http://doi.org/10.24867/JPE-2018-02-006

Journal of Production Engineering
Vol.21 No.2

JPE (2018) Vol.21 (2) Original Scientific Paper

Cerce, L., Borojevic, S., Kramar, D.

OPTIMIZATION OF THE PROCESS PARAMETERS FOR STABILIZATION AND IMPROVEMENT OF THE TURNING PROCESS CAPABILITY

Received: 03 September 2018 / Accepted: 22 November 2018

Abstract: *The paper deals with a narrow tolerances turning process. A statistical process control (SPC) on the existent machining process showed that the process was not stable and incapable. Before the machining process analysis a measurement system analysis (MSA) of the applied measuring system has been performed. In order to stabilize the process the machine tool linear axis calibration has been performed. The stability and capability of the machining process increased but the problem of the roundness was still present. The possible process parameters, which could affect the roundness, were examined with the design of the experiment methodology (DOE). The results showed that the clamping force has the largest effect. Therefor a new clamping fixture was suggested to eliminate the roundness problem.*
Key words: *Roundness, MSA, SPC, DOE*

Optimizacija parametara obrade u cilju stabilizacije i unapređenja mogućnosti procesa struganja. *Rad se bavi tačnošću pri obradi struganjem. Statistička procesna kontrola (SPC) u postojećem obradnom procesu pokazala je da je proces nestabilan i ograničen. Pre analize obradnog procesa izvršena je analiza korišćenog mernog sistema (MSA). U cilju stabilizacije procesa izvršena je kalibracija linearnih osa mašine alatke. Na taj način je povećana stabilnost i sposobnost procesa obrade, ali je problem ovalnosti i dalje bio prisutan. Projektovanom eksperimentalnom metodologijom (DOE) ispitani su mogući parametri obrade koji utiču na ovalnost. Rezultati pokazuju da sila stezanja ima najveći uticaj. Zbog toga je predložen novi stezni pribor radi eliminisaja problema ovalnosti.*
Ključne reči: *Ovalnost, MSA, SPC, DOE*

1. INTRODUCTION

In today's highly demanding markets the industrial organizations are under big pressure of competition and can only survive when high-quality products are produced. Manufacturers can achieve higher levels of quality by improving their manufacturing process and/or by product inspection where several different strategies are often available [1]. Each option has its own cost implications that must also be taken into account when the production cost are considered. Juran [2] was one of the first quality leaders who has connected quality control and assurance with costs, and includes all the costs that would appear if defects were produced. These quality-related costs are classified into prevention costs, appraisal costs, and failure costs.
In real production these costs are usually not clearly understood. These costs of quality often disappear as the costs of testing, the general developments costs, or the operating expenses, etc. which is misleading. Several studies present and evaluate the impact of quality management activities using cost of quality as a metric [3, 4] or by modeling [5, 6].

In our study cost related to the product inspection would like to be reduced by improving the manufacturing process. The product under consideration is die-casted part of the gearbox housing. Machined surfaces, where bearings are fixed, have narrow tolerances of 20 µm. The production batch is more than 500.000 pieces. 100 % dimensional control of the machined parts is performed at the measurement station, which requires a high level of control over the processing process and, consequently, the loss of time.

1.1 Problem statement - machining process instability

A problem occurs during the machining process in real production, because the machine tool, i.e. CNC lathe does not provide sufficient stability in terms of keeping the produced parts within the tolerance range. When the CNC lathe is in regular operation, the dimensions are either within the tolerance range or are moved against the tolerance limits. The problem also occurs when the machine tool is stopped (unexpected stop, cleaning, lunch break ...), and consequently cooled down. After the restarting of machine tool, the dimensions deviate considerably; thereby the produced parts are unaccepted. Because of this, 100 % dimensional control and on-line cutting tools offsets correction are necessary. This results in time and cost losses.

The aim of the presented work is to analyse the problem of dimensional deviations of produced parts. With the use of different quality management tools, the stabilization and the capability improvement of turning is expected.

