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ANALYSIS OF RESULTS OF CIRCULAR TESTS FOR NUMERICALLY CONTROLLED MACHINE TOOLS DEPENDENT ON POSITIONS OF TESTS IN WORK SPACES

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Summary

This study presents analysis of circular test used according to ISO 230-4 for quick diagnostic Computerized Numerical Controls condition. We built virtual machine, which implements earlier calculations of Volumetric Error. Using this Virtual Machine we simulated testing of circularity of Computerized Numerical Control machine tools. Virtual test was taken in ten different places for three different machine tools. Those machines had different characteristics of kinematic errors and squarness and also different sizes of working spaces. We observed significant differences in those indicators in dependence of place where the test was taken.

Keywords: circularity, sphericity, volumetric error, ball bar test, machine tool

Próba okrągłości w analizie stanu obrabiarek sterowanych numerycznie w zależności od położenia w przestrzeni roboczej

Streszczenie

Zaprezentowano analizę wyników próby okrągłości wg ISO 230-4, stosowanej do szybkiej diagnostyki stanu obrabiarek sterowanych numerycznie. Zbudowano wirtualną maszynę, realizującą wyznaczoną doświadczalnie mapę błędów przestrzennego pozycjonowania. Przeprowadzono z jej użyciem symulację próby okrągłości obrabiarek sterowanych numerycznie. Symulację wykonano w dziesięciu różnych położeniach przestrzeni roboczej dla trzech różnych maszyn. Obrabiarki różniły się zarówno charakterystykami błędów kinematycznych i prostopadłości, jak i rozmiarami przestrzeni roboczej. Wykazano istotne różnice w wartości błędu okrągłości i sferyczności w zależności od położenia w polu roboczym maszyny.

Słowa kluczowe: błąd okrągłości, sferyczność, błąd przestrzenny pozycjonowania, pręt teleskopowo kulowy, obrabiarki

1. Introduction

Computerized Numerical Control (CNC) machine tools are recently treated as standard in manufacturing industry, because they allow to get more complicated shapes of workpieces with more and more accuracy. During the work the accuracy

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of the machine tool can be decreased, because all production process can be affected by many error sources such as temperature, position errors, vibration, wear of linear guideway etc. [1,2,3] To decrease influence of those sources it is necessary to diagnose machine tools as frequently as it is possible and try to compensate the errors up to date. There exist lots of types of diagnostic tests showing condition of CNC machine tool. Rules of CNC machine tool measurement are described in international standards. The most common is ISO 230 titled ‘Test code for machine tools’ [4]. The most popular tests are accuracy and repeatability of positioning axes test, ball bar test, R-test, thermal drift, laser tracer [1-9]. They need different methods, equipment and time to give different quality of results. For example, the laser tracing test can generate a whole 3D vector field with Volumetric Error, but it is expensive and time consuming [1]; a quick but not such a sound test is a ball bar test that is based on measuring of a circular deviation [2]. This test becomes more and more common thanks to being cheapest and lowest time consuming.

This study presents an analysis of influence of positioning of testing circle ball bar testing to circularity in three different kinds of machine tools. Taking into account machine tools’ Volumetric Error there seems to exist a relationship between position of ball bar test and the results independently of quality of machine tool.

2. Volumetric error of machine tools

We examined three different kind of machine tools by laser tracer (Fig. 1). First machine tool was a machine from Polish producer with a very high accuracy. Its cyclic pitch error is 3 µm. The second machine is also from a Polish producer equipped with linear scales but without compensation of positions of the axis. The last machine was an old laser cutter with a large kinematic error. The machine tools characteristics are listed below in Table 1.

