Feedback system machine with numerical control - coordinate measuring machine.

V.S.Zavyalov¹, D.U.Mikhailov², A.C. Yatskevich³

¹ ITMO University (Saint Petersburg National Research University of Information Technologies, Mechanics and Optics)
² Mitotoyo RUS
³ DMG MORI

*E-mail: d.mikhailov@mitutoyo.ru

Abstract Modern trends in the development of industry require an increase in the degree of automation of part processing in mechanical engineering. At the same time, the complexity of the workpieces is constantly increasing. One of the important directions of improving the production system within the framework of the concept of industry 4.0 is the organization of inter-machine interaction. A feedback system has been developed for a CNC machine - coordinate measuring machine. This system allowed to reduce downtime of the DMG MORI CTX Beta 800 TC machine for periodic adjustments and to increase dimensional stability of processing. The measurements were carried out on a Mitutoyo KO-GA-ME CMM, after which the correction value was calculated and transmitted to the machine. An algorithm has been compiled allowing to create such a system for processing parts of any complexity.

1. Introduction

Computer numeric control (CNC) machines allowed to achieve high accuracy and processing productivity. However, the need to control the dimensional wear of the cutting tool and periodic adjustments leads to significant downtime of the equipment. Currently, on most CNC machines, periodic adjustment of the control results is carried out by the machine operator. He must analyse the results of the control, decide on the need for adjustment, calculate the correction and make it into the machine. This approach leads to a significant investment of time, makes mistakes due to the human factor.

The fourth industrial revolution involves reducing the influence of the operator on the production system and the transition to inter-machine interaction [1-2]. For CNC machines, this means the need to develop a feedback system between the machine and the instrumentation. In [3], the creation of network interactions within the framework of production lines was noted as one of the engines of digital transformation.

The foundations of statistical processing of measurement results were laid back in the 20s [4] of the last century by Walter Shewhart, but modern computational capabilities can significantly improve statistical methods of control and provide automation of processing of results [5-6].

Digitalization of product quality control at the earliest stages of its manufacture is an important task of modern industry. So, the McKinsey Digital Compass [7] displays 8 major growth directions. Quality is one of them and includes three components:
- Digital quality management
- Advanced process control (APC)
- Statistical process control (SPC)

The idea of adaptive control is not new, but most of its implementations are designed for the simplest processing cases, including the minimum number of sizes [8-11]. A modern CNC machine can process more than a hundred surfaces in one operation, and the adaptive control system integrated in the machine will not allow in such a situation to ensure timely control in sufficient quantity. It is advisable to take out control on a coordinate measuring machine (CMM) and connect it to the machine with a feedback system.

The cycle time for measuring a part on a CMM is significantly lower than the processing time, and control results can be obtained until the next part is finished.

The report “Competencies of the Future” [12] suggests that the process of design and technological preparation of production will be carried out by one specialist. The preparation of a control plan using automated control and measuring equipment should be carried out as part of the technological preparation of production. Currently, it is not enough to control the parameters specified in the technological
documentation; it is necessary to ensure the connection of the controlled parameters and the parameters of the processing machine.

Worldskills is a global non-profit organization organizing championships for work professions around the world. During WorldSkills Kazan 2019 within the competence Milling on CNC machines Mitutoyo RUS and DMG MORI supported by ITMO University organized a feedback system CNC – CMM. This work is an example of the university’s interaction with industrial enterprises, such interaction is an important link [14-16] in the digital transformation of the Russian economy.

2. Methods
Figure 1 shows the workpiece. Processing was carried out on a DMG MORI CTX Beta 800 TC machine with Robo2go automation package, under control of the Sinumerik 840D sl CNC system, version 4.7. The finished part was transferred to CMM - Mitutoyo KO-GA-ME.

Figure 1. Workpiece.

2.1. Workpiece processing
The CTX Beta 800 TC machine (Figure 2) allows you to automatically load a part, process it in the main spindle, transfer the part to the counter spindle, process the other side of the part in the counter spindle, and automatically unload the finished part. The algorithm was demonstrated using an example of a Globus type part, which has several curved surfaces from different sides and requires both turning and milling.

Figure 2 CTX Beta 800 TC.
In general, the task of adjusting the dimensions of a part according to the program can be obtained in the following ways:

1. Correction of the position of the coordinate system for certain elements of the part;
2. Correction of coordinates within the program using variables in the program text;
3. Correction of tool sizes in the tool table.