Note: The manuscript was presented at the 13. International Scientific Conference MMA held in Novi Sad, Serbia, 28.-29. September, 2018.

2. MACHINING PROCEDURE AND QUALITY CONTROL

The produced part is bearing housing made of Al alloy with 5 key diameters (Fig. 1). They are manufactured in a tolerance range from 20 to 40 µm. The dimensions of all five holes are 100% controlled at a special measurement station. The other dimensions have a wider tolerance range, so there is no need for 100% control, and they are checked only twice a day.

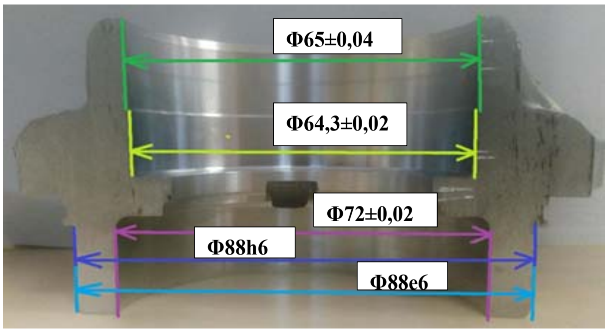

Fig. 1. Cross section of the bearing housing [7]

2.1 Machining procedure

The product is manufactured with longitudinal internal and external turning on 4-axis (*X*, *Y*, *Z* and *C*) CNC lathe with sub-spindle. Poly-crystalline diamond (PCD) cutting inserts are used because their wear is negligible when machining Al alloys. The negligible wear consider as wear, which does not represent an influential factor on the stability of the processes. The used cutting parameters are presented in the table below.

Diameter [mm]	Cutting insert	f_n [mm/rev]	a_p [mm]
64.3	DCMW 11T304	0.08	0.37
65	DCMW 11T304	0.08	0.37
72	DCMW 11T304	0.08	0.37
88e6	CCGW11T308	0.12	0.37
88h6	CCGW11T308	0.12	0.37

Table 1. Cutting parameters.

The clamping of the workpiece is carried out automatically with a robot. The workpiece is placed in a clamping device with three supporting points (Fig. 2), which form a plane perpendicular to the longitudinal (*Z*) axis of turning.

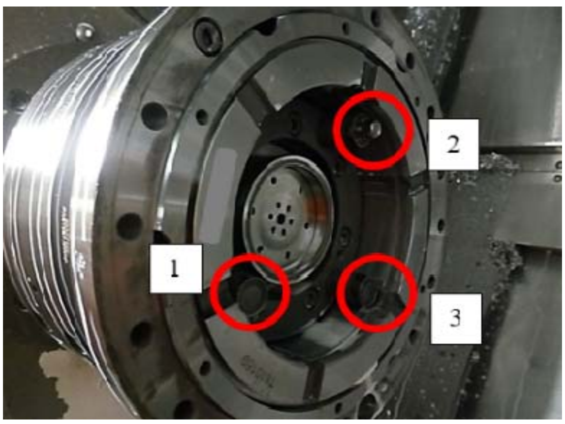

Fig. 2. Three point clamping device. [7]

2.2 Quality control

In the mass production, it is important that the machining process runs smoothly without stops. At the end of the production process the prescribed dimensional tolerances and surface roughness have to be achieved. The stability of the machining process is monitored by measuring the dimensions of the workpiece on the special measuring system (Fig. 3), which is located next to the machining centre.

