STRAIGHTNESS EXAMINATION OF CMM AXES

Received: 27 September 2015 / Accepted: 20 November 2015

Abstract: It is generally known that the parts with tight tolerances can only be measured on precise, or accurate measuring machines. Accuracy is one of the indicators of quality of measuring equipment. By controlling the parameters of accuracy from the very beginning of machine life cycle, it is possible to maintain the permissible limits of its quality characteristics. The straightness deviation represents line flow in two perpendicular planes. The straightness is one of the essential characteristics of exploitation that must be strictly controlled. Measurement of straightness is applied in many areas such as manufacturing and testing of precision instruments, measuring dimensions of large objects, assembly and adjustment of large equipment.

In this paper, the emphasis is placed on the straightness of the numerically controlled measuring machines (CMM) elements movement along the X and Y axes. The measurement is carried out by laser measuring system (LMS).

Key words: CMM, Straightness, Laser measuring system

1. INTRODUCTION

The paper describes numerically controlled measuring machines, and presents some of experimental results obtained during the straightness examination of coordinate measuring machine elements along the X and Y axes, on the example of Carl Zeiss Contura G2. All results are presented graphically.

Methods for determining the work table moving straightness can be realized by measuring the angle deviation or lateral displacement of the table during the movement. An auto-collimator, precision level, or laser interferometer can be adopted to determine the angle deviations, whereas a straightedge, taut-wire and microscope, alignment telescope, four-quadrant photodetector, or laser interferometer can be used to determine the lateral displacements.

Although some other methods have been proposed, the laser interferometer for lateral displacement measurements is widely used due to the advantages of high signal to noise ratio, high linearity, high resolution, non-contact, and direct measurement. Laser interferometer was used in the experiment, which was carried out in this paper.

Numerically controlled measuring machines are complex metrology systems. Key elements for the development of CMM are computers, sensors and micro electrical engineering. Numerically controlled measuring machines have two primary applications. The first application of CMM is for measuring and control of all types of tolerance, and second is for adaptive conformity quality management.

The basic characteristics of CMM are [1]:
- Metrological universality
- High resolution, accuracy and reliability compared to conventional measurement technique
- High productivity
- Complete automation of almost all the work cycles
- High flexibility
- Low total cost of metrology process
- Relatively simple and quick preparation process, calibration, adjustable measuring objects, programming and handling CMM system

The parameters that determine the quality of a CMM are shown in Figure 1 [1].

![Fig. 1. Elements of CMM quality parameters [1]](image-url)
2. AXES STRAIGHTNESS

The straightness represents deviation of line flow in the two perpendicular planes (Figure 2). Figure 2a) and 2b) shows parameters of deviation from straightness and Figure 2c) shows the straightness measurement results.

In this way is obtained 6 straightness parameters:
- $A_{xy}$ - straightness of X axis measured in the Y direction
- $A_{xz}$ - straightness of Z axis measured in the X direction
- $A_{yx}$ - straightness of Y axis measured in the X direction
- $A_{xz}$ - straightness of X axis measured in the Z direction
- $A_{zy}$ - straightness of Z axis measured in the Y direction
- $A_{yz}$ - straightness of Y axis measured in the Z direction

By SRPS standard straightness testing includes:
- The line straightness in two planes
- The straightness of the machine parts (components)
- The straightness of movement (movement paths of machine elements)

Path straightness testing is crucial for examination the straightness of machines slide and base. The path straightness of the machine can be defined as parallelism of machine element movement trajectory and the reference line, which is parallel to a measured axis.

Testing can be done in several ways, such as trial by using a measuring ruler and measuring comparator, using stretched wire and a microscope, and using a laser alignment, or a laser interferometer.

As already mentioned, in this paper straightness is measured by the LMS. During the measurement the laser beam passes through the interferometer (Wollaston prism) and being separates in two beams at an angle $\theta$. These beams are normally deducted from the reflector and return to the laser head, passing through the interferometer, where they are again combined into a single beam. It should be noted that the reflector consists of two rigidly connected mirrors under precise angle. The lateral movement of the interferometer relative to the axis of the reflector is detected inside laser head, and sent to data recording device (Figure 3).