Table 1. Machine tools characteristics

Machine volume [X] [Y] [Z] [mm]		**Machine 1**	**Machine 2**	**Machine 3**
		[0 : 600] [-20 : 380] [-10 : 540]	[-270 : 270] [-250 : 260] [270 : 720]	[150 : 1110] [-280 : 280] [-400 : 0]
EXX	µm	12.0	56.8	898.7
EYY		3.9	74.4	174.8
EZZ		8.2	74.7	692.3
C0Y	µrad	0.1	-101.5	-1100
B0Z		-2.3	67.1	-931
A0Z		-81.1	-183.2	-3800

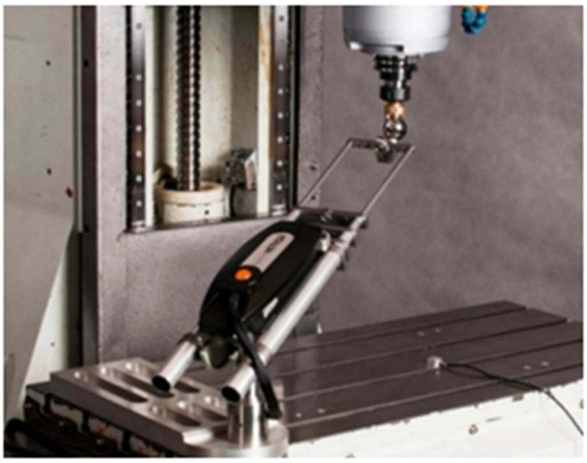

Fig. 1. Laser tracer used to determine Volumetric Error vector field

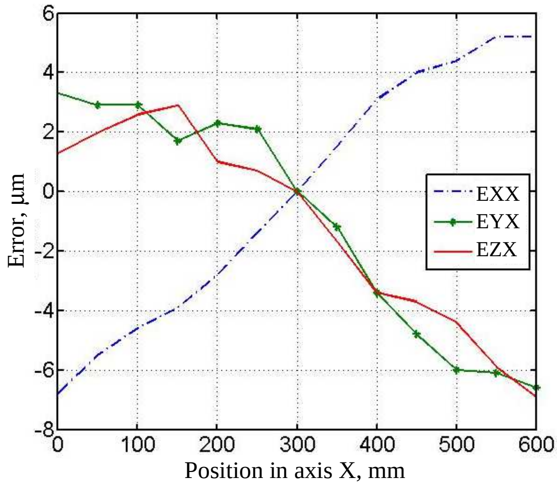

Fig. 2. Characteristic of straightness and position

In laboratory in ITM of ZUT in Szczecin we examined real machines by laser tracer. We used multi-iteration algorithm to build mathematical model of Volumetric Error (VE) of each machine. It includes such errors as position errors, straightness errors, rotation errors and squareness of axis. The characteristic of position and straightness errors of one of the examined machine were presented in Fig. 2.

We found the vector field distribution appearing position error. We assumed that machines compensate their backlash in their control systems. Also, all machines servo mechanism are properly regulated, in other words there is no mismatch.

We used the VE data obtained by the experiment as an input to a simulation on a virtual machine tool, which was constructed in ITM by the authors.

3. Standard procedures

Machine tool test procedures were developed according to international standards. The standards ISO 230-4 – 2005 propose test procedures during circular interpolation. The procedure requires fixed assigned feed rate and diameters. The test gives performance index called circularity deviation G. It is defined as a difference between maximum and minimum distance of points of actual path from the center of the least squares circle.

We build simulator of each machine with their Volumetric Error vector field and carry out simulation of circular examination according to ISO 230-4. We decided to proceed with the simulation in ten different positions. We set two Z-values of the centers, and for both of them we generated five centers of the circles: one in the very middle of the work space, and the other four in its corners. We made tests in three planes XY, YZ, XZ. In plane XY we encircle the whole circle in contrast to planes YZ, XZ where the test was performed in range from -20° to 200°. As a result we obtained ten different sets of points. Each set contains point from three concentric circles. The trajectories are shown in Fig. 3.

