MEASUREMENT OF LINEAR POSITIONAL ERROR AND STRAIGHTNESS ERROR BY LASER INTERFEROMETER

Rusnaldy [1)]

Abstract

This paper presents the results of measurement of linear positional error and straightness error of a vertical machining center (VMC) using laser interferometer. The laser interferometry tests were performed to measure the linear positional error and straightness error.

Keyword: Linear positional error, straightness error, laser interferometer

INTRODUCTION

Errors in machine geometry occur in all axes and are composed of three translational and three rotational components per axis. There are also orthogonality and parallelism errors between axes [1]. Errors will always exist in machine performance after it built and tested.

Linear positional error and straightness error are aspect of positional precision. The laser interferometer is ideal for measuring positional and straightness precision, since it satisfies the second principle of measurement, i.e non-contact methods of measurement are preferable to contact methods [2].

In this work, the Laser Interferometry tests were performed to measure the linear positional error, and straightness error.

LINEAR MEASUREMENTS

The design of the Renishaw ML10 Laser Interferometer System is shown schematically in Figure 1. The data can be seen in figure 2.

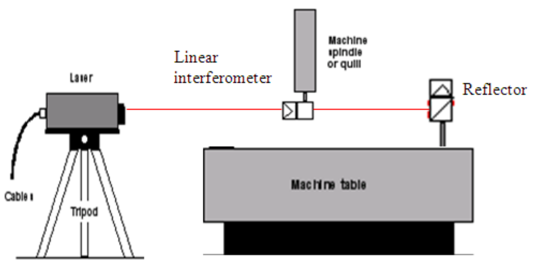
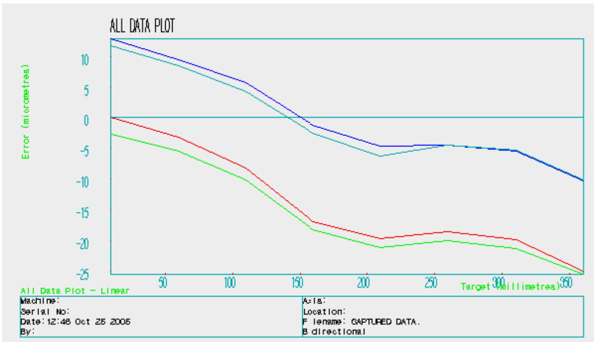


Figure 1. Laser interferometer measurement

We used a linear interferometer optic that is combined with the laser head. The laser head is then mounted on a separate tripod. Machine table moved toward to laser head (forward) and moved backward every 50 mm (from 10 to 360 mm). The zero point was set as starting point (initial point) of reflector on the machine table.

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RENISHAW CALIBRATION INTERFEROMETER SYSTEM
All Data

Machine:                              Serial No:
Date:12:46 Oct 25 2005                By:
Axis:                                 Location:
TITLE:                                Filename: CAPTURED DATA.RTL

Units of data values are micrometres

Target   1 (+) (  10.0000 millimetres)
    1)  12.9          2)  11.8
Target   1 (-)
    1) -2.7           2)  0.0

Target   2 (+) (  60.0000 millimetres)
    1)  9.5           2)  8.5
Target   2 (-)
    1) -5.5           2) -3.1

Target   3 (+) ( 110.0000 millimetres)
    1)  5.7           2)  4.3
Target   3 (-)
    1) -10.1          2) -8.2

Target   4 (+) ( 160.0000 millimetres)
    1) -1.2           2) -2.6
Target   4 (-)
    1) -18.2          2) -16.9

Target   5 (+) ( 210.0000 millimetres)
    1) -4.7           2) -6.3
Target   5 (-)
    1) -21.2          2) -19.7

Target   6 (+) ( 260.0000 millimetres)
    1) -4.5           2) -4.5
Target   6 (-)
    1) -20.1          2) -18.6

Target   7 (+) ( 310.0000 millimetres)
    1) -5.5           2) -5.3
Target   7 (-)
    1) -21.4          2) -19.9

