Analaysis of Position Accuracy Using Laser Interferometer in Vertical Milling Machine

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***Abstract* - This paper presents the results of accuracy characterization of a Vertical Machining Center (VMC) in the form of linear errors and temperature variation using a low powered He–Ne laser (Renishaw) calibration system along with environmental controller unit. Temperature distribution of the machine was measured using temperature sensors strategically attached to predetermined locations on each axis guides. The accuracy of the VMC is characterized in the form of geometric and thermal errors as a function of machine tool nominal axis position, temperature distribution (air temperature, air pressure). Results show that axis drive motors are the major heat sources. Linear positional accuracy is best when the machine is in cold condition and deteriorates with increasing machine operation time for all three axes. *X*-axis had worst linear displacement accuracy and maximum reversal errors among the three axes being tested. One of the major errors in machine tools namely geometric error was discussed at length and surface. Continuous usage of a machine tool causes heat generation at the moving elements and this heat causes expansion of the various structural elements of the machine tool. It is this expansion of the structural linkages of the machine that leads to inaccuracy in the positioning of the tool. Thus the overall volumetric error of a machine tool is not only dependent on errors due to the assembly and the specific kinematic structure of the machine but also on the thermal errors., an attempt is made to review the work carried out over the last decade in the estimation and compensation of temperature dependent errors.**

I. INTRODUCTION

One of the most important activities related to the maintenance of the machine tool is periodically checking the geometric and kinematics accuracy of machine tools. Static and dynamic stiffness of machine tools is one of the basic prerequisites for the proper operation of the machine tools. Measurements of certain parameter accuracy of machine tools in the appropriate time of period provide the information needed to define the static and dynamic stiffness of machine tools. On the other hand, the measurement of geometric deviations such as straightness, parallelism, flatness and so on, giving the ability to assess the level of accuracy that is specific machine tools can be used.

The light source is split at the surface of the half silvered mirror, half the light being reflected through 90° towards a fixed distance mirror, the remaining half being allowed to pass through to a moveable mirror. The mirrors are aligned so that the recombined beams reflected from the mirrors are parallel and are reflected back towards an observer. If the moveable mirror is positioned further away so that its position is shifted by one quarter wavelength, then the beam will return to the observer 180° out of phase and destructive interference will occur, resulting in darkness.

The result is known as "destructive interference". In destructive interference the two input waves cancel one another resulting in darkness. One retro-reflector is rigidly attached to a beam-splitter, to form a fixed length reference arm. The other retro- reflector moves relatively to the beam splitter and forms the variable length measurement arm.

The laser beam 1 emerging from the ML10 has a single frequency with a nominal wavelength of 0.633 μm and long-term wave-length stability (in vacuum) better than 0.1 ppm, (all relevant). If the difference in path length does change, the detector sees a signal varying between the extremes of constructive and destructive interference each time the path changes.

In practice, for the measurement accuracies, such compensation is only required for linear displacement (positional accuracy) measurement where the change in the difference between the path lengths of the two beams is significant.

The Reni Shaw ML10 system is a modular system, capable of measuring, displacement, velocity, angular (pitch and yaw) displacement, flatness, straightness, parallelism and squareness, depending on the measurement kits supplied.

1.1 Positioning Accuracy of Machine Tools

Machine tool positioning accuracy is a core descriptor of a machine and indicates its expected level of performance. The accuracy of the components machined is primarily affected by the positioning errors of the machine tools. There are a number of standards and guidelines outlining how to evaluate machine tool positioning accuracy. Therefore a total of 21 errors are present in a three axes machine tool. To achieve higher positioning accuracy, the angular, straightness, and squareness errors must be measured and compensated. The above errors are related to the built-up quality of the machine and to be controlled during manufacture of the machine or improved by mechanical maintenance of machine during periodic calibration.

