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DETERMINATION OF ACCURACY OF POSITIONINGCNC MACHINE TOOLS

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Abstract: Positioning represents taking the position of the executive body machine tools. The positioning accuracy means the deviation of the actual position of the executive body of the programmed machine tool, with its multiple bidirectional positioning at different points in each of the coordinate axes (the independent movement along the axes – independent axes). This paper presents the basic parameters for four standard relating to the positioning accuracy CNC machine tools. The results of testing machining center for milling are shown for four standards,and measurement uncertainty is determined for the ISO 230-2: 2014 standard.
Keywords: Positioning accuracy, Measurement uncertainty, Laser measuring system, CNC machine tools

1. INTRODUCTION

As one of the main goals of modern metal industry imposes the development of the products with satisfactory accuracy.To satisfythis goal, metal industry needs themachine tools that will make such products with a minimal percentage of reject. It is well known that parts with tight tolerances can be produced only on precise mashineor machine tools with appropriate accuracy. Accuracy is one of the indicators of themachine toolsquality. By controlling the parameters of accuracy from the beginning of machinelife cycle, can be maintained, within acceptable limits, its quality characteristics.

Positioning accuracy and repeatability of the machine tool are core descriptors of a machine tool and indicate the machine's expected level of performance. There are a number of standards and guidelines how to evaluate machine tool positional accuracy and repeatability.They differ in the analysis procedures and in key parameters definition. The numerical result, as a report on the positioning accuracy and repeatability for any machine can vary, depending of theapplied standard [4].

The aim of this paper is to present the results obtained by different standards for positioning accuracy of CNC machine tools.As the significance of the standards is the same, it is important to know the difference between them and how calculated values can be compared with each other. The measurement accuracy of positioning is carried out on the milling machining center,and the results are presented in tables for all three axes.

2. OVERVIEW OF STANDARDS FOR NC MACHINE TOOLS POSITIONING ACCURACY EXAMINATION

There are several standards and guidelines that define how to examine the positioning accuracy and repeatability of machine tools. The main difference between them is in the analysis and definition of parameters. As all standards have the same significance, it is important to know the differences between them, and how the obtained values can be mutually compared. The analysis of the four standards used in Europe and in our country (Serbia) is shown below:

≡ ISO 230-2: 2014
≡ DIN ISO 230-2: 2000
≡ VDI/DGQ 3441
≡ SRPS M.GO.101: 1991

2.1. ISO 230-2: 2014

The newest standard ISO 230-2: 2014 - Part 2, relates to the testing of machine tools, or determine the accuracy and repeatability of numerically controlled machine toolspositioning.

Previous versions of this standard are: ISO 230-2: 2006, ISO 230-2: 1997 and ISO 230-2: 1998.There is no international standard based on ISO 230-2: 2014. Purpose of standard is to define examination methods fornumerically controlled machine toolspositioning accuracy and repeatabilityand components for the direct measurement of the independent axis of machine tools. It is used for examination at the final check and adjust the machine tools from the manufacturer, and for periodic verification of machine tools parameters in exploitation.

Standards from 2006 and 2014 contain measurment uncertainty, which in previous versions was not included in the report as an important parameter.The measurement uncertainty is defined by above standard, which will be shown below for milling machining center.

2.2. DIN ISO 230-2: 2000

DIN ISO 230-2 is German standard which is based on the international ISO 230-2: 1997 standard. Refers to research into machine tools - Part 2, respectively determination of positioning accuracy and repeatability with numericallycontrolled machine tools.

Purposeof the standard is to define examination method for numerically controlled machine toolspositioning accuracy and repeatability and components for the direct measurement of independent axes. It is used, as previously described standard, at the final check and adjust the machine tools from the manufacturer, and for periodic verification of machine parameters in exploitation.

2.3. VDI/DGQ 3441

Statistical examinationof the machine toolswork accuracy and positioning accuracy. Translation of German edition - 3/1977. This recommendation does not have the earlier version, and, also, no other international standards is based on VDI / DGQ 3441.

Scope of the standards are guidelines that show how statistical methods can be applied to machine tools that are and are notconnected to a specific partfor determintionof the machine tools operating accuracy and positioning accuracy. The recommendation consists two parts, one part is related to the working accuracy. The aim of the examinationwithin working accuracy is determination of the maximum accuracy which can be realized in a specificmachine tools in manufacturing of the specific part. The second part of the recommendation describes the positioning accuracy of the machine toolsby direct measurement, in terms of idling.