Target   8 (+) ( 360.0000 millimetres)
    1) -10.3          2) -10.2
Target   8 (-)
    1) -25.5          2) -25.0
```

Figure 2. Test results of linear error

Note :

Blue line : Test 1 (forward)

Light blue line : Test 2 (forward)

Green line : Test 1 (backward)

Red line : Test 2 (backward)

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It has been observed that as the distance between reflector and linear interferometer increases the linear error also increases. The maximum error was found at starting point of reflector.

STRAIGHTNESS MEASUREMENTS

The straightness of a workpiece is one of the most important common standards used to determine its profile accuracy. Basically, straightness error originates from straight-going motion error, variation in cutting quantities and thermal distortion coming from machine tools and the manufactured workpiece.

Rigid body models of machine components can be seen in figure 3.

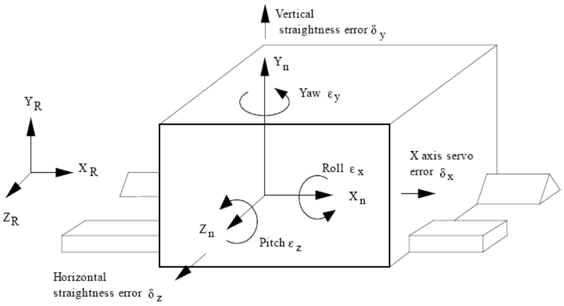

Figure 3. Rigid body models of machine components

The Renishaw Laser System uses a straightness interferometer to measure horizontal or vertical straightness (flatness). **Straightness** is defined as the variation in the horizontal (*y*) direction over the length of travel. This variation may result from bending and misalignment of the bearing ways, in addition to the causes mentioned above. **Flatness** is a term used to refer to the variation in the vertical (*z*) direction over the length of travel. The variation may come from machining inaccuracies in the bearing structure, dirt and contamination, or accurate motion.

The laser system measures relative changes in the lengths L_1 and L_2, and from this computes the straightness error, as shown in Figure 4.

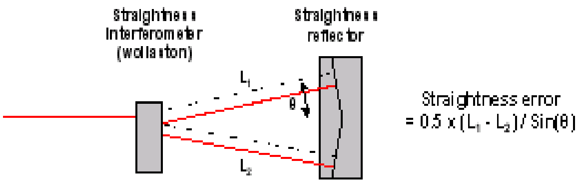

Figure 4. Straightness measurement

In this experiment, we measured the horizontal and vertical straightness. And the results can be seen in figure 5 and 6 for horizontal and vertical straightness respectively.

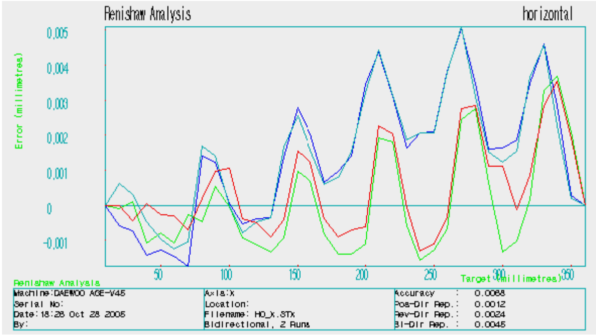

Figure 5. Horizontal Straightness

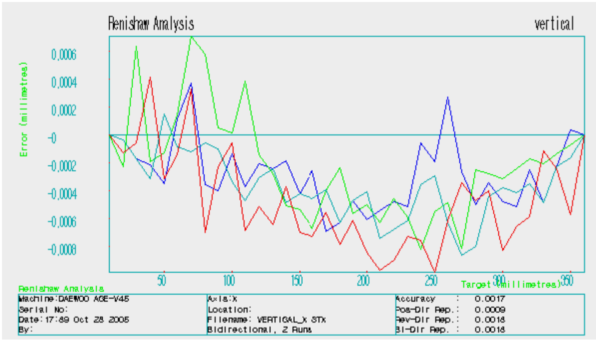

Figure 6. Horizontal Straightness

Note :
Blue line : Test 1 (forward)
Light blue line : Test 2 (forward)
Green line : Test 1 (backward)
Red line : Test 2 (backward)

The error range for flatness and horizontal straightness are 0.00004 – 0.00087 mm and 0.00006 – 0.00504 mm respectively. It was found that the horizontal straightness error is bigger than the flatness error.

THE THREE ERROR COMPONENTS USING HOMOGENEOUS TRANSFORMATION MATRIX (HTM) METHOD

All rigid bodies have three rotational (ε_x, $\varepsilon_y, \varepsilon_z$) and three translational (δ_x, δ_y, δ_z) error components associated with their motion as shown in figure 3. Consider the case of an ideal linear motion carriage shown in figure 3., with x, y, z offsets of a, b, and c respectively. Its HTM with respect to a parallel Cartesian reference frame is :

$$R_{T_n} = \begin{bmatrix} 1 & 0 & 0 & a \\ 0 & 1 & 0 & b \\ 0 & 0 & 1 & c \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Translational errors δ_x, δ_y, and δ_z directly affect their respective axes. Having neglected second order terms, the resultant HTM describing the error in position of the carriage with respect to its ideal position is :

$$E_n = \begin{bmatrix} 1 & -\varepsilon_z & \varepsilon_y & \delta_x \\ \varepsilon_z & 1 & -\varepsilon_x & \delta_y \\ -\varepsilon_y & \varepsilon_x & 1 & \delta_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The actual HTM for the linear motion carriage with errors is thus

$$R_{T_{nerr}} = R_{T_n}.E_n$$

$$R_{T_{nerr}} = \begin{bmatrix} 1 & -\varepsilon_z & \varepsilon_y & a+\delta_x \\ \varepsilon_z & 1 & -\varepsilon_x & b+\delta_y \\ -\varepsilon_y & \varepsilon_x & 1 & c+\delta_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The straightness errors were measured by translating the carriage by amount 360 mm along the X axis (a= 360 mm, b=0, c=0). From the results we got the absolute average of $\delta_y =$ 0.00034 mm and $\delta_z =$ 0.00177 mm

$$R_{T_{nerr}} = \begin{bmatrix} 1 & 0 & 0 & 360 \\ 0 & 1 & 0 & 0.00034 \\ 0 & 0 & 1 & 0.00177 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The new position for x, y, z after translating of 360 mm along X axis is x' = 360 mm, y' = 0.00034 mm and z' = 0.00177 mm.

CONCLUSIONS

A laser interferometer was used for evaluating the linear position and straightness error of a vertical machining center (VMC). The results show that he maximum value of linear error was found at starting point of reflector and it was found that the horizontal straightness error is bigger than the flatness error.

REFERENCES

1. Slocum, A.H, *Precision Machine Design*, Society of Manufacturing Engineers, USA, 1992
2. Nakazawa, H, *Principles of Precision Engineering*, Oxford, University Press, USA, 1994