In our case, the third method was enough to adjust the diameter of the sphere. In this case, the tool offset along the Z axis affected the diameter of the sphere, and the offset along the X axis affected the position of the center of the sphere. To access the tool table in the Sinumerik 840D system there is a block of commands $TC_DP [17], of which the most interesting for solving the task are:

$TC_DP 3 - Tool length, axis 1
$TC_DP 4 - Tool length, axis 2
$TC_DP 5 - Tool length, axis 3
$TC_DP 6 - Tool radius

The command syntax is as follows:

$TC_DPx [ T , D ] , where

T – system tool number
D – number of cutting edge.

The system number of the tool of the current tool (located in Spindle 1) can be found by the command $ p_toolno, or by sorting through the system parameters of all the tools in the store. In our case, it was known that the measured surface was formed by the fine cutter, which had number 39. This number will be constant until the tool is removed from the CNC system, and it can be unloaded from the magazine.

The number of the current cutting edge (active) is available by the command $ p_tool. In our program, the tool had three cutting edges

1. For the manufacture of parts, and direct work in conjunction with CMM.
2. For control, for automatic measurement of a tool on the machine.
3. For control, initial values.

Thus, we see that, when receiving information from the CMM, we always need to change the edge number 1. Using three edges allows us to introduce additional conditions, for example, so that the corrected edge 1 does not differ by more than 0.2 mm from the original one and by 0.1 mm from the measurement on the machine. The CTX Beta 800 TC is equipped with a laser measuring system, which allows you to measure the tool according to the program and to control wear and breakage of the tool. The "Radius" parameter for a turning tool will contain the radius of the cutting edge, and for a rotating tool it will contain its radius, for example, mills or drills.

To update the information in the tool table, it was decided that the result of the KIM operation should be in the form of a subprogram, in the form interpreted by the CNC system. To do this, it was necessary to obtain a text file with the extension .mpf containing variables and a label for the end of the subroutine. For example:

R10=0.03
M17

This file was directly called on the local network as a subroutine, immediately before the finishing of the spherical surface, and then the tool dimensions were adjusted by the value of the variable R10.

IF (ABS($TC_DP3[39,1]-R10)-$TC_DP3[39,3]<0.2) ; if the new value differs from the original by no more than 0.2
$TC_DP3[39,1]=$TC_DP3[39,1]+R10 ; correction by axis X
$TC_DP5[39,1]=$TC_DP5[39,1]-R10 ; correction by axis Y
ELSEIF
MSG("ERROR - Check the tool") ; message about exceeding tolerance
M0 ; stop program
ENDIF

After that repeat all cycle again until the entire batch of parts is completed.

2.2. Part control.

Workshop CMM Mitutoyo KO-GA-ME [18] have accuracy MPEE0 = 2.4 + 5.7L/1000 It is designed for use in workshop conditions, can be built into automatic lines and has high productivity.

The Ø48±0.06 of the sphere was controlled. target value was calculated first according formula (1)
Correction is calculated according formula (2)
\[ corr = actual\ value - target\ value \] (2)

The calculated value was displayed and saved in the sphere.mdf file. The machine and CMM were connected to the same LAN using a router. A Result network folder was created on the computer with KIM, where the sphere.mdf file was saved. The machine read this file and made adjustments to the tool compensation map. At a figure 4 you can see structural scheme of feedback system CNC – CMM.

2.3. Correction algorithm
A generalized algorithm for developing a feedback system is presented in Figure 5. For each processing cycle, a set of characteristics is selected that determine its geometry. The calculation formula and the correction method are set. The structure of the file with variables containing the calculation results is set. This approach allows you to develop a feedback system for complex parts containing a large number of
machined surfaces. Not only KIM software, but also a statistical process control system can be used as a data source, which significantly expands the capabilities of this system.

Figure 5. Correction algorithm

3. Results and Discussion
The system built as part of this work allows us to reduce the human influence on the process of processing parts on a CNC machine, which makes it possible to reduce the number of downtime in the work of machines and improve product quality. A fairly simple case of this system was considered, however, the capabilities of the CMM allow us to achieve a similar result for more complex parts. To do this, for each size in the drawing it is necessary to determine with what tool the surfaces of its forming are processed and set the formula for calculating the correctors. When using software for statistical production control, this system allows one to take into account more than one last value in the analysis. This approach will allow to take into account the natural variation of the processing results and compensate only for systematic errors.

Using a feedback system: CNC machine - CMM is an important step in implementing the concept of Industry 4.0, in machine building. Despite the advantages described, the autonomous operation of this system can lead to the production of a large number of products with deviations in case of unreliable results. In the framework of this work, the difference between the current value of the corrector and the initial value was used to verify the correctness of the measurement. In a real system, it is necessary to develop criteria for the reliability of measurement results. When introducing such a system in an enterprise, considerable attention should be paid to cybersecurity issues [19-20]. Proper risk management in the implementation of automatic systems allows you to produce products with lower costs.