1.2 Method of Positioning Error Measurement

Positioning error results in a relative error between the cutting tool and work-piece which produces inaccuracy on the components. Identification and compensation of these errors are necessary to improve the machine tool accuracy.

Various methods of checking the positioning errors of a multi-axes machine are

(i) Using slip gauges, step gauges or length bars,
(ii) By measuring a part machined by it on a precision Co-ordinate Measuring Machine (CMM),
(iii) Using Laser Interferometer System or
(iv) Using Ball Bar System etc.

The laser interferometers are commonly used to make extremely accurate measurements of linear displacement and thereafter giving compensation to the machine controller, as the compensation data for positioning and backlash errors are readily available in the system. The basic theory for laser interferometers dates back to the early 1900s with the Michelson Interferometer being one of the earliest devices to demonstrate interferometric measurements of length. A laser interferometer uses a laser source that emits a focused monochromatic light beam.

The normal set-up for a laser interferometer uses a stationary laser source, a beam splitter, a stationary reference reflective target, and a mobile reflective target. The emitted beam is projected through the beam splitter which results in two separate beams of light. These beams are then projected onto the two targets (one stationary and the other movable) and reflected back to the beam splitter which combines them into a single beam again.

II. LITERATURE REVIEW

1. "Location Dependency of Positioning Error in a 3-Axes Cnc Milling Machine" R.K. Gupta, S.P. Srivastava, S.K.Yadav, V. Prasad, S.B. Jawale ,December 12th–14th, 2014

To produce complex components within a close tolerance value, the machine tools are required to be more accurate than the specified accuracy of the components. Generally to achieve better accuracy of machine tools, laser interferometer systems are used to measure the positioning error and thereafter error compensation is done to improve the accuracy. In case of big size milling machines, it is observed that the accuracy of the machine is not always uniform throughout its work table area. This paper presents a study of error distribution across the work table surface that enables to identify the best location for machining close tolerance components. It also indicates the error involved in the machining, corresponding to the various locations of the machine work table. Keywords: Tolerance, Positioning error, Milling machine.

2. "Improvement of Positional Accuracy of Precision Micro Milling Centre Using Pitch Error Compensation And Interferometer", Goran Mijuskovic, Peter Krajnik, JanezKopac, ISSN 1330-3651, Tehnickivjesnik 20, 4(2013), 629-634

An experimental procedure was performed on precision micro milling center to improve positional accuracy and keep tolerances within the required range for precision manufacturing in tool and die industry.

The micro milling processes play an important role in tool and die industry which is facing increasing demands on global market, namely demands related to positional accuracy and repeatability. Laser interferometer was used for measurements of 3-axis machining Centre, where the values for positional accuracy and repeatability were calculated according to ISO 230-2 standard for all three axes. Values of positional accuracy for *X*- and *Y*-axes were out of manufacturer's tolerance (3 µm), while positional repeatability was satisfactory and below 0.7µm for all axes. Based on determined positional errors, correction of pitch error compensation table was performed. The improvement of positional accuracy was significant, with values around 1 µm and below. Finally, measurement uncertainty for accuracy and repeatability was estimated for all axes according to the same standard.

3. "Calibaration of Machine Tools by Using of Laser measurement systems", S. Ekinovic, H. Prcanovic, and E. Begovic, January 2013

The need for very precise measurements has emerged with evolution of automatic and CNC machine tools. Precision and accuracy are amongst main requests on modern machine tools. To define and know this characteristic of machine tools standard measuring procedures have been used for many years. Yet, others more advanced approaches and equipment's, like laser measuring systems, are also available for measuring machine parameters like straightness of movements, repeatability, surfaces flatness, parallelism etc. This paper shows comparison of measuring results and measuring procedure between two different laser measuring systems, Damalini D525 and Renishaw ML10. Measurements are performed on DMU monoBlock60, CNC universal milling machine. Same type of measurements, straightness measurement of main shaft movement in Y direction, is performed simultaneously by means of both of the laser systems.

