Volumetric positioning accuracy of a vertical machining center equipped with linear motor drives (evaluated by the laser vector method)

O.Svoboda
Research Center of Manufacturing Technology, Czech Technical University in Prague, Czech Republic.

Abstract

The accuracy of machined workpieces represents the main criterion for every workshop. One of the most important contributing factors is the geometric accuracy of the machine tool.

Machines are nowadays equipped with control systems enabling engineers to perform various types of compensations. In the case of geometric compensations the question stands whether to apply only axial compensations or also inter-axial compensations. The article shows the differences in the geometric accuracy of a vertical machining center equipped with linear motor drives measured in three different statuses. The machine tool was checked by the classical method according to the ISO 230-2 standard in different positions within the working volume in each axis and also by the sequential diagonal measurement technique determining the diagonal positioning accuracy. The three statuses are represented firstly by the machine tool without compensations, secondly by the machine tool compensated from an ISO 230-2 measurement and thirdly by the machine tool volumetrically compensated from a sequential diagonal measurement.

1 Introduction

The laser vector technique introduced by Charles Wang from the Optodyne company in [1] enables engineers to perform an analysis from the data obtained during a sequential diagonal measurement of the positioning accuracy. The practical measurement is provided by a laser interferometer attached to the table of the machine tool and a flat mirror clamped in the spindle (see Figure 1).

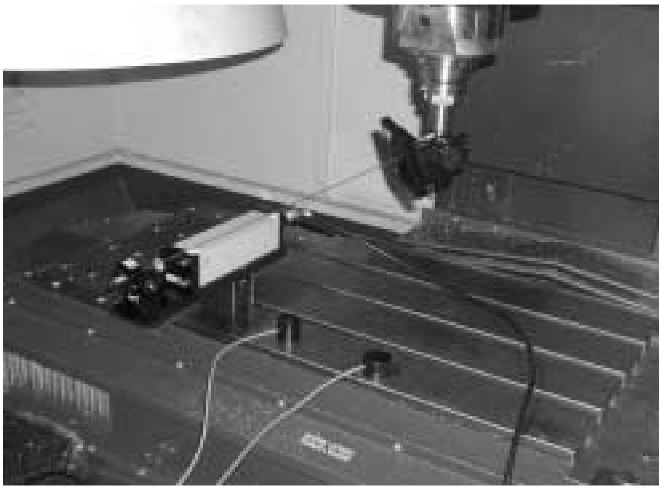

Figure 1: The diagonal measurement set-up

2 Theoretical interpretation of the measurement

According to the theoretical background of this method the measured volumetric error after each step of the sequence is influenced by three position error components. In the case of motion in the X-direction the error components are: $E_x(x)$, $E_y(x)$, $E_z(x)$. These components are sensitive to all the motion errors including the position error, two straightness errors and three angular errors.

It is possible to calculate and graphically display the course of the above mentioned error components for each axis after completing the whole measurement in four body diagonals of the working volume of the machine tool. In addition squareness errors in the xy, yz and xz planes can be evaluated. The measurement is in a direct relation with the ISO 230-6 standard, therefore the regular diagonal positioning errors are accessible for every diagonal and the parameters E_d (diagonal systematic deviation of positioning) and B_d (diagonal reversal value) may be calculated.

A direct output of the results is presented by the generation of compensation tables for various types of control systems. The main advantage lies in the possibility to perform inter-axis compensation between all the machine axes from a single measurement.

3 The measured machine

MCFV5050LN is the first Czech made machining center equipped with linear motor drives. A cross table with two driven axes X, Y and a vertically oriented spindle (Z-axis) form the structure of the machine. The strokes of each axis are as follows: X-axis 500mm, Y-axis 400mm, Z-axis 400mm. Drives were supplied by Siemens, type 1FN1.

Figure 2: Vertical machining center MCFV5050LN

The control system is SINUMERIC 840D, which enables axial and inter-axial compensation of positioning errors.