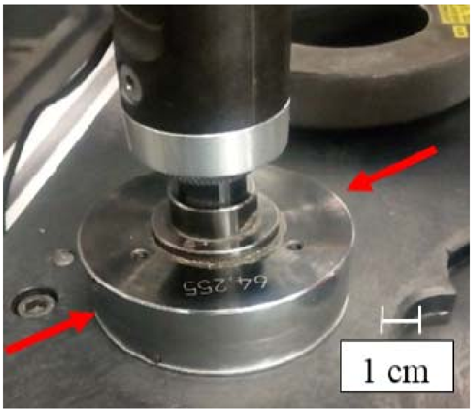

Fig. 3. Measurement system for ϕ64.3 mm [7]

3. OVERVIEW OF THE CURRENT STATE OF THE PRODUCTION PROCESS

An overview of the existing situation is an important step that gives us a feedback on the quality of the production process. In our case the production process consist of the machining and the measuring process. If we realize that the quality of produced parts is not adequate, three characteristic states of the production process occur:

1. The part is acceptable, but the measurement system does not show exact result, thus the product is detected as unacceptable.
2. The machining process is inadequate, which results in an unacceptable product.
3. The measurement process and the machining process are inadequate.

Therefore, the measuring and machining process have to be analysed to establish the current state of the production process.

The measuring process is analysed with the use of Measurement System Analysis (MSA) method, while SPC (Statistical Process Control) and DOE (Design of experiment) methods are used to analyse the machining process.

3.1 Measurement System Analysis (MSA)

MSA is a set tool used to evaluate the statistical properties of the process measurement systems. The purpose of MSA is to statistically verify that current measurement systems provide:

- Representative values of the characteristic being measured,
- Unbiased results,
- Minimal variability.

The following parameters have been used for MSA analyze:

- 3 operators,
- 10 samples,
- 3 measurements for each sample.

The result of MSA method is the calculated percentage of process variation (*%GRR*). If the *%GRR* is:

- < 10% - The measurement system is acceptable.
- Between 10% and 30% - The measurement system is acceptable depending on the application, the cost of the measurement device, cost of repair, or other factors.
- > 30% - The measurement system is not acceptable and should be improved [8].

The gage R&R study has been made on all 5 machined diameters, which are 100% measured. The measuring procedure consist of next steps:

- Calibration of the measuring device.
- First operator measures ten samples, which are marked with numbers from one to ten.
- Second operator measures ten samples.
- Third operator measures ten samples.

This steps has been repeated two times. In this way, every operator measured ten samples three times. Before each operator start with the measurement, the measuring device has been calibrated. Based on the measured results, the percentage of process variation is calculated for each machined diameters. Fig. 4 illustrates the results of Gage R&R study for diameter ϕ64.3 mm.

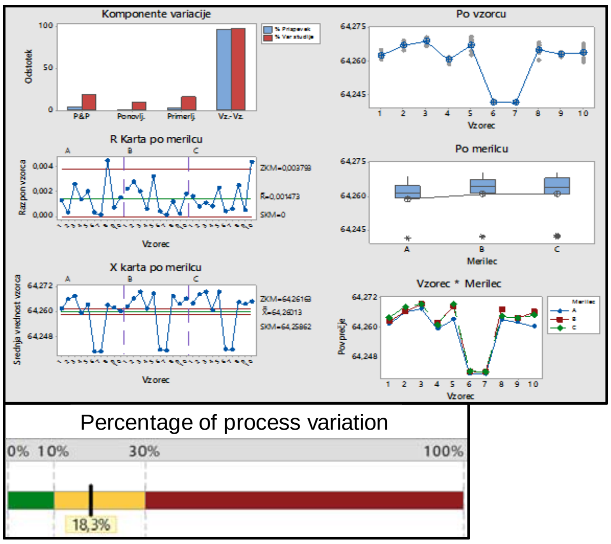

Fig. 4. Results of Gage R&R study for diameter ϕ64.3 mm. [7]

The calculated process variation for diameter ϕ64.3 mm is 18.3%. The measurement system is conditionally acceptable.

The same procedure has been used to calculate the measurement process variation for all other diameters. Fig. 5 present the overall result of Gage R&R study for all diameters.

