

CALIBRATION OF OPTICAL MEASURING MACHINE USING LASER INTERFEROMETER

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ABSTRACT

Laser interferometry is a well-established method for measuring distances with high accuracy. The Renishaw XL laser measurement system enables the complete calibration of machine tools, coordinate machine and other position sensitive systems. Allowing the measurement of a wide range of geometric and dynamic machine characteristics and has many variety applications in scientific and engineering research. They offer the ultimate high accuracy, repeatable and traceable measurement. The system provides a number of different measurement options, using the different type of optics. Optical measuring machine up to 1000 mm manufacturer Carl Zeiss was calibrated with the Renishaw XL-80 laser measurement system. Laser XL-80 is used to determine linear positioning, angular (yaw and pitch) and straightness errors of machine axes, to check performance though targeted maintenance and correction for linear positioning errors using compensation unit XC80 which contain sensors for air humidity and air pressure as well as sensors for material temperature (up to three) and air temperature.

Keywords: calibration, laser interferometry, laser measurement system, optical measuring machine

1. LASER INTERFEROMETRY

Laser interferometer system can be used to determine linear positioning and straightness errors in machine axes, to improve performance through targeted maintenance and correction for linear positioning errors using error compensation (using sensors for measurement of air and material temperature, air humidity and air pressure). Although the technology has been developed over the years since, the basic principle of using the very small, stable and accurately defined wavelength of light as a unit of measure has remained [1]. Laser interferometers offer the ultimate in high accuracy, repeatable and traceable measurement, using externally mounted optical components [5].

2. LINEAR MEASUREMENT

In the laboratory for Production measurement of Mechanical Faculty Sarajevo was tested Universal measuring machine (UMM) up to 1m manufacturer Carl Zeiss with Renishaw XL80 laser system. The accuracy of the interferometer for linear measurement with the compensation unit is ± 0.5 ppm for the range from 0÷40 m with resolution of 0.001 μm . Testing methods used on UMM with laser system XL80 were linear, angular, and straightness measurement.

Laser system measures the linear deviation (position accuracy) and repeatability of the position by comparing the actual values on scale with the readings on the laser system [6]. Linear measurements use following optical elements: beam splitter, two linear reflectors, two targets and fixing elements.

Optical elements are placed at UMM as shown in Figure 1.

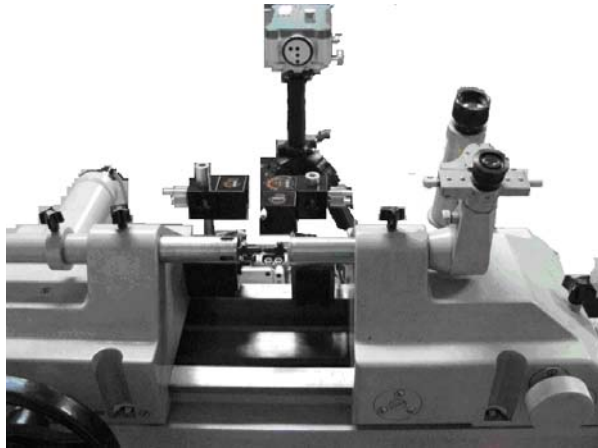


Figure 1. Optical elements on UMM

For measuring of linear positioning accuracy, there must be a relative linear motion of optical components one to another. Linear reflector on the beam splitter was fixed with two lock screws. This combination of elements is known as “linear interferometer” and in this way form a reference path for the laser beam. Usually reflector is used as a moving optical component, while the linear interferometer is used as a motionless optical component [5]. Those roles can be replaced, but this reduces the maximum the extent to which measurements can be performed, from 40 m to 15 m. Fixed optics - linear interferometer is mounted on guides of UMM and a movable optical retro-reflector is mounted on a slider tailstock of UMM. Coherent laser beam falls on the beam splitter. Beam splitter splits the beam into two beams. First beam (known as the reference beam) is directed towards the reflector connected to the beam splitter, while the other beam (measurement beam) passes through the beam splitter toward the second reflector. Reflected beams are meeting again in the beam splitter and directed in the detector located in the laser head. Because these beams come from the same, coherent, source, they will interfere. When the moving retro-reflector start to move, the frequency of the reflected beam in the measuring section is also changing. The detector counts the difference of frequency between the reflected beams. The measured value of displacement is calculated by:

$$L = f_p \cdot \frac{\lambda}{2} = N \cdot \frac{\lambda}{2} \quad \dots \quad (1)$$