4 Results of measurements

4.1 Summary of performed measurements

The above-specified machine tool was measured in two different ways. Firstly by the sequential diagonal method and secondly each axis separately in the traditional way according to ISO 230-2 in different places within the working volume (see Figure 3).
First of all the machine was measured by both diagonal and ISO 230-2 method in a status when all geometrical compensations performed by the control system were disabled. This status is further stated as “raw machine”. The measurement according to ISO 230-2 was performed in the following positions for each axis:
X axis measured in position Y=200 mm, Z=100 mm
Y axis measured in position X=250 mm, Z=100 mm
Z axis measured in position X=250 mm, Y=200 mm
Six compensation tables for Sinumerik 840D were obtained from the results of this measurement. After their activation a second status of the machine tool further stated as “Classic compensation” was settled.

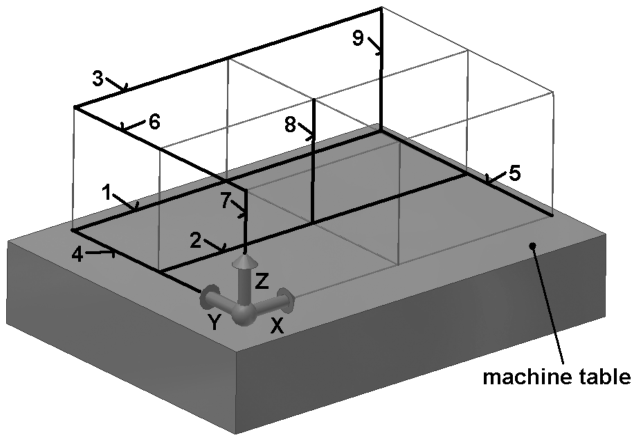

Figure 3: Overview of measured lines

The second step was measuring the raw machine by the sequential diagonal method, which yielded into the generation of 18 compensation tables. After their activation in the control system a third status of the machine tool was settled. This status is further stated as “Volumetric compensation”.

All the graphs displayed in the rest of this paper show results of measurements done for the three above specified statuses of the machine tool. A different colour shade and a different marker belong to each status.

4.2 The diagonal measurement

The machine tool was measured according to the sequential diagonal measurement technique separately for each status. The stroke of the Z-axis was reduced to 100-400 mm. Strokes of the X and Y-axis were nominal. The results are shown in Figure 4 and evaluated according to ISO 230-6 in Table 1.

Table 1: Evaluation of the volumetric accuracy parameters (according to ISO 230-6)

	Raw machine	Classical compensation	Volumetric compensation
E_d[µm]	59.8	58.4	38.4
B_d[µm]	2.6	1.8	2.1