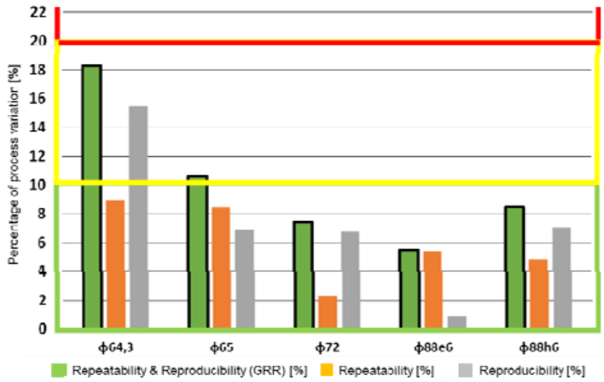

Fig. 5. Results of Gage R&R study for all diameters [7]

The Gage R&R study showed that the measuring process is acceptable and capable for preforming accurate measurement (Fig. 5, all the results of *%GRR* are below 30%).

From the results of Gage R&R study it can be concluded, that the causes of the instability of the production process must be found in the machining process. To find the cause of instability, the current state of the machining process should be analysed.

3.2 Analysis of the capability of the machining process

After analysing the measurement system used for the control of machined parts, and found to be appropriate, the ability of the machining process was analyzed. SPC is a method that determines the ability and stability of the machining process based on the obtained data. The method provides feedback on the past and current state of the process. Based on the current state we can predict how the process will behave in the future. In this way we can prevent the destabilisation of the process, which leads to the production of unaccepted products and consequently increased costs.

After the measurements have been taken, the SPC analysis has been carried out with the use of Minitab program. The analysis has been performed on all diameters of the workpiece, which are 100% controlled in a regular production process.

The upper graph (Fig. 6) shows the *X*-chart (Avarage), that present the course of dimensional measurements. The upper and lower control limits are printed on the graph. If the measure is above or below the control limit, the measurement is colored red. From the *X* chart, we can determine whether the product is within tolerance limits or predict when the product will no longer be good.

The lower graph (Fig. 6) shows the *R*-chart (Range). The *R*- chart tells you whether the variation of the product's properties has been maintained within acceptable limits. The lower control limit is always zero because the range between two measurements is viewed with an absolute value.

The process was stable up to 40th produced part (Fig. 6, *X*- chart). It was not within the control limits, but it was within tolerance. If the process is stable and is not within the control limits, it means that there was a mistake on the start of the process.

Fig. 6. X – R chart of measurements for diameter ϕ64.3 mm.

Possible mistakes are:

- the machine tool has not been warmed up to the operating temperature or
- the initially produced parts has not been measured and consequently the cutting tool offsets corrections has not been performed.

From the *X*-chart (Fig. 6 above), it is apparent that a small correction of the cutting tool offset (few micrometres), would have resulted that the measurements would be within the control limits. After 40th part produced, however, it is visible that the measurement has slid to the upper control limit and across.

From the *R*-chart (Fig. 6 below), it is evident that the measurements did not fluctuate significantly. Just some measurements range are out of the control limits.

The process capability histogram for a diameter of ϕ64.3 mm is presented in Fig. 7. A large dispersion of measurements around the mean value is evident.

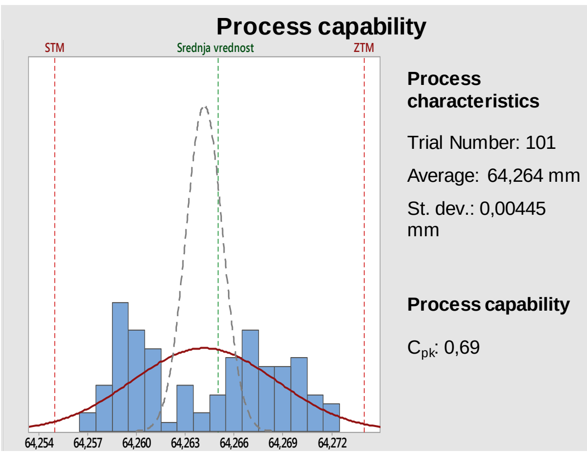

Fig. 7. Process capability analysis for a diameter of ϕ64.3 mm.

