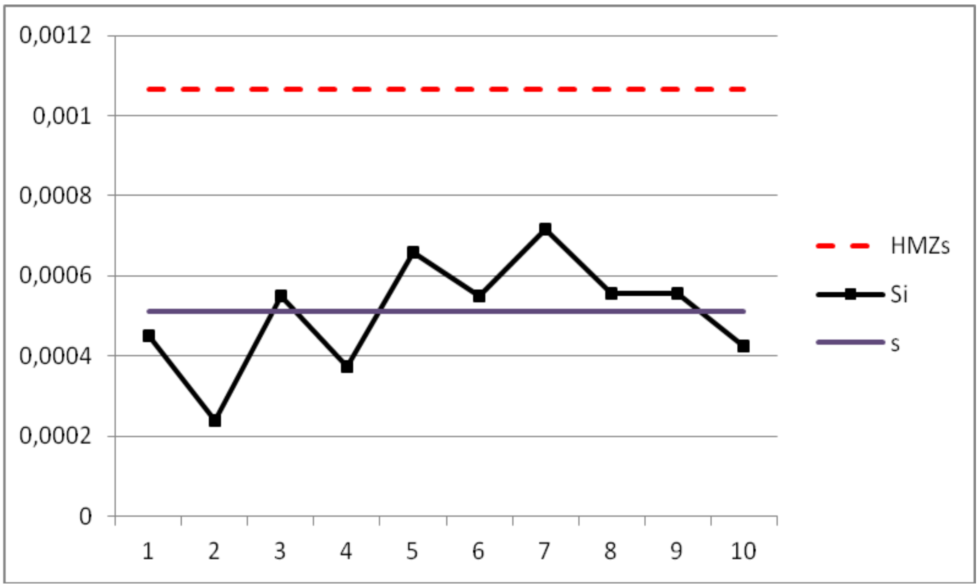


Fig. 4 s- card

The stability tests showed that there were no disturbing elements acting on the process and it was possible to proceed with the calculation of the capability indices of the production facility Cm and Cmk.

Calculation of the capability indices of the production facility *Cm* and *Cmk*

To calculate the capability indices of the production facility Cm and Cmk , the average of all measured values X_N had to be calculated:

$$\bar{X}_N = \frac{1}{N}\sum_{i=1}^{N} X_i = \frac{1}{50}\sum_{i=1}^{N} 6{,}952 + \cdots + 6{,}949 = 6{,}9501\ \boldsymbol{mm}$$

and the standard deviation of all measured values σ_{N-1}:

$$\sigma_{N-1} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(X_i - \bar{X}_N)^2} =$$

$$= \sqrt{\frac{1}{50-1}\sum_{i=1}^{N}(6{,}952 - 6{,}9501)^2 + \cdots + (6{,}949 - 6{,}9501)^2}$$

$$= \mathbf{0,00169}\ \boldsymbol{mm}.$$

It was then possible to proceed to the calculation of the capability index of the production equipment Cm:

$$C_m = \frac{USL - LSL}{6.\sigma_{N-1}} = \frac{T}{6.\sigma_{N-1}} = \frac{0{,}060}{6.0{,}00169} = \mathbf{5,9009}$$

and corrected index Cmk:

$$C_{mk} = \frac{USL - \bar{X}_N}{3.\sigma_{N-1}} = \frac{6{,}980 - 6{,}9501}{3.0{,}00169} = \mathbf{5,8694}$$

$$C_{mk} = \frac{\bar{X}_N - LSL}{3.\sigma_{N-1}} = \frac{6{,}9501 - 6{,}920}{3.0{,}00169} = \mathbf{5,9324}$$

CONCLUSION

The capability of the production equipment of the Feeler VMP 30 A CNC machine was evaluated. Fifty samples were taken, labelled in the order in which they were taken. In the first measurement, the measured values were within the tolerance range, but after plotting the values on the chart, it was found that the values did not follow a normal distribution. Corrective action had to be taken and this was to change the manufacturing technology of the extractor component. On re-measurement, the measured values were again recorded on the form and recorded on the individual value card. The values were subject to a normal distribution and so could be divided into artificial subgroups, the mean Xi values calculated and the standard deviation si for each subgroup. The joint mean value of X and the mean standard deviation of s were then calculated. Before applying the mean values to the X - card, the upper limit of the HMZ**x** hit and the lower limit of the DMZ**x** hit were calculated. Also, the upper hit limit for the standard deviation of the HMZ**s** was calculated and the values of the standard deviation of s**i** were plotted on the s - card.

From the previous results, it was possible to move on to the calculation of the manufacturing equipment capability indices Cm and Cmk. The requirements for the manufacturing equipment capability indices were met with Cm = 5.900 > 1.66 and Cmk= 5.869 > 1.67, respectively.

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