COMPARISON OF GEOMETRIC ACCURACY OF MACHINE TOOLS FOR VARIOUS TECHNOLOGICAL CONDITIONS AND DIFFERENT WORKTABLE POSITIONS

MATÚŠ KOŠINÁR[1], MIROSLAV CÍSAR[2]
IVAN KURIC[3] NICOLAE UNGUREANU[4]

Abstract: Paper presents the aspects of diagnostic inaccuracies CNC machine tool. Paper deals with the measuring methods of CNC machine tools using single - parametric diagnostics, when we evaluated of CNC machine tool accuracies in various locations worktable and at various feed rate. CNC machine tool accuracy was compared with a load (machine loaded machining) and unloaded with direct and indirect methods of measurement.

Keywords: accuracy, CNC machine tool, direct and indirect, harmonic analysis**.**

1. INTRODUCTION

The machining accuracy of the part is not only influenced by technological system (machine – tool – workpiece), as well as external enviroment (environment temperature, pressure, vibration and etc.) [1, 4]. In identifying geometric accuracy is usually measured unweighted (not machining) machine tool.

---

[1] *Matúš Košinár, MSc, Department of Automation and Production Systems, Faculty of Engineering, University of Zilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia tel. 00421-41-5132811. e-mail matus.kosinar@fstroj.uniza.sk*

[2] *Miroslav Císar, MSc., Department of Automation and Production Systems, Faculty of Engineering, University of Zilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia tel. 00421-41-5132759. e-mail miroslav.císar@fstroj.uniza.sk*

[3] *Prof.Dr.Ing.Ivan Kuric, Department of Automation and Production Systems, Faculty of Engineering, University of Zilina, Univerzitná 8215/1, 010 26 Žilina, Slovakia tel. 00421-41-5132759. e-mail ivan.kuric@fstroj.uniza.sk*

[4] *Prof.Dr.Ing.Nicolae Ungureanu, Faculty of Engineering, Technical University of Cluj Napoca, North University Center of Baia Mare, Dr. V. Babes St, 62A, RO-430083, Romania tel. 0040-362-401 265. e-mail nicolae.ungureanu@cunbm.utcluj.ro*

Leading manufacturers of machine tools try to ensure that the machine will have the same properties (positioning accuracy, quality, etc.) in and out of cut, under certain conditions (tool wear, cutting speed, feed and etc.) [4]. However, it is questionable whether the machine tool maintains this property for machining parts in different places worktable and at different technological parameters.

When we measure the CNC machine tool precision there can be used not only one diagnostic method, but the multiparametrical approach too. It is difficult to select the suitable measurement methods by multiparametrical diagnostics to achieve the rating of the machine in the shortest time as well as with the lowest cost. These methods are independent and their evaluation has synthesized character. One more expensive method can be replaced by one less cost-intensive method.

According to this information, we set the following hypothesis for the experiment: „Geometric accuracy of CNC machine will depend on various techno-logical conditions as well as the location of the machined part on a worktable. Geometrical accuracy of produced part and its course time should be correlated with the precision of machine tool, which is measured by one parametric ". The machine tool is shown in Figure 1.

Fig. 1. Machine tool Hurco VMX 30t

2. EXPERIMENTAL RESEARCH

Our topics were to compare the experimental research of the loaded and unloaded state of the machine tool in different positions worktable and at different cutting speeds by tracking geometric accuracy.

We will also monitor the range of correlation between direct and indirect methods of detection accuracy CNC machine tools.

When the machine tool inaccuracies are measured we analyze the working axis X and Y at the beginning. The method is the same for the remaining axes (XZ, YZ) too. The only difference is the mounting method of machined samples and measureing equipment.

3. EXPERIMENTAL CONDITIONS

Machine tool measuring was done at various places of worktable by different feed-rates (500, 1000, 1500 mm·min^{-1}). Two positions where the measurement was carried out and machining were defined as central and peripheral location. The central location is near the middle of worktable and peripheral position in the upper left corner of the worktable. For each feed-rate were machined three samples, total number was eighteen samples.