2.4. SRPS M.GO.101: 1991

This standard specifies examination methods of the accuracy and repeatability of positioning elements of machine tools with numerical control, by direct measurement of independent axes on the machine. The methods are applied to linear or rotary motion. It refers to the measurement repeatability and accuracy of the positioning of moving parts along or around each axis of machine tools.

This standard is in accordance to ISO 230-2 standard from 1988, and differs only in that it does not contain a point 8, which refers to the agreement between buyer and seller.

2.5. Comparison of parameters between individual standards

Table 1 shows the recommended parameters, which should contain the any report, after examination positioning accuracy of machine tools. In Tables 2, 3, and 4 are given standards and parameters which compared with each other, as well as their similarities and differences. DIN ISO 230-2 standard, has not been compared with other standards, because it is identical with ISO 230-2: 2014 standard, with the exception of the measurement uncertainty. In nomenclature is given the list of used index.

3. MEASUREMENT INSTRUMENTATION

Examinationof the accuracy of positioning numerically controlled machining center FM 38 was carried out using a laser measuring system (LMS) 5526 company "Hewlett-Packard".

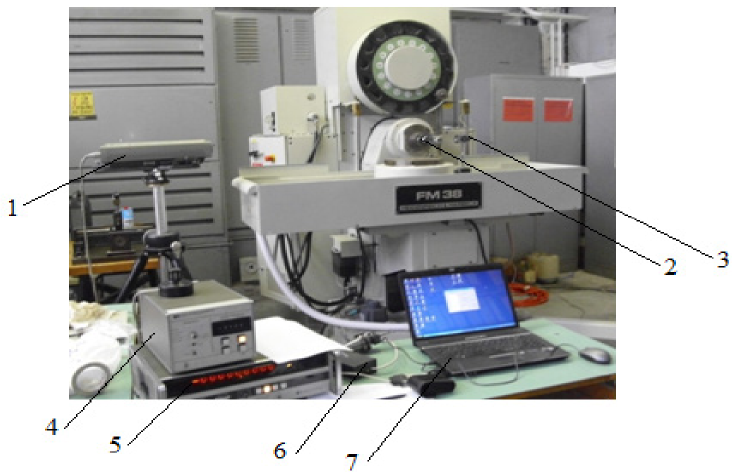

Figure 1.Numerically controlled machining center FM 38 with LMS:
1. The laser head (He- Ne gas laser) - 5500 C; 2. The interferometer; 3. Reflector; 4. Automatic compensator; 5. Laser display HP 5505; 6. AD card; 7. A computer with corresponding software

Figure 1 provides a numerically controlled machining center FM 38 with the set LMS.

Laser head 5500C is one of the first HP laser metrology which has an integrated optical receiver for the return laser beam [4].

Automatic compensator 5510 is used to correct the influence of the environment, such as temperature, humidity and air pressure, where exist appropriate sensors connected to an automatic compensator.

Power is supplied by the laser pointer 5505, through the power cable. Compensator simplifies the compensation process and eliminating the need for the operator performs any calculations.

Table 1. Parameters recommended for reporting

ISO 230-2: 2014	DIN ISO 230-2: 2000	VDI/DGQ 3441	SRPS M.GO.101 1991
A_{14}; uncertainty (k=2)	A	P_a	A
$A\uparrow_{14}\ i\ A\downarrow_{14}$	$A\uparrow\ i\ A\downarrow$	P_{smax}	R
E_{14}; uncertainty (k=2)	E	$\bar{P_s}$	$R\uparrow\ i\ R\downarrow$
$E\uparrow_{14}\ i\ E\downarrow_{14}$	$E\uparrow i\ E\downarrow$	U_{max}	$\bar{B}$
M_{14}; uncertainty (k=2)	M	$\bar{U}$	-
R_{14}; uncertainty (k=2)	R	-	-
$R\uparrow_{14}\ i\ R\downarrow_{14}$	$R\uparrow\ i\ R\downarrow$	-	-
B_{14}; uncertainty (k=2)	B	-	-
$\bar{B}_{14}$	$\bar{B}$	-	-

Table 2. Identical and similar parameters in the ISO 230-2: 2014 and VDI/DGQ 3441