Where is: N – Number of pulses, λ – Wavelength

3. INFLUENCE OF ENVIRONMENTAL PARAMETERS ON THE ACCURACY OF MEASUREMENT

During the linear measurements or tests of UMM, should take into account the environmental conditions, because changes in conditions affects the accuracy of measurements. Table 1 gives the environmental conditions in the laboratory during the measurements with which is compensated wavelength of laser.

Table 1. Enviromental conditions

Data	Start	End	Units
Time :	2011-02-16 14:44	2011-02-16 15:19	
Air temperature :	19.52	20.30	deg C
Air pressure :	945.20	944.80	mbar
Rel. humidity :	39.84	40.04	%
Material Temperature 1 :	20.36	20.55	deg C
Material Temperature 2 :	-10.00	-10.00	deg C
Material Temperature 3 :	-10.00	-10.00	deg C
Exp. Coeff :	11.70	11.70	ppm/deg C
Environment factor :	0.31641373	0.31641329	

When performing linear measurements environmental conditions have to be stable.

4. ERRORS IN LINEAR MEASUREMENT

Errors that may occur during the linear measurements are as follows: environment conditions errors, cosine error, backlash error, Abbe's error, and other. Errors caused by environment conditions were removed using a compensation unit which is an integral part of the equipment XL80 laser system. Errors caused by changing the wavelengths are less important, but they can not be ignored. Roughly make an error of 1ppm (i.e. $1 \mu\text{m} / \text{m}$) change. Cosine error is eliminated by proper alignment of optical components, or a laser beam. Backlash error is the error associated with changes in ambient parameters during the measurement. This error occurs when the temperature of compensation (air and material), pressures and humidity do not include any portion of the optical path (backlash) and this error was eliminated by reducing the backlash to a minimum.

Abbe's error occurs when, during the measurements, the measured part is not moving ideally straight and angular displacements occur, causing tilting retro-reflectors. To reduce the Abbe's error, it is necessary to place optical elements of interferometer in the plane with measuring axis and bring them to a minimum distance of the same. In this way, Abbe's error can be avoided only when there is no angular displacement of reflectors in the axis of measurement. In some cases (second error), significant errors can be caused by the electronic part of the interferometer.

5. RESULTS OF MEASUREMENT

After necessary preparation to carry out a proper linear, angular and straightness measurement, UMM in measuring range from 100 to 800 mm was tested. With linear measurement the decimeter scale of UMM was checked and measurement results are shown in Figure 2- Linear measurement.

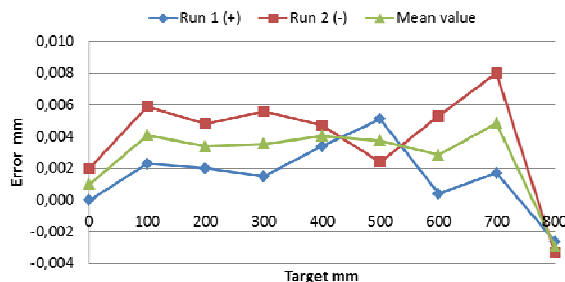


Figure 2. Linear measurement range 0-800 mm

From diagram on Figure 2 it can be concluded that the tested UMM has good accuracy and repeatability for this measurement range. In diagram on Figure 3 is given a data error of angular deviation on the vertical axis UMM in the specified measuring range.