3. MEASURING INSTRUMENTS

Testing the straightness of above mentioned CMM (Carl Zeiss Contura G2) elements along the X and Y axes was carried out using a laser measuring system (LMS) 5526 A, produced by "Hewlett-Packard", with the accuracy of 0.5 µm/m ± 0.2 µm/m (Figure 4). This system consists of:
- Laser head (He-Ne gas laser)- 5500 C
- Automatic compensator- 5510A
- Laser display HP- 5505A
- Straightness adapter
- Optical components

Laser head 5500C is one of the first HP laser for metrology which has an integrated optical receiver for the return laser beam [4-6].

Automatic compensator 5510 A is used to correct the influence of environmental factors such as temperature, humidity and air pressure. These factors are measured by using the appropriate sensors connected to the compensator.
Optical components for measuring straightness are used:

- **Straightness interferometer** (Figure 6), depending on the length of the measuring way can be used short range and long range interferometer. In this case is used short range interferometer that allows examination of straightness from 100 mm up to 30 m.

- **Straightness reflector** (Figure 6), as well as an interferometer, can be for a short and for a long range examination. It consists of a pair of flat mirrors rigidly connected under the precise angle. The difference between the short and long range straightness reflector is in the angle between mirrors. In this case, is used short range reflector.

![Straightness interferometer and straightness reflector](image)

**Fig. 6. Straightness interferometer and straightness reflector [4]**

4. STRAIGHTNESS TEST RESULTS OF THE MEASUREMENT SENSOR CARRIER MOVEMENT

To test the straightness of above mentioned CMM elements along the X and Y axes is used already described laser measuring system, while collecting and processing data are carried out with computer system.

Measuring the straightness of CMM elements moving along X direction is done in relation to the two planes XY and XZ plane. The only difference in these two measurements is in adjustment of the LMS, i.e. straightness reflector.

Total measuring way in the X direction is 700 mm, and the distance between the measuring position is Li = 70 mm. The movement of the measuring sensor carrier was performed using a PC, the measurement was performed in linear cycle (Figure 7), and the first passage is used to test the program. After this passage, measurements were carried out five times in both horizontal and vertical planes. Measured straightness values for measuring sensor movement along the X axis, measured relative to the Z axis, are shown in Table 1. The calculated values of deviations from straightness are shown in Table 2 and graphically in Figure 8.

![Segment of linear measuring cycle](image)

**Fig. 7. Segment of linear measuring cycle [7]**

Due to lack of space below will not be displayed measurement results and calculated values of deviations from straightness, but only graphical presentation. Figure 8 shows the deviation from straightness of the X axis in relation to Y.

![Graphical representation of deviation from straightness of the X axis in relation to Y](image)

**Fig. 8. Graphical representation of deviation from straightness of the X axis in relation to Y**

![Graphical representation of deviation from straightness of the X axis in relation to the Z axis](image)

**Fig. 7. Graphical representation of deviation from straightness of the X axis in relation to the Z axis**

Measuring the motion straightness of CMM elements in the Y direction is also carried out in relation to the two planes. Total measurement length is 800 mm, and the distance between the measuring positions are Li = 80 mm. The movement of the portal was performed using a PC, the measurement was also performed by linear cycles and the first pass is used to test the program. After this passage, measurements were carried out five times in the YX and YZ planes.

In Figures 9 and 10, are graphs showing deviation of the Y axis in relation to the X and Z axes.