ISO 230-2: 2014	VDI/DGQ 3441	Identical or similar
Mean bi- directional positional deviation of an axis, M_{14} $M_{14}=max[\bar{x}_i]-min[\bar{x}_i]$	Positional deviation, P_a $P_a=\left\|\bar{\bar{x}}_{jmax}-\bar{\bar{x}}_{jmin}\right\|$	*Identical*- The difference beatween the maximum and minimum averaged positional deviation over the forward and reverse directions.
Mean Reversal value of an axis, $\bar{B}_{14}$ $\bar{B}_{14}=\frac{1}{m}\sum_{i=1}^{m}B_i$ Where:$B_i=\bar{x}_i\uparrow-\bar{x}_i\downarrow$	Mean Reversal Error, $\bar{U}$ $\bar{U}=\frac{1}{m}\sum_{i=1}^{m}U_i$ Where:$U_i=\left\|\bar{x}_i\uparrow-\bar{x}_i\downarrow\right\|$	*Similar*- Average reversal error Due to differences in the equation the values may very.
Reversal value of an axis $B_{14}=max[\left\|B_i\right\|]$	Max reversal error a position $U_{max}=max[U_j]$	*Identical*- Max reversal error.
Bi-directional accuracy of positiong of an axis, $A_{14}=max[\bar{x}_i\uparrow+2s_i\uparrow;\bar{x}_i\downarrow+2s_i\downarrow]-min[\bar{x}_i\uparrow-2s_i\uparrow;\bar{x}_i\downarrow-2s_i\downarrow]$	Positional Uncertainty, P $P=\left[\bar{\bar{x}}_j+\frac{1}{2}(U_j+P_{sj})\right]_{Max}$ -$\left[\bar{\bar{x}}_j-\frac{1}{2}(U_j+P_{sj})\right]_{Min}$	*Similar*- Maximum range of values based on mean positional errors, corresponding standard deviation and reversal errors along the axis.
Unidirectional repeatability of positiong of an axise, $R_{14}\uparrow$ or$R_{14}\downarrow$ $R_{14}\uparrow=max[4s_i\uparrow]$ $R_{14}\downarrow$=max$[4s_i\downarrow]$	Max Positional Scatter, P_{smax} $P_{smax}=P_{sjmax}=max[6\bar{s}_j]$	*Similar*- Indicates the maximum spread of data points that occurred at an individual target position. P_{smax} will always be larger then sither $R_{14}\uparrow$ or $R_{14}\downarrow$, as P_{smax} uses three times the standard deviation in its calculation while $R_{14}\downarrow$, only uses twice the standard deviation. P_{smax} is related to averaged deviation over the forward and reverse directions.
Repeatability of an axis, R_{14} $R_{14}=max[R_i]$	No equivalent parameter	If B_{14} and U are zero then $2/3P_{smax}$ shuld be similar to R_{14}. Otherwies it is expected that $\bar{U}+2/3P_{smax}$ should be similar to R_{14}.

Table 3. Identical and similar parameters in the ISO 230-2: 2014 and SRPS M.GO.101: 1991

ISO 230-2: 2014	SRPS M.GO.101 1991	Identical or similar
Mean Reversal value of an axis, $\bar{B}_{14}$ $\bar{B}_{14}=\frac{1}{m}\sum_{i=1}^{m}B_i$	Mean Reversal value of an axis, $\bar{B}$ $\bar{B}=\frac{1}{n}\sum_{j=1}^{n}B_j$	*Identical*- Average reversal error.
Bi-directional accuracy of positiong of an axis,$A_{14}=max[\bar{x}_i\uparrow+2s_i\uparrow;\bar{x}_i\downarrow+2s_i\downarrow]-min[\bar{x}_i\uparrow-2s_i\uparrow;\bar{x}_i\downarrow-2s_i\downarrow]$	Bi-directional accuracy of positiong of an axis, $A=max[\bar{x}_j\uparrow+3s_j\uparrow;\bar{x}_j\downarrow+3s_j\downarrow]$ $-min[\bar{x}_j\uparrow-3s_j\uparrow;\bar{x}_i\downarrow-3s_j\downarrow]$	*Similar*- but SRPS M.GO.101: 1991 uses three standard deviations in its calculations while the ISO 2014 uses two. A is expected to be greater than A_{14}.
Unidirectional repeatability of positiong of an axise, $R_{14}\uparrow$ or$R_{14}\downarrow$ $R_{14}\uparrow=max[4s_i\uparrow]$ $R_{14}\downarrow=max[4s_i\downarrow]$	Unidirectional repeatability of positiong of an axise, $R\uparrow\ or\ R\downarrow$ $R\uparrow=max[6s_j\uparrow]$ $R\downarrow=max[6s_j\downarrow]$	*Similar*- direct conversions between the two standards exist, $R_{14}\uparrow=2/3R\uparrow;R_{14}\downarrow=2/3R\downarrow$ Likewise, $R\uparrow=\frac{3}{2R_{14}}\uparrow;\ R\downarrow=3/2R_{14}\downarrow$

Repeatability of positioning of an axis, R_{14} $R_{14} = max[R_i]$ Where: $R_i = [2s_i \uparrow +2s_i \downarrow +\lvert B_i \rvert; R_i \uparrow; R_i \downarrow]$	Repeatability of positioning of an axis, R $R = max[R_j]$ Where: $R_j = [3s_j \uparrow +3s_j \downarrow +\lvert B_j \rvert; R_j \uparrow; R_j \downarrow]$	*Similar*- based on same concept, however SRPS M.G0.101: 1991used three standard deviation in its calculation as opposed to two standard deviation used in ISO 230-2: 2014. R će will be bigger than R_{14}.