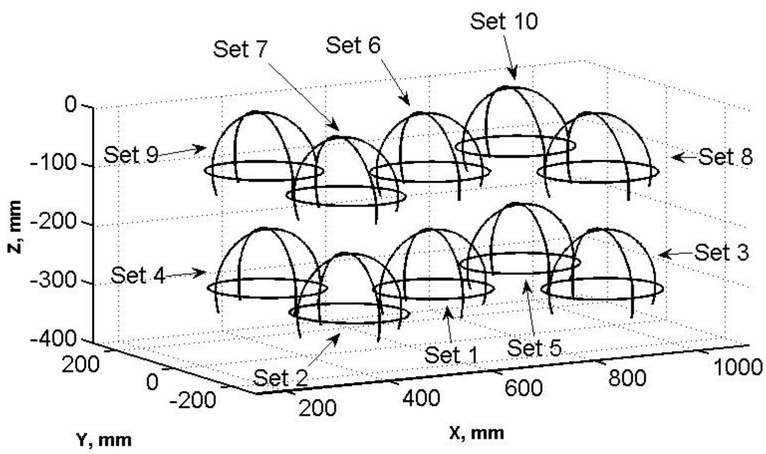

Fig. 3. Trajectories of simulated ball bar tests for ten different places

For each circle we found their circular deviations with corresponding radius of least square circle. We also calculated their sphericity and corresponding radius of least square sphere. The results for each machine we present in Tables below.

Table 2. Results of ball bar test for Machine 1

Machine 1	Circular deviation			Radius deviation			Spheracity	Radius deviation
Circle \ Plane	XY	YZ	XZ	XY	YZ	XZ		
1	10	5	7	-3	-7	0	10	-3
2	10	4	7	-1	-4	3	11	-1
3	10	4	8	-1	-4	2	12	-1
4	10	3	7	-1	-3	3	12	-1
5	10	3	9	-1	-3	2	13	-1
6	7	3	17	-3	-4	-3	16	-3
7	9	3	15	-1	-3	1	17	-1
8	8	3	19	-1	-3	1	19	-1
9	7	2	16	-1	-2	1	18	-1
10	9	2	19	-1	-2	1	19	-1
Standard Deviation	1	1	5	1	1	1	3	1
Average	9	3	12	-1	-4	1	15	-1
Range	4	3	12	2	4	5	9	2

Table 3. Results of ball bar test for Machine 2

Machine 2	Circular deviation			Radius deviation			Spheracity	Radius deviation
Circle \ Plane	XY	YZ	XZ	XY	YZ	XZ		
1	30	26	34	-10	-13	-5	46	-10
2	16	28	35	5	0	8	40	5
3	13	28	48	4	0	5	41	4
4	75	22	39	-3	-22	17	99	-3
5	76	22	49	-6	-22	10	102	-6
6	45	23	25	-11	-17	-4	45	-11
7	16	21	15	6	2	9	25	6
8	18	21	24	7	2	10	28	7
9	93	35	20	-12	-36	18	106	-11
10	99	35	26	-12	-36	15	118	-12
Standard Deviation	33	5	11	8	14	8	35	8
Average	48	26	32	-3	-14	8	65	-3
Range	86	14	35	19	38	23	93	19

4. Results

To illustrate how different trajectories we get in this test depending of place where the test was taken, we translated all circles to the same center, as is shown in Fig. 4.

Table 4. Results of ball bar test for Machine 3

Machine 3	Circular deviation			Radius deviation			Spheracity	Radius deviation
Plane / Circle	XY	YZ	XZ	XY	YZ	XZ		
1	438	198	66	65	-115	239	454	66
2	292	129	148	131	218	24	304	132
3	173	128	79	245	218	238	185	246
4	310	199	111	-58	-181	63	400	-57
5	470	202	65	35	-181	237	485	35
6	364	273	809	38	-108	164	810	39
7	256	215	906	100	160	11	831	100
8	176	216	822	182	160	163	712	182
9	279	275	884	-43	-153	50	861	-41
10	379	282	799	17	-153	162	789	17
Standard Deviation	95	52	377	91	168	86	234	90
Average	314	212	469	71	-13	135	583	72
Range	297	153	841	303	400	228	676	302