The average of the measurements does not differ significantly from the desired mean value, but their distribution around the average value is poor, which result in standard deviation of 4.4 µm. The actual process capability index C_{pk} for diameter of ϕ64.3 mm is 0.69, is not acceptable (it should be at least 1.3).The same procedure has been used to calculate the C_{pk} of all other diameters. The results are given in Table 2.

Diameter [mm]	Average [mm]	σ [mm]	C_{pk}
ϕ64.3	64.264	0.0044	0.69
ϕ65	65.018	0.0046	1.33
ϕ72	71.95	0.0040	0.73
ϕ88e6	87.914	0.0043	0.64
ϕ88h6	87.986	0.0049	0.55

Table 2. Results of the SPC analysis for all diameters.

The table 2 shows that the existing situation is unacceptable. The process capability index C_{pk} are in all cases lover then 0.73 except in the case diameter ϕ65 mm (C_{pk} = 1.33). However, this diameter is not relevant for observing the process's capability due to the width of the tolerance. This means that such manufacturing process would produce more than 35.000 unaccepted pieces in a series of million. The machining process needs to be improved.

3.3 Machine tool positional accuracy measurement and calibration

To increase the accuracy of the machined parts, the positional accuracy and repeatability of the used machine tool has been analysed. The measurements of the linear *X*-axis has been performed with the Renishaw ML10 Gold laser interferometer system. With a high accuracy of a single-frequency laser source containing beam stabilization electronics, interpolation and counting of interferential lines, the size of errors can be measured with a nanometer resolution. With the use of EC10 compensation device, the system ensures the linear displacement accuracy of 0.7 µm/m. The compensation device measure and compensate the environmental effects (air and material temperature, relative humidity and air pressure) [7, 9].

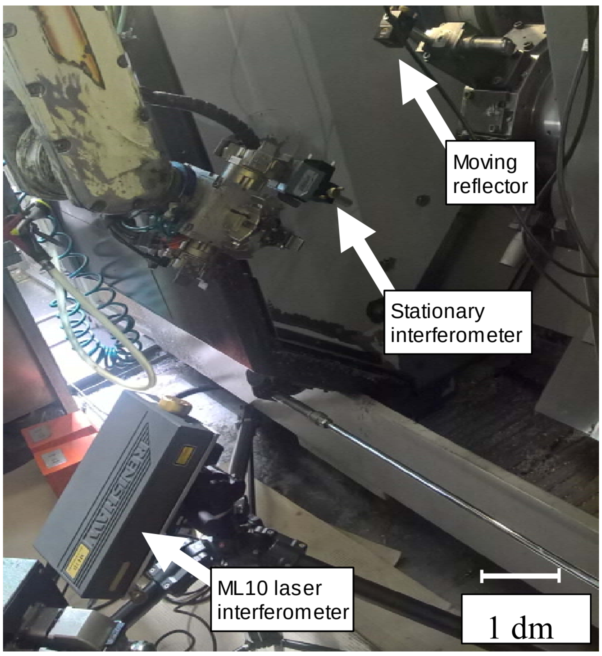

Fig. 8. Positional accuracy measurement setup.

For the positional accuracy measurement, the optics were positioned as follows (see Fig. 8):

- The stationary interferometer was placed on the main spindle while the moving reflector on the machine turret.
- The reflector was moved with a certain step along *X*-axis.

The results of current state of the machine tool positional accuracy measurement are presented in Fig. 9.

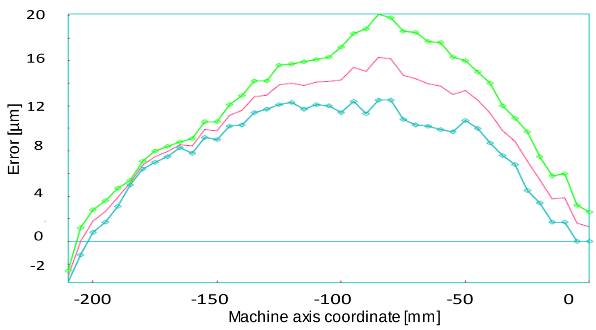

Fig. 9. Current state of X axis positional accuracy and repeatability.