The aim fo the experiment was to measure the CNC obrábaciehostroja, where we measure the difference between the programmed and real done trajectory. The result will be represented by roundness deviation of the machine tool. Another procedure will be machining the samples at prescribed feed-rate in position worktable. As a result we will compare the geometric characteristic, where we compare the correlation of deviations from roundness and harmonics profile machined parts and measured path.

The first and second measurement was carried out at constant conditions. The innovation difference is changing the measuring Ballbar device, which measure of circularity deviation. (old version Ballbar QC10). See Tab. 1.

Table 1. **Conditions measuring for experimental samples in the year: 2009 and 2012**

Hurco VMX 30t	**2009**	**2012**
	Ballbar QC10	Ballbar QC20-W
Experiment parameters		
Premier nominal path	300 mm	300 mm
Feedrate	500,1000,1500 mm min^{-1}	500,1000,1500 mm min^{-1}
Axis movement	XY	XY
Location of the measurement device		
Centre of circle (X,Y,Z) centre	373 / 235 / -490	373 / 235 / -490
Centre of circle (X,Y,Z) side	605 / 161 / -521	605 /161 / -521
Enviromental temperature	(See Fig. 2)	
Enviromental temperature	20,65 °C	21,4°C
Temperature measuring device	20, 8°C	21,9°C
Machine temperature	20,9 °C	21,5°C
Other environmental conditions		
Atmospheric pressure	970 Pa	974 Pa

Experimental measurements are performed on the machine tool Hurco VMX 30t when measuring circular interpolation used equipment from Renishaw Ballbar QC10 and Ballbar QC20-W. Profile circularity of machined samples was measured by a measuring device TALYROND 73. Experimental conditions are shown in Tab. 2.

In the second measurement the measuring device used compensation Ballbar QC20-W. The device is calibrated before measurement using Calibrator Zerodur. Coordinate axes of both experiments were the same (Axes XY) in Ref. [3].

Table 2. **Conditions machining for experimental samples in the year: 2009 and 2012**

Experiment		**Hurco VMX 30t**	
Experimental sample		Fig. 4	
Material		11500.3	
Basic dimension		289 × 280 mm	
Weight		7,4 kg	
Quantity		6 samples	
Machining parameters		**Enviromental conditions**	
Spindle speed	2600 min^{-1}	Temperature	20,65°C
Feedrate	500, 1000, 1500 mm min^{-1}	Atmospheric pressure	970 Pa
Cutting depth	1,5 mm	Machine temperature	21,5°C
Tool	Two edges end mill ø14 mm	Clamping samples	clamp

In the first experiment six samples were machined tool prepared. The evaluation pointed to the insufficient number of samples required of correct evaluation. Comparison of the results was also inadequate. These deficiencies were used in the second experiment, when a larger number of samples chosen of cultivation, but also a different way of evaluation.

Fig. 2. Measurement of environmental conditions using compensatory unit of equipment Laser XL 80

4. DIRECT MEASUREMENT METHOD

Direct measurement method is suitable for unloaded machine which is not affected by impacts of the machining process. This measurement method obtains information about the current machine state in Ref. [2].

Two devices were used for measuring unloaded machine (not during machining). Both devices have almost same construction; one of these is newer version. Full identification of device is Renishaw Ballbar QC10 a QC20W (see Fig. 3). Ballbar QC20W has a higher reading speed and bluetooth. Other advantage of the newer version is the possibility of concluding a working space of the machine.

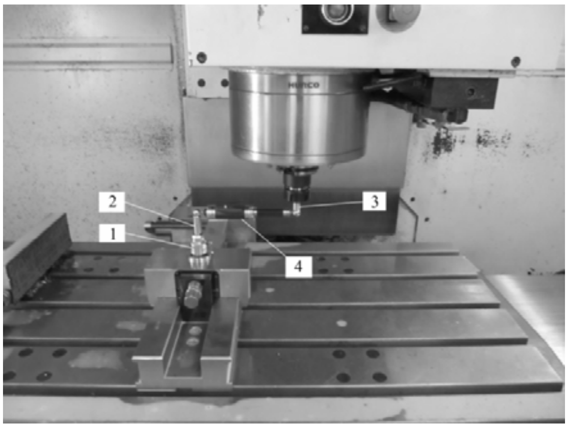

Fig. 3. Measuring device Ballbar QC20
1. Magnetic center holder; 2. Magnetic centre cup attached to rack;
3. Magnetic centre cup clamped in collet; 4. Measuring device Ballbar.