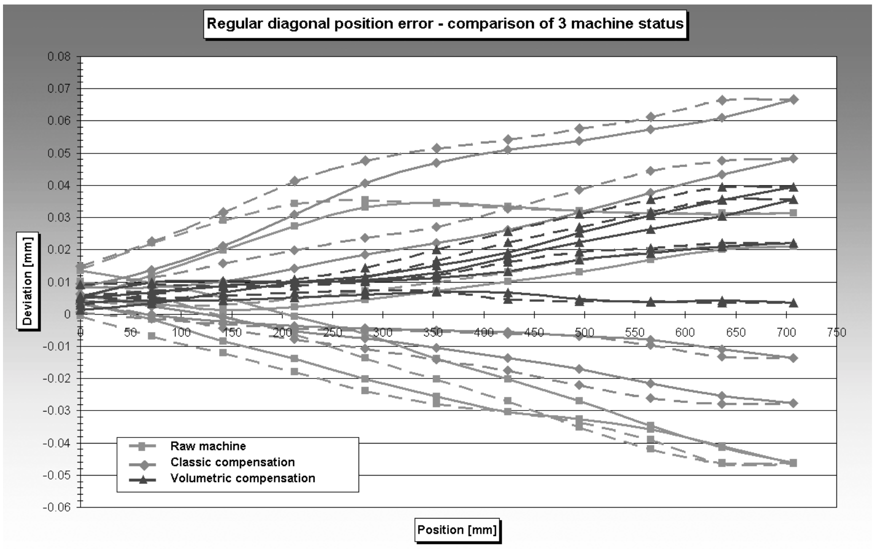

Figure 4: Positioning errors on the measured diagonals

It is evident that the raw machine shows the worst positioning accuracy on the body diagonals (E_d=59.8 µm). The activation of 6 compensation tables caused a slight improvement of the diagonal systematic deviation of positioning (E_d) and a remarkable improvement in the diagonal reversal value (B_d). A considerable improvement in the parameter E_d was achieved in case of the machine status with 18 active compensation tables. The difference in E_d value in comparison with the classical compensation is 34.3% and compared with the raw machine we get an improvement of 35.8%. It is also clearly visible from the graph in Figure 4 that especially the volumetrically compensated machine has the least deviations in most of the body diagonals.
According to the above mentioned facts we can assume the volumetric compensation has a positive effect on the improvement of diagonal positioning accuracy.

4.3 Positioning according to the ISO 230-2 standard

The following paragraphs bring an analysis of the positing accuracy in each axis in different positions. The plotted graphs comprise the three machine statuses in order to examine the effects of geometric compensation on the positioning accuracy and repeatability. It is expected that especially the inter-axis compensations should improve the positioning all over the working volume.

4.3.1 X-axis positioning accuracy

Figures 5, 6 and 7 show the results of measurements performed along lines 1, 2 and 3 (numbering according to the specification in Figure 3).

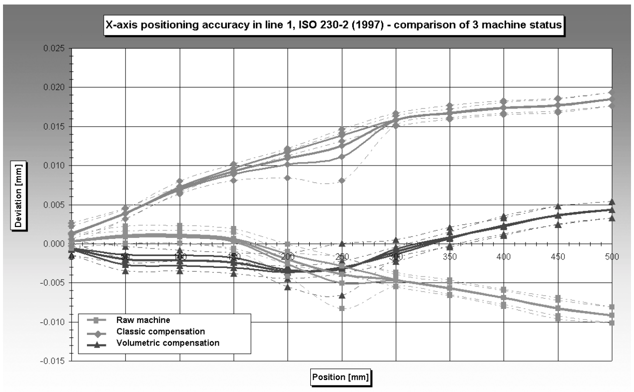

Figure 5: X-axis positioning accuracy in line 1

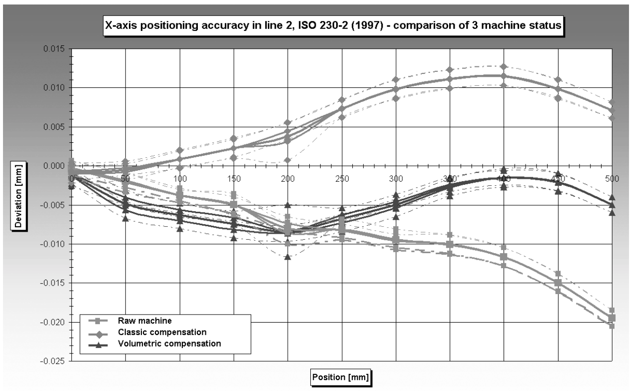

Figure 6: X-axis positioning accuracy in line 2

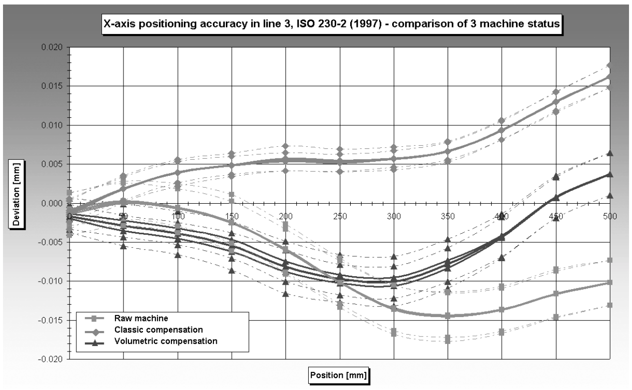

Figure 7: X-axis positioning accuracy in line 3

The positioning accuracy of the X-axis shows the worst results in the measured lines in case of the raw machine and the machine after compensation from the ISO 230-2 measurement. The maximal absolute deviations are approximately 25 µm in both cases, whereas the raw machine has mainly negative deviations and the compensated shows positive deviations. A reduction of the deviations to the range from +5 µm to -12 µm appeared after the activation of 18 compensation tables. Dependence on the measured position is evident. The volumetrically compensated and the raw machine achieved the best results in position Y=400 mm, Z=100 mm (line 1), whilst the machine with 6 active compensation tables shows in the same position the worst deviations.