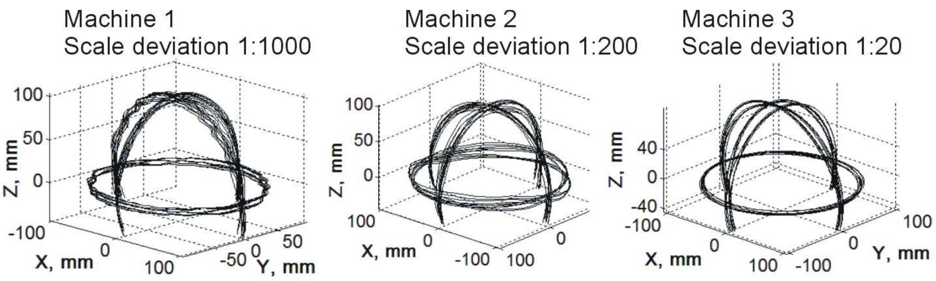

Fig. 4. Different trajectories of ball bar tests in each machine

We observed a relation between higher and lower position of test space. The lower position (set 1, 2, 3, 4, 5) was nearest the table and the higher position of testing (set 6, 7, 8, 9, 10) was upper than the center in Z-axis. The circular trajectory of ball bar test in XY – plane was projected in this plane and shown in Fig. 5.

In this figure we can observe different shape errors and dimension errors in each lower and higher position. The Analysis of results of U Mann–Whitney statistic test shown significant difference between position in Z – axis, not only in plane XY, but in others also. For Machine 1 there significant differences in plane XY and also XZ ($p = 0.012186$), for Machine 2 in plane XZ, and for machine 3 in planes YZ, XZ with the same value of p. The same situation is observed with spheracity. The significant difference was shown for machine 1 and machine 3.

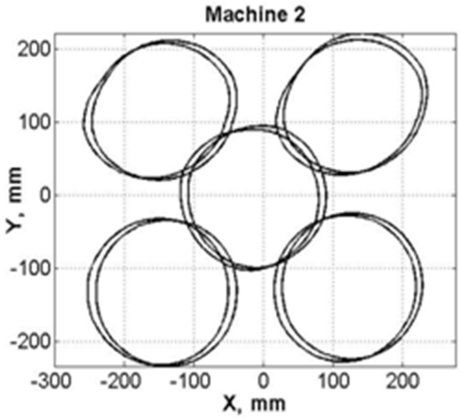

Fig. 5. The projection on XY – plane shows differences of shape and dimension errors in Machine 2

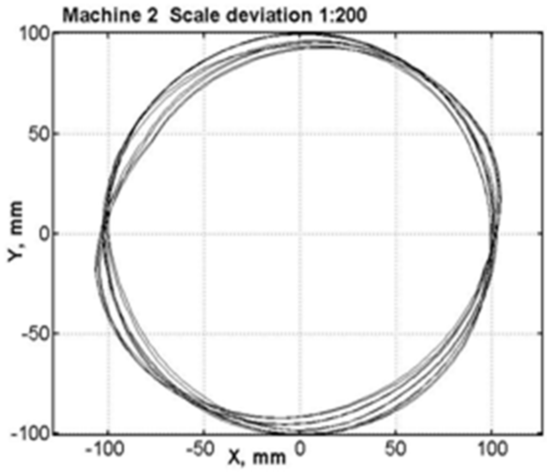

Fig. 6. Ten ball bar test circle in XY plane in Machine 2

Our next observation is the fact, that the middle of a working space (set 1) is not the best or the worst results of testing. Therefore there is no reason to take the test in this place. Furthermore, in a second machine tool a particularly interesting phenoma can be seen. We observed that the results of tests in different places can give a different diagnosis as was shown in Fig. 6. In place 1, the result of ball bar test is a circle, so it does not show any squerness error, and in position 10, the test suggests that the error exist.

5. Conclusions

As we expected we observed differences for each trajectory of circular test. We noticed significant disagreement of results in higher and lower position. The differences are not only in dimension but also in shape, suggesting different diagnosis and solutions in different places. Furthermore, the most popular position for ball bar test, the center position, does not give a best or the worst case, so there is no reason to take the test in this place to diagnose a whole machine. This differentiation we classified as a method error.

Despite ball bar test is relatively cheap and fast it is not good enough to rate accuracy of machine tools. We recommend to keep prudence during interpretation of this parameter.

The possible future perspective is analyzing of machine tools before and after compensation of Volumetric Error. Then it may be possible that the differentiation of test results might change.

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