The results illustrated in Fig. 9 are showing a large deviation of approx. 20 µm in the range of -80 mm to -180 mm (*X* machine coordinate), which is exactly in the range of the maximum error of the machined parts. Based on the measurement results, the compensations are calculated and entered into the machine tool controller. After the calibration of *X*-axis, the positional accuracy and repeatability significantly increase. The results are presented in Fig. 10.

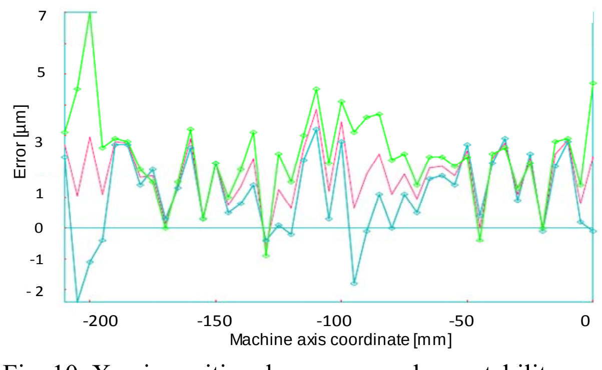

Fig. 10. X axis positional accuracy and repeatability after calibration.

From the presented results shown in Fig. 9 and Fig. 10, it is evident that the position accuracy of the machine tool in the *X*-axis has been improved from the initial 25 µm to 9 µm. The repeatability was approx. 3 µm.

3.4 Analysis of the capability of the machining process after machine tool calibration

After verifying the accuracy of the machine tool and subsequent calibration of it, the SPC analysis has been performed again. The C_{pk} of the machined process has been calculated from 101 workpiece diameter measurements. Fig. 11 present the *X* – *R* chart of measurements for diameter of ϕ64.3 mm. From the *X* – *R* chart (Fig. 11) and the process capability histogram (Fig. 12) can be seen, that the stability of the process after the calibration of the machine tool has been improved. Few measurements are still outside the control limits, but the number of it in comparison with the initial state (Fig. 6) is negligible.

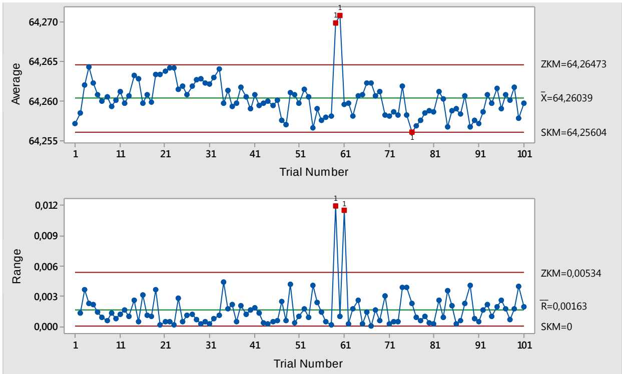

Fig. 11. X – R chart of measurements for diameter ϕ64.3 mm after machine tool calibration.

From the results, presented in the histogram in Fig. 12 a good dispersion of measurements is evident, but a shift in the mean value is noticed. Also the standard deviation of 2.4 µm is smaller than before the machine tool calibration (Fig. 7).

As a result, the C_{pk} index for diameter of ϕ64.3 mm increased to 0.74. From Table 2 and Table 3 it is clear, that the C_{pk} index increased for approx. 20% for all diameters (except for ϕ88h6). The capability of the process significantly improved at ϕ65 mm and ϕ72mm ($C_{pk}>1,3$). For all other diameters, the C_{pk} index has not improved sufficiently ($C_{pk}<1,3$).