Table 4. Identical and similar parameters in the SRPS M.G0.101: 1991 and VDI/DGQ 3441

SRPS M.G0.101 1991	VDI/DGQ 3441	Identical or similar
Mean Reversal value of an axis, $\bar{B}$ $\bar{B} = \frac{1}{n}\sum_{j=1}^{n} B_j$ Where: $B_j = \bar{x}_j \uparrow - \bar{x}_j \downarrow$	Mean Reversal Error, $\bar{U}$ $\bar{U} = \frac{1}{m}\sum_{j=1}^{m} U_j$ Where: $U_j = \lvert \bar{x}_j \uparrow - \bar{x}_j \downarrow \rvert$	*Similar*- Average reversal error. Due to slight differences in the equations the values may vary.
Bi-directional accuracy of positiong of an axis, $A = max[\bar{x}_j \uparrow +3s_j \uparrow; \bar{x}_j \downarrow +3s_j \downarrow] - min[\bar{x}_j \uparrow -3s_j \uparrow; \bar{x}_i \downarrow -3s_j \downarrow]$	Positional Uncertainty, P $= \left[\bar{\bar{x}}_j + \frac{1}{2}(U_j + P_{sj})\right]_{Max}$ -$\left[\bar{\bar{x}}_j - \frac{1}{2}(U_j + P_{sj})\right]_{Min}$	*Similar*- Maximum range of values based on mean positional error and corresponding standard deviations about each target position. As the positional uncertainty, P uses the averaged standard deviation over the forward and reverse directions it is expected to be slightly smaller than the bi-directional accuracy, A.
Unidirectional repeatability of positiong of an axise, $R \uparrow$ or $R \downarrow$ $R \uparrow = max[6s_j \uparrow]$ $R \downarrow = max[6s_j \downarrow]$	Max Positional Scatter, P_{smax} $P_{smax} = P_{smax} = max[6\bar{s}_j]$	*Similar*- Indicates the maximum spread of data points that occurred at an individuals target position. As P_{smax} is based on the averaged standard deviation it is expected to bi slightly smaller than $R \uparrow$ or $R \downarrow$.
Repeatability of positioning of an axis, R $R = max[R_j]$ Where: $R_j = [3s_j \uparrow +3s_j \downarrow +\lvert B_j \rvert; R_j \uparrow; R_j \downarrow]$	No equivalent parameter.	If B and U are zero then P_{smax} should be similar to R. Otherwise it is expected that $\bar{U} + P_{smax}$ should be similar to R.

From optical components for measurement of positioning accuracy are used: remote interferometer (Figure 2a) and remote reflector (Figure 2b).

Figure 2. a) Interferometer b) Reflector

For the purpose of collecting and processing the results, laser measuring system HP 5526 add certain hardware components, such as computer and digital parallel / serial interface are used. Based on the analysis of selected standards for examination the accuracy of the positioning machine tools is developed software for examination the accuracy of positioning numerically controlled machine tools within the programming language "MATLAB". Results can be displayed numerically or graphically within the software.

4. TESTING METHODOLOGY

The methodology of testing the accuracy of positioning numerically controlled machine tools has been adopted in accordance to VDI / DGQ 3441 standard. The standards such as SRPS M.G0.101: 1991 and ISO 230-2: 1988, as well as newer version of standardsare very similar in terms of examination methodology.

According to VDI / DGQ 3441 standard, examination the accuracy of positioning is done at no load and temperature steady state of the machine tools.

On the control unit of the machine is programmed to move the executive body ie. slide along the axis of the test. This movement can be performed by linear cycle or a cycle of steps (Figure 3). In the recommendation VDI / DGQ 3441 standard this is not defined, while SRPS M.G0.101 1991 standardrecommended the two cycles of movement during testing positioning accuracy. In examining the positioning accuracy machining center FM 38 is used a linear movement cycle.