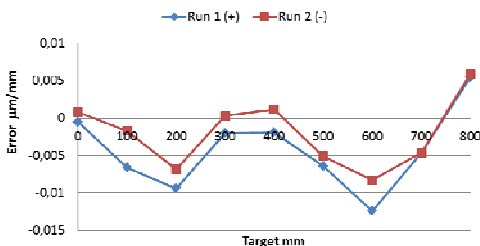


Figure 3. Angular yaw measurement x axis

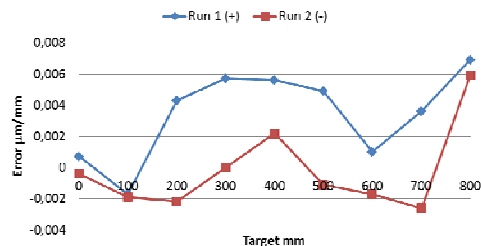


Figure 4. Angular pitch measurement x axis

From diagram on the Figure 3 can be seen that slider tailstock which moves in guides UMM has good accuracy and repeatability for angular deviation around the vertical axis, which leads to the conclusion that guides on UMM are intact The diagram on Figure 4 represents a data error of angular deviations around a horizontal axis UMM in the specified measuring range.

From Figure 4 it can be seen that the angular deviations around a horizontal axis do not have good repeatability of measuring results and maximum standard deviations for this measurement is $0.47 \mu\text{m}$. After completion of angular and linear measurements we approached straightness measurement. The results are given in diagram Figure 5. In diagram on Figure 5 are given the results of measurements of straightness in a horizontal plane above the measuring range.

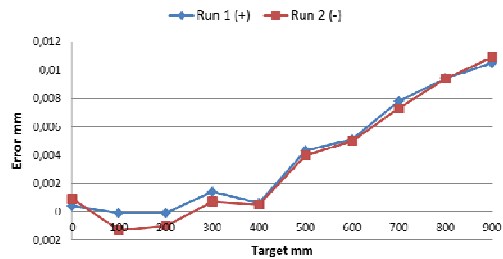


Figure 5. Straightness measurement x axis in horizontal plane

From Figure 5 can be seen that there is good accuracy and repeatability of measurement results in the specified range, and it can be concluded that the guides of UMM gently sloping to $1.2 \mu\text{m}$ After all tests we calibrated the UMM. Calibration points where 300, 500 800 and 1000 mm. The results are given in Table 1.

Table 2.Measuring results –calibration of UMM

Measuring points (mm)	Arithmetic mean of measuring results \bar{x} (mm)	Standard deviation s (mm)	Standard uncertainty u (mm)	Expanded uncertainty u_p (mm)
300	299,9992	0,0026	0,0013	0,0026
500	500,0021	0,0025	0,0012	0,0025
800	800,0018	0,0024	0,0012	0,0024
1000	1000,0024	0,0035	0,0017	0,0035

6. CONCLUSION

From these measurements it can be concluded that the UMM meets all metrological requirements and can be used throughout the measurement range due to the fact that the largest uncertainty of measurement according to the manufacturer is $u_p = \pm 7.5 \mu\text{m}$ and the errors are identified with linear, straightness and angular measurements do not affect the measuring results of a UMM.

7. REFERENCES

- [1] Dorion T., Stoup J.: Uncertainty and Dimensional Calibrations, Journal of Research of the National Institute of Standards and Technology, Volume 102, Number 6, November-December 1997.
- [2] O'Hora M., Bowe B., Toal V., Peyton S.: Modernization of Hilger and Watts gauge block interferometer, Optical Engineering, 035601-1 March 2005/Vol. 44(3).
- [3] Steinmetz C.R.: Sub-micron position measurement and control on precision machine tools with laser interferometry, Precision Engineering, Volume 12, Issue 1, 1990.
- [4] www.feanor.com
- [5] www.renishaw.com
- [6] Renishaw XL 80 laser measurement system manual