Measurements were performed in 2009 and 2012. In 2009, at time of first experiment machine tool was already operating one year. Long interval between measurements provides clear information about machine tool state development.There are only few measurements from year 2009, but it still enough for comparasion. All measurements were made in accordance with ISO 230-4:2005.

5. INDIRECT MEASUREMENT METHOD

Indirect measurement method for loaded machine tool (during machining) consists of test samples machined to required dimension and subsequent assessment by the measuring device. In the indirect measurement method is also carried out two measurements with an interval of three years. We avoid the mistakes of the first measurement, so as to avoid the lack of data necessary for the measurement evaluation.One of the most important factors was that the sample was clamped by clamps and not by vice, because sample was deformed due to the applied force. It was necessary to eliminate force due tool entering sample, where it was necessary to use trochoidal milling.

To measure the roundness profile was used measuring device TALYROND73.

6. EVALUATION OF MACHINE TOOL IN ACCURACIES IN VARIOUS POSITIONS WORK-TABLE

In the evaluation of ballbar QC20 (QC10) results were used data from the software ballbar 20. Final processing was done in Microsoft Excel software, where the data is decomposed to harmonic components of the profile. In the program ballbar 20 is evaluated according to ISO 230-4:2005 and results from the program were used to verify the results processed in Excel.

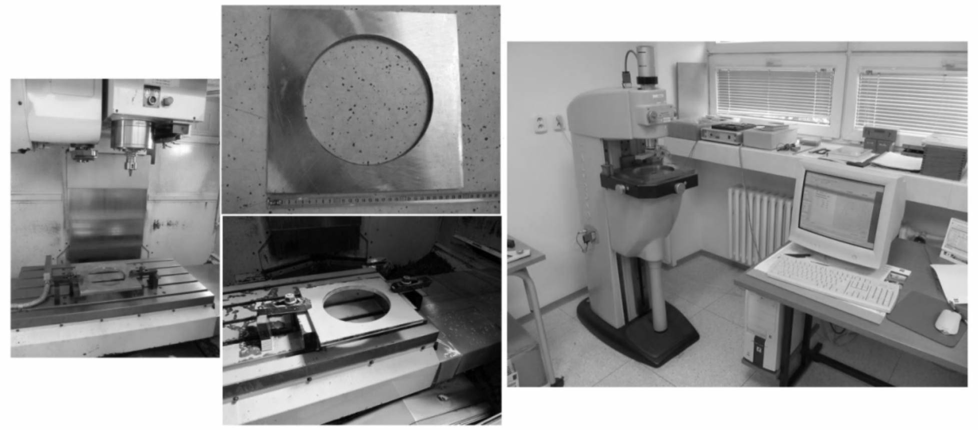

Fig. 4. a - sample after machining in clamping unit; b - Talyrond 73 measuring device

Because of incompatibility of measurement records from software Ballbar 20 and Microsoft Excel was created convertor in the programming language Visual Basic.NET. Program is able to convert *.B5R files to *.Sig. During the conversion program filter input data file because the file contains data for multiple measurements. For evaluation were needed only data gained during one turn without starting and ending part of the machine tool movement.

The measurement was performed in two periods with a break of three years in two position (in the central and edge position). Tables shows that three years of machine tool operation caused a significant change in the accuracy of roundness deviations positions on the worktable CNC machine.