4. Conclusions
This work showed the possibility of organizing the inter-machine interaction of the CNC machine - CMM. The developed feedback system solves the problem of automatic tuning of the machine during processing of workpieces. An algorithm has been compiled allowing to create such a system for
processing parts of any complexity. Possible ways of adjusting the geometry of the workpieces are described and the implementation of one of them is considered - adding a new value to the corrector table.

References
[1] Bloem J. et al. The fourth industrial revolution //Things Tighten. – 2014. – T. 8.
[2] Colombo, Armando W., et al. "Industrial cyberphysical systems: A backbone of the fourth industrial revolution." *IEEE Industrial Electronics Magazine* 11.1 (2017): 6-16.
[3] Li, Guoping, Yun Hou, and Aizhi Wu. "Fourth Industrial Revolution: technological drivers, impacts and coping methods." *Chinese Geographical Science* 27.4 (2017): 626-637.
[4] Shewhart, Walter Andrew. *Economic control of quality of manufactured product*. ASQ Quality Press, 1931.
[5] Gibson, P. R., and K. Hoang. "Automatic statistical process control of a CNC turning centre using tool offsets and tool change." *The International Journal of Advanced Manufacturing Technology* 9.3 (1994): 147-155.
[6] Hegde, Harsha G., N. S. Mahesh, and Kishan Doss. "Overall Equipment Effectiveness Improvement by TPM and 5S Techniques in a CNC Machine Shop." *SASTech* 8 (2009): 25-32.
[7] Wei, Dominik, et al. "Industry 4.0-how to navigate digitization of the manufacturing sector." *McKinsey & Company* 58 (2015).
[8] Masory, Oren, Yoram Koren, and Roland Weill. "Adaptive control system for turning." *CIRP annals* 29.1 (1980): 281-284.
[9] Latifinavid, Masoud, Abdulhamit Donder, and Erhan ilhan Konukseven. "High-performance parallel hexapod-robotic light abrasive grinding using real-time tool deflection compensation and constant resultant force control." *The International Journal of Advanced Manufacturing Technology* 96.9-12 (2018): 3403-3416.
[10] Xu, L. M., et al. "Methodology and implementation of a vision-oriented open CNC system for profile grinding." *The International Journal of Advanced Manufacturing Technology* 100.5-8 (2019): 2123-2131.
[11] Lin, Z. H., and D. C. Hodgson. "In-process measurement and assessment of dynamic characteristics of machine tool structures." *International Journal of Machine Tools and Manufacture* 28.2 (1988): 93-101.
[12] Competencies of the future. Report on the results of the international foresight session FutureSkills, 20 saa 2017
[13] https://worldskills.org/
[14] Vasetskaya, Natalia, and Vladimir Glukhov. "System of interaction between universities, scientific organizations and industrial enterprises under conditions of digital economy in Russia." *IOP Conference Series: Materials Science and Engineering*. Vol. 497. No. 1. IOP Publishing, 2019.
[15] Abramyan K.V., Pompeev K.P., Timofeeva O.S., Yablochnikov E.I. The use of modeling systems in the formation of engineering competencies in the field of digital production // MODERN MECHANICAL ENGINEERING: SCIENCE AND EDUCATION MMEESE-2019 Proceedings of an International Scientific and Practical Conference Russia, June 20, 2019. - C. 3-14
[16] Rudskoy, A.I., Borovkov, A.I., Romanov, P.I., Kolosova, O.V. “General Professional Competence of a Modern Russian Engineer.” *Vysshee obrazovanie v Rossii* No. 2 (220) (2018)., pp. 5-18. (In Russ., abstract in Eng.).
[17] https://support.industry.siemens.com/cs/document/109769996/sinumerik-840d-sl-tool-management?dti=0&lc=en-WW
[18] https://www.mitutoyo.co.uk/files/4414/2244/5610/Ko-ga-me.pdf
[19] Chhetri, Sujit Rokka, et al. "Security trends and advances in manufacturing systems in the era of industry 4.0." 2017 IEEE/ACM International Conference on Computer-Aided Design (ICCAD). IEEE, 2017.
[20] Chhetri, Sujit Rokka, et al. "Manufacturing supply chain and product lifecycle security in the era of industry 4.0." *Journal of Hardware and Systems Security* 2.1 (2018): 51-68.