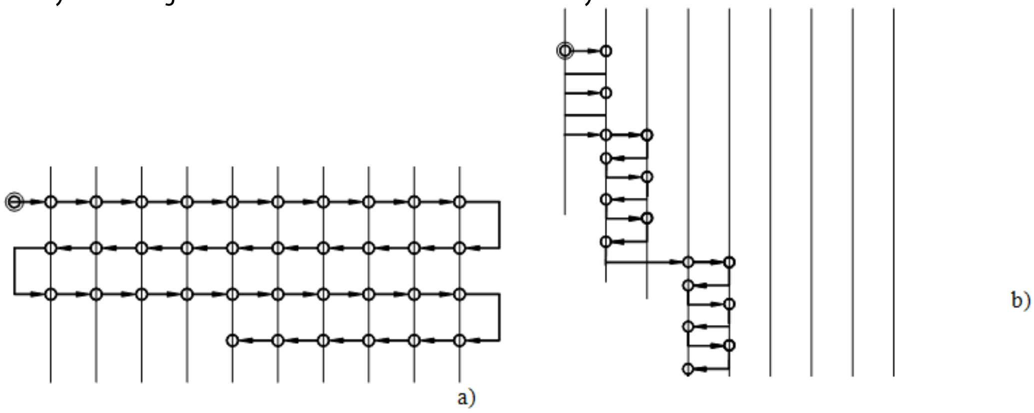

Figure 3. Standard examination cycles when testing the accuracy of positioning:(a) linear, (b) step by step

5. PRESENTATION OF RESULTS

The measurement accuracy of positioning is performed on the milling machining center, which is installed in the Laboratory for Machine Tools at the Faculty of Technical Sciences. The examination was performed when setting the parameters in the control system Sinumerik 840 D machining center. In the mentioned settings above, first set appropriate parameters after "bol-bar" examination, and then set parameters after examination the accuracy of the positioning. Tables 5, 6 and 7 show evaluated results in the direction of all three axes, at the end of the setup process parameters in the control system. Direct loaded values from display (LMS) to the computer using the appropriate interfaces are not given in these tables, neither are given deviation from the programmed value, but they provide processed data according to certain standards. The reason is limitation of space. Graphical interpretation of results for the X axis is shown in Figures 4, 5, 6 and 7.

Table 5. Examination results for X - axis (milling machining center FM 38)

VDI/DGQ 3441		SRPS M.GO.101		DIN ISO 230-2		ISO 230-2	
P	25,682	A	25,5121	A	19,0315	A	19,0315
P_a	6,26	$\overline{B}$ (B_{sr})	1,022	A↑ (A_d)	18,6344	A↑ (A_d)	18,6344
$\overline{P}_S$ (P_{srs})	18,643	R↑ (R_d)	21,4117	A↓ (A_l)	19,0315	A↓ (A_l)	19,0315
P_{smax}	19,4825	R↓ (R_l)	19,0286	E	6,96	E	6,96
$\overline{U}$ (U_{sr})	1,146	R	21,396	E↑ (E_d)	5,78	E↑ (E_d)	5,78
U_{min}	0,18	x	x	E↓ (E_l)	6,92	E↓ (E_l)	6,92
U_{max}	2,2	x	x	M	6,26	M	6,26
x	x	x	x	R	14,9974	R	14,9974
x	x	x	x	R↑ (R_d)	14,2745	R↑ (R_d)	14,2745
x	x	x	x	R↓ (R_l)	12,6857	R↓ (R_l)	12,6857
x	x	x	x	B	2,2	B	2,2
x	x	x	x	$\overline{B}$ (B_{sr})	1,022	$\overline{B}$ (B_{sr})	1,022

Table 6. Examination results for Y- axis (milling machining center FM 38)

VDI/DGQ 3441		SRPS M.GO.101		DIN ISO 230-2		ISO 230-2	
P	30,1049	A	30,4866	A	28,311	A	28,311
P_a	22,61	$\overline{B}$ (B_{sr})	4,7	A↑ (A_d)	25,1021	A↑ (A_d)	25,1021
$\overline{P}_S$ (P_{srs})	6,81848	R↑ (R_d)	8,13216	A↓ (A_l)	28,311	A↓ (A_l)	28,311
P_{smax}	7,53757	R↓ (R_l)	7,16743	E	23,96	E	23,96
$\overline{U}$ (U_{sr})	5,144	R	14,5356	E↑ (E_d)	21,26	E↑ (E_d)	21,26
U_{min}	0,48	x	x	E↓ (E_l)	3,96	E↓ (E_l)	3,96
U_{max}	7,26	x	x	M	22,61	M	22,61
x	x	x	x	R	12,0771	R	12,0771
x	x	x	x	R↑ (R_d)	5,42144	R↑ (R_d)	5,42144
x	x	x	x	R↓ (R_l)	4,77828	R↓ (R_l)	4,77828
x	x	x	x	B	7,26	B	7,26
x	x	x	x	$\overline{B}$ (B_{sr})	4,7	$\overline{B}$ (B_{sr})	4,7