![Graphical representation of deviation from straightness of the Y axis in relation to the Z axis](image)

**Table 1. The measured straightness for movement along the X axis**

<table>
<thead>
<tr>
<th>Index</th>
<th>I measur</th>
<th>II measur</th>
<th>III measur</th>
<th>IV measur</th>
<th>V measur</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0359</td>
<td>0.0372</td>
<td>0.0395</td>
<td>0.0407</td>
<td>0.0413</td>
</tr>
<tr>
<td>2</td>
<td>0.0416</td>
<td>0.0420</td>
<td>0.0425</td>
<td>0.0431</td>
<td>0.0438</td>
</tr>
<tr>
<td>3</td>
<td>0.0474</td>
<td>0.0480</td>
<td>0.0486</td>
<td>0.0491</td>
<td>0.0497</td>
</tr>
<tr>
<td>4</td>
<td>0.0532</td>
<td>0.0539</td>
<td>0.0546</td>
<td>0.0552</td>
<td>0.0558</td>
</tr>
<tr>
<td>5</td>
<td>0.0591</td>
<td>0.0598</td>
<td>0.0605</td>
<td>0.0612</td>
<td>0.0618</td>
</tr>
</tbody>
</table>

![Graphical representation of deviation from straightness of the Y axis in relation to the X and Z axes](image)

**Table 2. Calculated values of deviations from straightness**

<table>
<thead>
<tr>
<th>Index</th>
<th>Dedastur [rn]</th>
<th>Probula [rn]</th>
<th>Simbli ushitur [rn]</th>
<th>Dz [rn] [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.0359</td>
<td>0.0372</td>
<td>0.0395</td>
<td>0.0407</td>
</tr>
<tr>
<td>2</td>
<td>0.0416</td>
<td>0.0420</td>
<td>0.0425</td>
<td>0.0431</td>
</tr>
<tr>
<td>3</td>
<td>0.0474</td>
<td>0.0480</td>
<td>0.0486</td>
<td>0.0491</td>
</tr>
<tr>
<td>4</td>
<td>0.0532</td>
<td>0.0539</td>
<td>0.0546</td>
<td>0.0552</td>
</tr>
<tr>
<td>5</td>
<td>0.0591</td>
<td>0.0598</td>
<td>0.0605</td>
<td>0.0612</td>
</tr>
</tbody>
</table>

87
Data on deviation from straightness by individual axes are obtained based on the movement of coordinate measuring machine movable elements along the X and Y axes. Total deviation from straightness measured for the X axis is displayed spatially, and on the same chart are showed value variation in the two axes, Y and Z (Figure 11). Deviation from straightness along Y axis, relative to the axes X and Z, is displayed in the same way (Figure 12).

5. CONCLUSION

The application of numerically controlled measuring machines is becoming more common in modern industrial systems. To ensure the implementation of various CMM metrology tasks and high accuracy, the machine itself must possess a high level of quality.

The issues presented in this paper deals with examination of straightness of CMM elements motion. Since the value of the deviations from straightness on numerically controlled machines are very small, they can be carried out only by a laser measurement system.

Testing was performed by moving the measurement sensor along the X and Y axes, and the deviation from straightness is measured in the direction of Y, and Z axes, i.e. in the direction of X and Z axes.

Along the X axis with respect to the Y axis is obtained maximum deviation of -2.916 µm, and with respect to the Z axis is obtained deviation -1.584 µm.

The maximum values of deviations from straightness for movement along the Y axis, with respect to the X axis are 3.24 µm, and with respect to the Z axis 2.916 µm.

The obtained results show that the straightness of the machine is at a satisfactory level.

6. REFERENCES


ACKNOWLEDGEMENTS

The work is part of research project on "Modern approaches in the development of special bearings in mechanical engineering and medical prosthetics," TR 35025, supported by the Ministry of Education, Science and Technological Development, Republic of Serbia.

Authors: M.Sc. Mirjana Bojanić, Prof. dr Miodrag Hadžistević, M.Sc. Cvijetin Mladenović, University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia, Phone: +381 21 450-366, Fax: +381 21 454-495. E-mail: bojanicm@uns.ac.rs;miodrags@uns.ac.rs; mladja@uns.ac.rs.