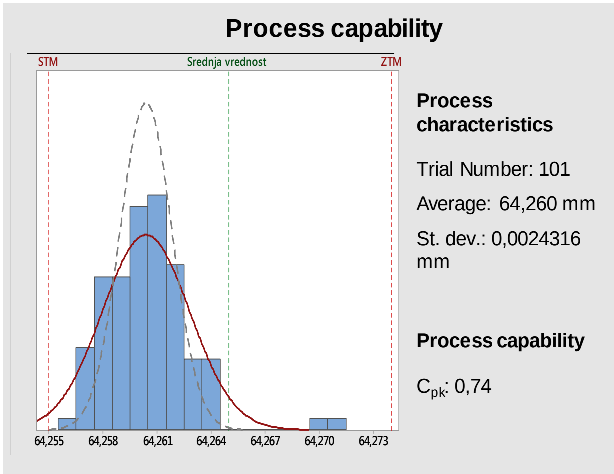

Fig. 12. Process capability analysis for a diameter of ϕ64.3 mm after machine tool calibration.

For the diameters ϕ88h6, the C_{pk} index is lower than on the initial state (Table 2). The result is not expected, probably there was an error in performing the measurements.

Diameter [mm]	Average [mm]	σ [mm]	C_{pk}
ϕ64.3	64.260	0.0024	0.74
ϕ65	65.012	0.0024	1.63
ϕ72	71.952	0.0014	2.18
ϕ88e6	87.919	0.0038	0.81
ϕ88h6	87.982	0.0037	0.34

Table 3. Results of the SPC analysis for all diameters after machine tool calibration

As a conclusion, the stability of the machining process after machine tool calibration is more stable, but the problem of some diameter roundness deviation persist. To analyze the influence of machining parameters on the roundness deviation, DOE analyse has been performed and is presented in next chapter.

3.5 DOE - Optimization of process parameters

The aim of DOE analyze is to determine the influence of process parameters on the roundness of machined diameters. Based on the influence of process parameters, the optimization was performed for minimal roundness deviation. The investigated process parameters were:

- Feed rate [f_n],
- Depth of cut [a_p],
- Clamping force [F_{vp}].

Preliminary experiments has been carried out in order to prove the maximum and minimum values of the input parameters (Table 4).

Level	f_n [mm/vrt]	a_p [mm]	F_{vp} [kN]
-1	0.05	0.06	3
0	0.12	0.371	7.5
1	0.19	0.681	12

Table 4. Machining and clamping parameters

The parameters ranges has been determined based on the cutting tool manufacturer and clamping system supplier specifications.

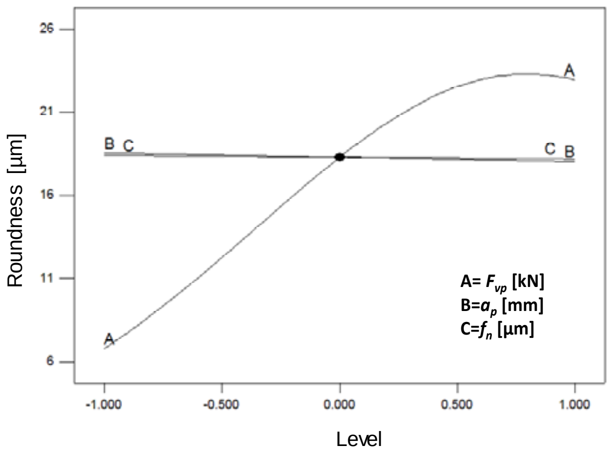

Fig. 13. The influence of the input (process) parameters on the machining roundness.

For the design of experiments, the central composite design has been applied. The experiments were carried out and the regression model has been calculated based on ANOVA. Fig. 13 illustrates the influence of the input (process) parameters on the machining roundness deviation. It can be seen, that the major influential parameter is the clamping force F_{vp}, which affect the roundness deviation proportionally.

In the step of the optimization, optimal input parameters for minimal roundness deviation were selected and confirmed with the confirmation test. Optimal setting parameters are:

- F_{vp} = 3 kN,
- a_p = 0.06 mm,
- f_n = 0.12 mm/rev.