Table 7. Examination results for Z- axis (milling machining center FM 38)

VDI/DGQ 3441		SRPS M.GO.101		DIN ISO 230-2		ISO 230-2	
P	12,5399	A	13,5448	A	12,5232	A	12,5232
P_a	8,46	$\overline{B}$ (B_{sr})	1,264	A↑ (A_d)	12,5232	A↑ (A_d)	12,5232
$\overline{P}_S$ (P_{srs})	2,29717	R↑ (R_d)	4,35982	A↓ (A_l)	7,09968	A↓ (A_l)	7,09968
P_{smax}	4,98743	R↓ (R_l)	7,14626	E	10,48	E	10,48
$\overline{U}$ (U_{sr})	2,08	R	7,60743	E↑ (E_d)	10,48	E↑ (E_d)	10,48
U_{min}	1,62	x	x	E↓ (E_l)	6,44	E↓ (E_l)	6,44
U_{max}	2,62	x	x	M	8,46	M	8,46
x	x	x	x	R	5,94496	R	5,94496
x	x	x	x	R↑ (R_d)	2,91454	R↑ (R_d)	2,91454
x	x	x	x	R↓ (R_l)	4,71084	R↓ (R_l)	4,71084
x	x	x	x	B	2,62	B	2,62
x	x	x	x	$\overline{B}$ (B_{sr})	1,264	$\overline{B}$ (B_{sr})	1,264

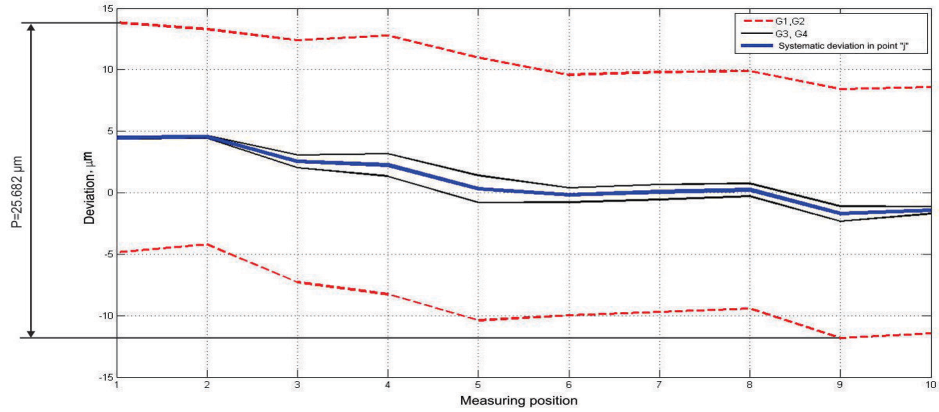

Figure 4. Graphical representationof the positioning accuracy X-axes according to VDI/DGQ 3441 standard

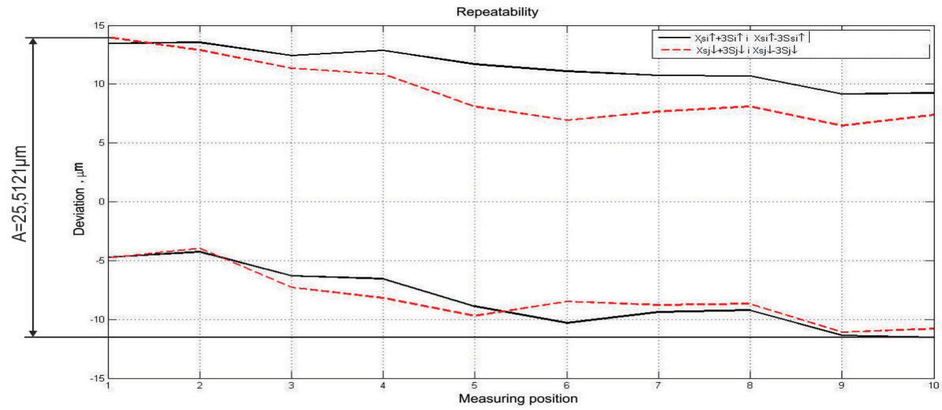

Figure 5. Graphical representation of the positioning accuracy X-axes according to SRPS M.GO.101standard