4.3.2 Y-axis positioning accuracy

Figures 8, 9 and 10 show the results of measurements performed along lines 4, 5 and 6 (numbering according to the specification in Figure 3).

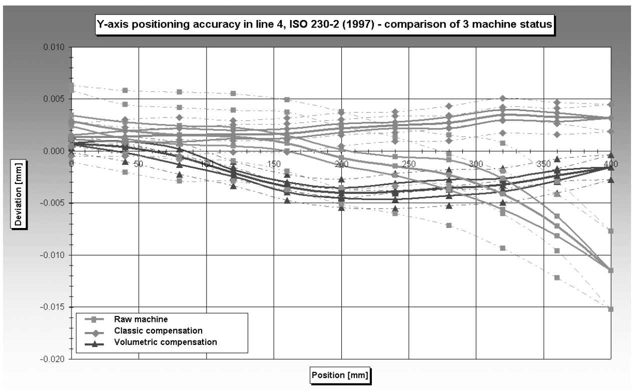

Figure 8: Y-axis positioning accuracy in line 4

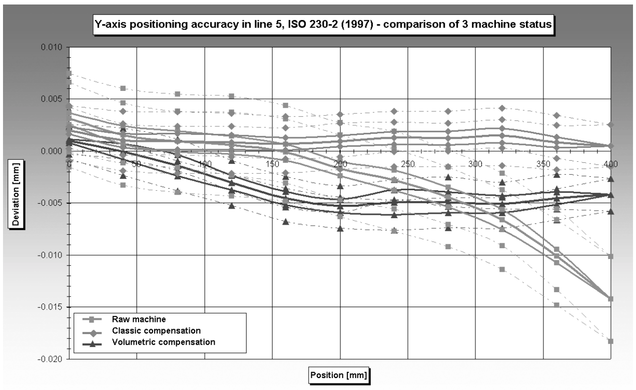

Figure 9: Y-axis positioning accuracy in line 5

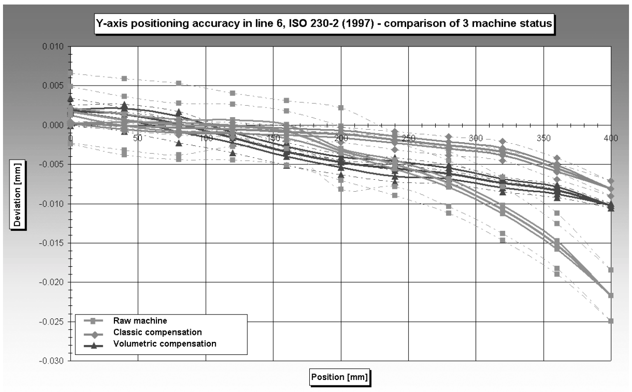

Figure 10: Y-axis positioning accuracy in line 6

The best positioning accuracy in the Y-axis was achieved by the classical compensation in all measured positions. Deviations vary from –5 µm to +5 µm. No significant dependence of the positioning accuracy on the location was found in the Z=100 mm plane in all machine statuses. An evident change of deviations' character from positive to negative occurred in case of the machine with 6 active compensation tables after moving to Z=400 mm. In contrast the volumetrically compensated machine kept the deviations' character in all positions and in all planes. The worst results were measured in position X=0 mm, Z=400 mm for all machine status.

4.3.3 Z-axis positioning accuracy

Figures 11, 12 and 13 show the results of measurements performed along lines 7, 8 and 9 (numbering specification from Figure 3). The positioning accuracy was measured in a reduced range from 110 mm to 400 mm of the full axis stroke.