The predicted roundness is 6.6 µm.
For the confirmation test the roundness of ten parts has been measured. The results are presented in the table below.

N	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Avarage**
Roundness [µm]	6	5	7	6	6	5	8	6	7	8	**6.4**

Table 5. Confirmation test results.

With the confirmatory test, we have proven that the regression model is appropriate because the proposed value of the response is within the confidence interval [6 - 6.7 µm].

4. CONCLUSIONS

In this paper, an industrial case study of quality improvement of manufacturing process is presented. The problem of dimensional deviations of produced parts has been analysed. With the use of different quality management tools, the stabilization and improvement of the turning capability has been achieved. With the use of DOE, the influence of process parameters on the roundness deviation of machined diameters is analyzed. It was found, that the clamping force F_{vp} has the biggest impact on roundness of the machined parts.
Furthermore, optimal input parameters for minimal roundness deviation have been defined. However, a new clamping device has to be designed to reduce the influence of clamping force on the roundness of the machined parts.
The costs of such quality improvement were not calculated, but the reduction of quality costs and time for inspection is evident. No 100% quality control is needed anymore. Parts are now sampled twice a day and SPC for quality conformation is performed. Even more reductions are expiated with the new clamping device.

5. REFERENCES

[1] Pop, Liviu Dorin, Nagy Elod. 2015. *Improving Product Quality by Implementing ISO / TS 16949.* Procedia Technology. 19: 1004-1011.

[2] Juran, Joseph M., A. Blanton Godfrey. *Juran's Quality Handbook (5th Edition)*. New York, USA: McGraw-Hill Professional Publishing, 1998.

[3] Khan, P. M., Sufyan Beg M.M., *Measuring Cost of Quality Measuring Cost of Quality Measuring Cost of Quality (CoQ) on SDLC Projects is Indispensible for Effective Software Quality Assurance.* International Journal of Soft Computing And Software Engineering, Vol.2, No.9, p. 1-15, 2012.

[4] Eniko, P., Soković, M., Kramar, D.. *Using quality tools for process development and improvement : case study on cylinder manufacturing.* Advanced quality, ISSN 2217-8155., 2016, vol. 44, 1, p. 27-32.

[5] Satanova, A., Sedliacikova, M., *Model for Controlling the Total Costs of Quality.* Procedia Economics and Finance, 26, p. 2-4, 2015

[6] Schiffauerova, A. and V. Thomson, *A Review of Research on Cost of Quality Models and Best Practices.* International Journal of Quality & Reliability Management, 2006. 23(4).

[7] DaimlerChrysler, Ford Motor Company, and General Motors Corporation. *Measurement Systems Analysis: Reference Manual,* 2010.

[8] Mlinar, A., *Optimization of the process parameters for stabilization and improvement of the turning capability*, diploma work, 2017.

[9] Kopač, J., Pušavec, F., Kramar, D.. *How to improve the positional accuracy of hsc machine tools*. V: 7. Congresso Brasileiro de Engenharia de Fabricação, 20-24 de maio de 2013, Penedo, Itatiaia-RJ, Brasil : COBEF, (Congresso Brasileiro de Engenharia de Fabricação, ISSN 2236-0395), 2013, p. 1-10.

Authors:

PhD. Luka Cerce, Assoc. Prof. Davorin Kramar, University of Ljubljana, Faculty of Mechanical Engineering, Department for Management of Manufacturing Technologies, Askerceva 6, 1000 Ljubljana, Slovenia, Phone.: +386 1 4771-737, Fax: +386 1 477 1 768.

E-mail: luka.cerce@fs.uni-lj.si
davorin.kramar@fs.uni-lj.si;

Assist. Prof. Stevo Borojevic
University of Banja Luka, Faculty of Mechanical Engineering, Stepe Stepanovića 75, 78000 Banja Luka, Bosnia and Herzegovina, Phone.: +387 51 433 000, Fax: +387 51 465 085.

E-mail: stevoborojevic@hotmail.com