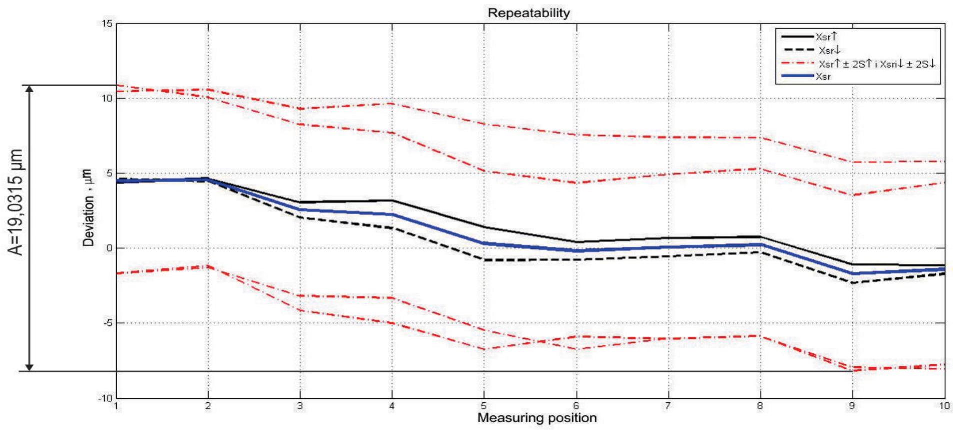

Figure 6. Graphical representation of the positioning accuracy X-axes according to DIN ISO 230-2standard

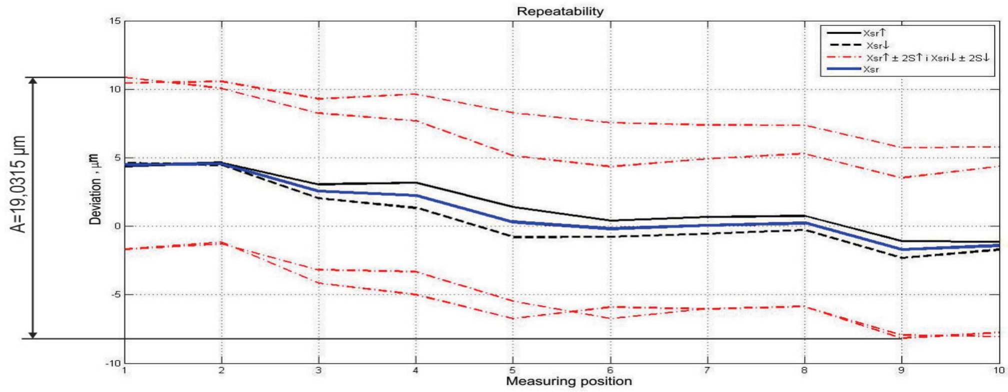

Figure 7. Graphical representation positioning accuracy X-axes according to ISO 230-2standard

For each measurement are unavoidable measurement error. Size of errors depends on the measured device, conditions in which the measurement is performed, as well as the knowledge and skills of the person who performed the measurement. As with other examinations and in examining the accuracy of positioning is necessary to define the environmental conditions and the condition of the machine tools in order to eliminate measurement errors as much as possible. Automatic compensator provides a fair compensation for the change in wavelength due to changes in environmental conditions (temperature, pressure and relative humidity), and compensation for dilatation machine parts due to changes in temperature materials, and for that size when calculating measurement uncertainty takes the value 0. Shown below is the measurement uncertainty (Table 7) for all three axis machining center with the calculated measurement uncertainty according to ISO 230-2: 2014 standard. Based on the analysis of the calculated values, it can be concluded that the same, since when calculating the number rounded on two decmale, differences in individual values occurs on the fifth decimal place, which is negligible, because all calculated values in micrometers.

Table 8. Measurment uncertainty for X, Y and Z axis

	X axis				Y axis				Z axis			
	Value	Unit	U	Unit	Value	Unit	U	Unit	Value	Unit	U	Unit
Measurment length	305	mm			216	mm			270	mm		
U_{device}			0,1	µm			0,1	µm			0,1	µm
$R_{misalignment}$	1	mm			1	mm			1	mm		
$U_{misalignment}$			0,0010	µm			0,0014	µm			0,0011	µm
$U_{M,machine\ tool}$			0	µm			0	µm			0	µm
$U_{M,\ device}$			0	µm			0	µm			0	µm
U_{VE}	1,7	µm			1,7	µm			1,7	µm		
U_{EVE}			1,02	µm			1,02	µm			1,02	µm
$U_{R+,R-}$			2,04	µm			2,04	µm			2,04	µm
U_B			0,92	µm			0,92	µm			0,92	µm
U_R			2,24	µm			2,24	µm			2,24	µm
$U_{E,E+,E-}$			0,47	µm			0,47	µm			0,47	µm
U_M			0,34	µm			0,34	µm			0,34	µm
U_A			2,09	µm			2,09	µm			2,09	µm