Table 3. **Roundness deviation of measuring at device TALYROND 73 in 2009 – 2012**

Samples machined position	**Feed rate [mm·min⁻¹]**	**Roundness deviation [µm]**			**Average roundness deviation [µm]**	**Range [µm]**
Centre position 2012	500	18,6	18,3	15,3	**17,4**	**3,3**
	1000	16,6	16,3	16,8	**16,57**	**0,5**
	1500	18,7	15,8	25,5	**20**	**9,7**
Side position 2012	500	26,1	18,9	27,2	**24,07**	**8,3**
	1000	19,5	22,1	22,8	**21,47**	**3,3**
	1500	19,1	20,6	16,8	**18,83**	**3,8**
Centre position 2009	500	**25,2**				
	1000	**19,2**				
	1500	**23,3**				
Side position 2009	500	**25,7**				
	1000	**22,9**				
	1500	**28,6**				

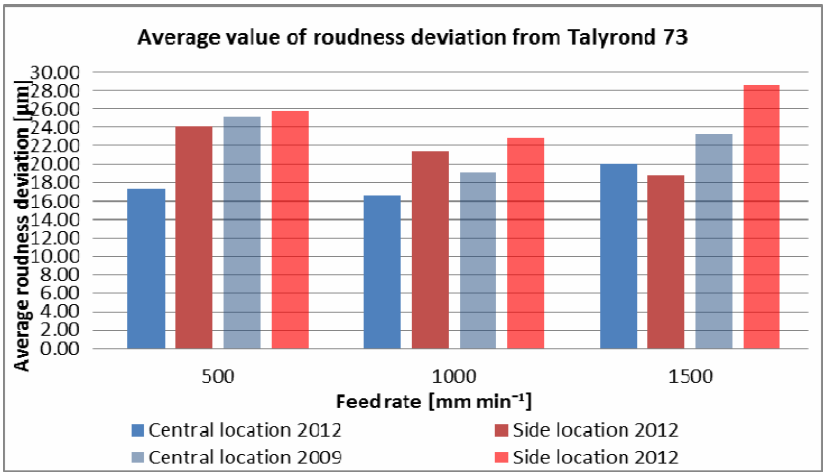

Fig. 5. Comparison of roudness deviations measured at TALYROND 73 (year 2009 and 2012).

7. RESULTS OF THE EXPERIMENT

Evaluation of measurement errors in 2012 (Ballbar QC20) for the central position detected maximum error was "Backlash Y" 28%. Maximum error for edge position was “Scaling mismatch” 22%, “Backslash Y” 21%. Reason for scaling mismatch is overrun or underrun of axis relative to another one. Machine can be affected by an angular error that causes runout of X or Y axis to the plane of the test during movement. That can be caused by lack of stiffness or obliqueness of feed guiding elements. This error results to dimensional errors of machined parts. That can be solved by verification of used compensations, checking of feed guiding elements and leadscrews, e.t.c. Accuracy trends can be predicted by using error values in percent obtained with software ballbar 20. This shows that the upward trend with the largest incrase in Backlash Y. Next error with significant upward trend, especialy in central position, is Scaling mismatch. These errors can be solved by methods mentioned above. FFT analysis was used to show the real profile. There were used data only from second experiment (actual macine tool condition). The data acquired from first one (machine tool condition in 2009) may be used to determine a trend of machine tool precision. Using these data it is possible to get a more accurate idea of the future development of machine tool errors and it's accuracy.

Pictures Fig. 6 and Fig 7 shows real roundness profile. Amplitude of second harmonic is lower in edge position than in central one. These differences are clearly visible on average roundness deviations. Situation was just opposite during first measurement in 2009. In results from TALYROND 73 is apparent dominant second harmonic as a result of tool entering to material. Compared to first measurement during new ones the impacts of strength at the start of machining were eliminated as much as possible but were not removed completely. Second harmonic component requires attention during data evaluation because it expresses profile ovality. This affects not only the maximum roundness deviation, but also the maximum protrusion and ovality, ie values that are important for proper evaluation.

Harmonics observed in the first experiment were small which means that deviations are so small that they can be considered identical. Also oval was similar for all positions and feed rates. Character of movement in the direction of axis *x* and *y* is the same. Error of the machine has the same nature, size at any point.