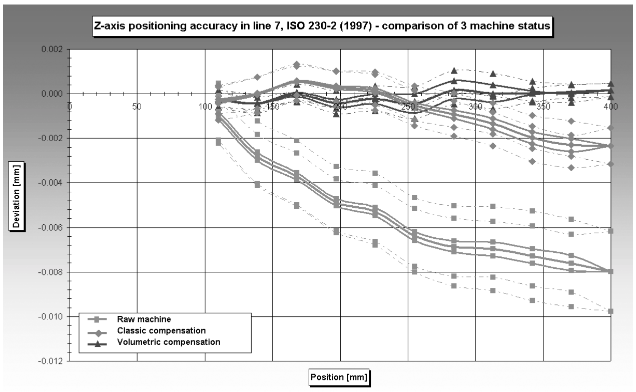

Figure 11: Z-axis positioning accuracy in line 7

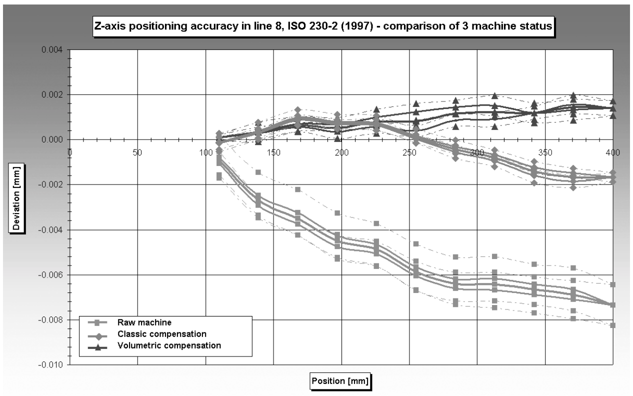

Figure 12: Z-axis positioning accuracy in line 8

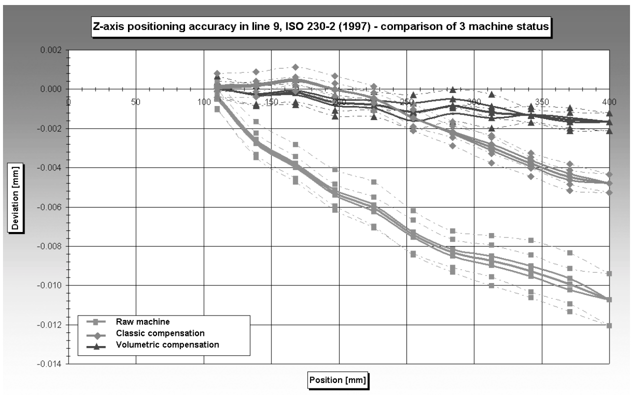

Figure 13: Z-axis positioning accuracy in line 9

The positioning accuracy in Z-axis doesn't differ significantly in various positions within the working volume. The raw machine has relatively significant positioning deviations in the range from 0 µm to –12 µm. Maximal deviations were measured in line 9 (X=500 mm, Y=400 mm), minimal errors are in line 8 (X=250 mm, Y=200 mm). The magnitude of deviations dropped to the range from +1 µm to –5 µm after the activation of six compensation tables. The most favourable course of errors is in this status in line 8. Further improvement of the machine tool positioning accuracy was reached after the volumetric compensation. Deviations in this machine status vary in all measured lines from +2 µm to –2 µm. The optimal curve was evaluated in line 7 (X=0 mm, Y=0 mm).

5 Conclusion

The laser vector method, respective of its practical output presented by 18 compensation tables, helped to achieve better results of positioning accuracy in the whole machine volume of the MCFV5050LN machining center. The positive effect of the inter-axial compensations on the volumetric accuracy was therefore verified for this configuration of the machine tool.

When classifying the positioning accuracy by the ISO 230-6 standard the vector method caused a reduction of deviations approximately 35% compared with the uncompensated and classically compensated machine.

Different results in each axis were obtained when measuring the machine according to ISO 230-2 in various positions of the working volume. The vector method gives the best results in all measured positions in the X and Z-axis. In case of the Y-axis the classical compensations give the least deviations in lines 5 and 6.

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References

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