Comparing these standards can be concluded that the positioning accuracy of CNC machine tools defines the maximum parameters according to DIN ISO 230-2 standard, with at least according to SRPS M.G0.101 standard. It should also have in mind that the majority of manufacturers of CNC machine tools information on the positioning accuracy displayed, as recommended, by VDI / DGQ 3441 standard. In processing the results of measurements of all standards used by certain statistical method, whereby the difference in the end results is a consequence of the applied statistical methods and types of errors are taken into account. Considering the fact that most manufacturers of CNC machine tools display the characteristics of the machines according to VDI / DGQ 3441 standard adopted these results as a "benchmark" and on the basis of their estimated relative difference results according to other standards. Deviation values according to different standards are not omit, range from a few percent to 30%. The above indicates that in conclusions about the accuracy of some CNC machine tools from the point positioning accuracy must have in mind the standard - recommendations on which estimation was done. It is also obvious that they can be compared only the results obtained by applying the same standards - recommendations.

The calculated measurement uncertainty for X, Y and Z axis is the same and it is very small, so it can be concluded that the measuring equipment is very accurate. Nevertheless, a small measurement uncertainty contributes to the application of the automatic compensator, which automatically compensates for ambient influences.

6. CONCLUSION

The problems exposed in this paper is to examine the positioning accuracy of machine tools. Due to the low value deviations positioning accuracy on machines with numerical control such tests can be made only by laser measuring systems.

The main objective of the examinationperformed is to achieve satisfactory positioning accuracy for all three axes of examination machining center. According to the available standards and recommendations of the allowable value is not defined parameter deviations positioning for certain types of machine tools, and therefore the adjustment of these machines was done in order to minimize the range value aberrations positioning and values of systematic and random errors in the direction of the investigated axis. The first examination is always carried out without correction entered in the control unit of the machine, and then according to the measurement results, subscribed correction at each point. Since the examination was done in several steps, due to the extensiveness, not shown results that preceded the results are given as final.

The calculated measurement uncertainty for X, Y and Z axis is the same and it is very small, so it can be concluded that the measuring equipment is very accurate. Nevertheless, a small measurement uncertainty contributes to the application of the automatic compensator, which automatically compensates for ambient influences.

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NOMENCLATURE

$A\uparrow; A\downarrow$ Unidirectional Accuracy of positioning of an Axis

A Bidirectional Accuracy of positioning of an Axis

$E\uparrow; E\downarrow$ Unidirectional systematic positional deviation of and axis

EBidirectional systematic positional deviation of an axis

M Mean bidirectional positional deviation of an axis, M

B Reversal value of an axis

$R\uparrow; R\downarrow$ Unidirectional repeatability of positioning

R Bi-directional repeatability of positioning of an axis

$\bar{x}_i\uparrow; \bar{x}_i\downarrow$Mean unidirectional positional deviation at a target position

$\bar{x}_i$ Mean bidirectional positional deviation at a position

$s_i\uparrow; s_i\downarrow$Estimator for the unidirectional axis repeatability of positioning at a target point

$\bar{B}$ Mean reversal error

P_{smax}Maximum positional scatter

U_{max}Maximum reversal error at a position

$\bar{U}$ Mean reversal error

P_a Positional

P Positional

$\bar{\bar{x}}_j$ System Deviation from the desired value at a target position

$\bar{s}_j$ Mean standard deviation at a target position

U_{device} -is the expanded uncertainty due to the measuring device

$R_{misalignment}$is the misalignment

$U_{misalignment}$ is the expanded measurement uncertainty due to misalignment

$U_{M,machine\ tool}$ is the expanded measurement uncertainty due to temperature measurement of the machine tool

$U_{M,\ device}$ is the expanded measurement uncertainty due to temperature measurement of the measuring device

U_{VE} is the range from the environmental variation error test

$U_{EVE}$is the expanded measurement uncertainty due to environmental variation

$U_{R+,R-}$ is the expanded uncertainty of the unidirectional repeatabilit y, k = 2, for five measument runs

$U_B$is the expanded measurement uncertainty of reversal error, k = 2, for one measurement run

$U_R$is the expanded measurement uncertainty of bi-directional repeatabilit y, k = 2, for five measurement runs

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