Machine Error was small enough to not require attention. Characters errors have changed significantly over the three years of deployment of the machine operation.

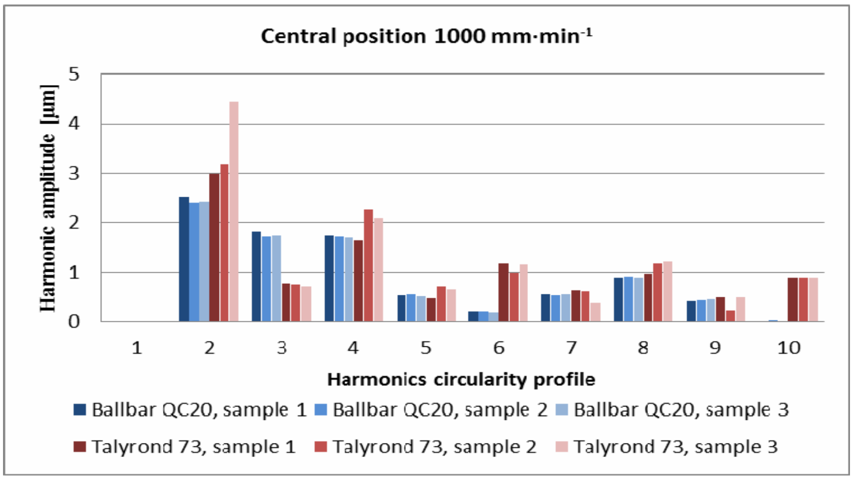

Fig. 6. CNC machine tool comparison of load and unload condition using harmonic profile in centre location at a feed rate 1000 mm·min^{-1}

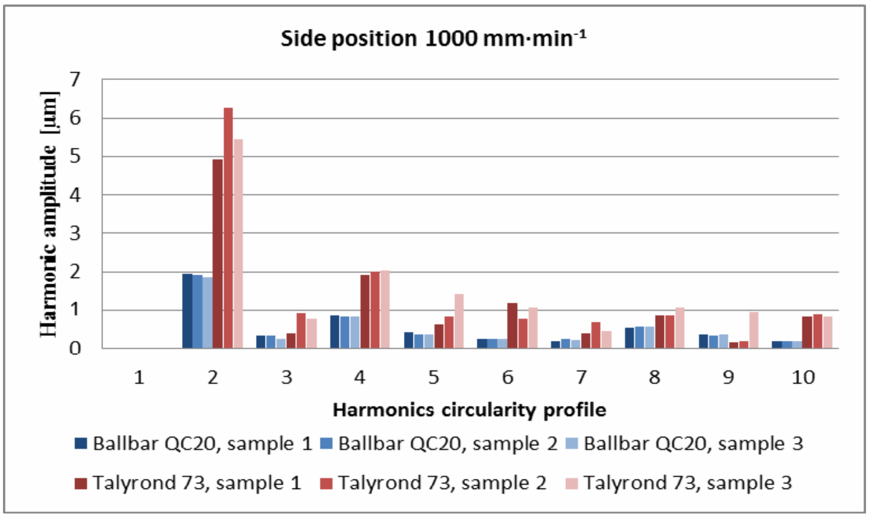

Fig. 7. CNC machine tool comparison of load and unload condition using harmonic profile in side location at a feed rate 1000 mm·min^{-1}

Table 4. **Ballbar QC and Talyrond 73 comparing of correlation index and harmonic analyzes in 2009 and 2012**

Ballbar QC10 (2012 – QC20) – Talyrond 73	**Feed rate [mm·min⁻¹]**	**Correlation index**	
		Measurement in 2009	Measurement in 2012
Centre position	500	0,73	0,73
	1000	0,84	0,84
	1500	0,88	0,88
Side position	500	0,45	0,45
	1000	0,57	0,57
	1500	0,45	0,45

Circularity deviation comparison for various positions (2012) shows that the error visible mainly in the central position. Shape difference is more significant for the central position, because it is increasingly influenced by machine error. Machine error was for the first measurement (2009) small and therefore not reflected on the value of deviations roundness. The small size of the errors apparent correlation index (Table 4), for which the rule is that the smaller the value of roundness deviation, the lower the correlation index is. Comparing measurements (2009 and 2012) showed that the choice between direct and indirect method, is not clear. It confirmed the fact that even if the manufacturer provides the same precision values at different positions, the actual accuracy in different positions depends on errors and wear of machine parts.

Machine error is reflected in the most common and most strained positions. Results of measuring machine tool Hurco VMX 30t shows error caused by wear of components in central position due to repeated machining the same position. Possible cause of this condition is for example damage due collision. These figures highlight the need to carry out regular inspection machine, which allows using the history of measurements to create a consistent trend of machine tool precision.

In the future, it is strongly recommended evaluation of the implementation of maintenance in order to avoid the described situation. One of possible ways is the internal audit system of the maintenance process, where the company reaches an objective assessment of maintenance management. Draft measures designed to improve the process and implement corrective actions: (EN ISO 19011:2003)

8. CONCLUSIONS

The development of various methods for measuring of machine tools is still a hot topic. There are a number various methods deployed in practice, where are constantly improved individual devices. A significant development is the measuring of geometric parameters machine tool where multiple measuring devices is replaced with a universal one alone. Progress in the development do not necessarily ensure wide use in the practice in Slovak manufacturing companies

The experiment consisted of measuring precision the machine tool by Ballbar QC20W (QC10), which is used to measure the of circular error. Machine tool during measuring of circular error was not machining. The measurement was carried out in two positions at different and feed rates. The conditions were the same as for machining. The samples were machined in two positions at different and feed rates. Measurement parameters were the same for both experiments, even if it was difficult due the environmental conditions Roundness profile of machined samples was measured by measuring device TALYROND 73. Experiences gained during the first experiments allow to avoid the mistakes made in the first measurement, and as far as possible to eliminate such errors.

Output data from measuring devices files are written in a different format, so it was necessary to create a program that allows data processing and export in readable form. For this purpose have been developed two programs: Talitali for TALYROND 73 and ConverterTest for Ballbar devices. Output data from measuring devices files are written in a different format, so it was necessary to create a program that allows data processing and export in readable form. For this purpose have been developed two programs: Talitali for TALYROND 73 and ConverterTest for Ballbar devices. These programs are also applicable in other experiments performed by mentioned measuring devices.

The data obtained were processed by measurement in Microsoft Excel, which were compared using the graphical display. profile Roundness was using Fast Fourier decomposed into harmonic components, next correlations indexes between each measurement were calculated. It was necessary to verify the procedures for the processing data measured and evaluation. Graphical results were compared through the Sigma-Round for Ballbar devices and ROFORM for Talyrond 73. Mathematical verification was possible only by ROFORM.

Experiments results showed deterioration of of machine tool Hurco VMX 30t, where worktable error growth was detected. The values of precision differences between the central and peripheral position were similar because of the same error character. At the time of the first experiment was achieved higher accuracy in the central position than the edge. This was due a low worktable feed error. It is recommended to perform machine tool servicing, in order to remove this error and prevent deterioration of the machine tool.

REFERENCES

[1]. **Demeč, P.,** *Presnosť obrábacích strojov a jej matematické modelovanie. vienala Košice*, 2001. ISBN 80-7099-620-X.

[2]. **Košinár, M.,** *Analýza presnosti obrábacieho stroja v rôznych miestach pracovného stola*. ŽU Žilina, 2009. Diplomová práca.

[3]. **Košinár, M., Dekan, J.,** 2011. *Diagnostické zariadenia monitorujúce stav obrábacích strojov*. STROJÁRSTVO = STROJÍRENSTVÍ. ISSN 1335-2938, 2009, ROČ. 15, Č.15, 2-3S.

[4]. **Marek, J.A.I.,** *Konstrukce cnc obráběcích strojů*, MM PUBLISHING 2010, ISBN 97-8802-547-9803.