Results presented in this paper shows that there are differences in between measuring results as well as in between measuring procedures for selected lasers. Hence, the correct choice of measuring device in that sense can save time and decrease costs of machine maintenance.

4. "Linear Positioning Errors of 3-Axis Machine Tool", Jerzy JÓZWIK, Przemysław MAZUREK, Marcin WIECZOREK, Marek CZWARNOWSKI ,CASTROA H.F.F., BURDEKINB M, pp. 89–97, 12,2012

This paper presents results of 3-axis CNC machine tool diagnostics performed with XL-80 laser interferometer and XC-80 environmental compensation unit, including pressure, humidity and temperature sensors. Furthermore, the paper includes the methodology and results of conducted measurements of linear positioning errors, which supplied data for further analysis. The conclusion section presents important results of conducted experiments. Measurement results were presented in figures, charts and tables.

5. "Prediction of Angular Errors on a Vertical CNC Milling Machine" R.A. MAHDAVINEJAD, No. M2, pp 181-19, September 15, 2011

The accuracy and precision of computer numerical control (CNC) machine tools directly affect the dimensional accuracy of machined parts. Accurate detection of machine tool errors with respect to positioning and orientation is imperative to the accuracy of the manufacturing process and, further, to eliminate errors through error compensation techniques. This paper presents a method to measure and determine angular errors resulting from drive axis out-of-straightness.

Measurement of errors in discrete steps has been carried out via laser autocollimator and the method of neural networks (NN) has been employed to predict the amount of errors in the range between the steps. The results from this study can be used as a model for industrial applications to identify errors prior to the programming of the manufacturing process.

6. "Laser Interferometry For Precision Engineering Metrology", Baer T., Kowalsk, Baldwin, D. R, Opt., 19, 3173, October 21, 2010

Interferometric techniques for the precision measurement of length have found increasing application since the turn of the century. With the advent of compact laser systems of narrow spectral bandwidth and corresponding high coherence, laser interferometry has developed into a standard technique for the measurement of length, displacement, angle and other related dimensional quantities at the highest precision. A number of manufacturers within the high-technology optical industries provide complete stand-alone or OEM length and displacement measuring systems. Most precision engineering concerns now take advantage of the high resolution and accuracy of these devices, both in the calibration of material standards such as gauge blocks and line standards, but also through on-line incorporation of such devices into computer-controlled lathes and three-axis co-ordinate measurement machines.

7. "A Basic Michelson Laser Interferometer For The Under Graduate Teaching Laboratory Demonstrating Picometer Sensitivity" Kenneth G. Libbrechta and Eric D. Black 264-33 Caltech, Pasadena, California 91125 (Received 3 July 2007; accepted 4 November 2007)

We describe a basic Michelson laser interferometer experiment for the undergraduate teaching laboratory that achieves picometer sensitivity in a hands-on, table-top instrument. In addition to providing an introduction to interferometer physics and optical hardware, the experiment also focuses on precision measurement techniques including servo control, signal modulation, phase-sensitive detection, and different types of signal averaging. Students examine these techniques in a series of steps that take them from micron-scale sensitivity using direct fringe counting to picometer sensitivity using a modulated signal and phase-sensitive signal averaging.

III. COMPONENTS REQUIRED

3.1 Instrument Set-up

The setup of the laser interferometer consists of arranging the stationary components (Laser Head, Beam Splitter, Stationary Reflector and Temperature Sensors) and mobile components (Mobile Reflector) of the system so that the relative motion between these components accurately reflects the motion of the machine under measurement. Mounting of the mobile reflector is normally done with a magnetic base, and it is mounted to mimic the motion of the cutting tool of the machine. The Laser Head is mounted off the machine, on a tripod, to insulate it from vibration of the machine in motion. For linear measurement the components are aligned so that the emitted beam leaves the laser head from the upper aperture and is returned from the mobile reflector to the lower aperture, throughout the entire range of motion to be measured.

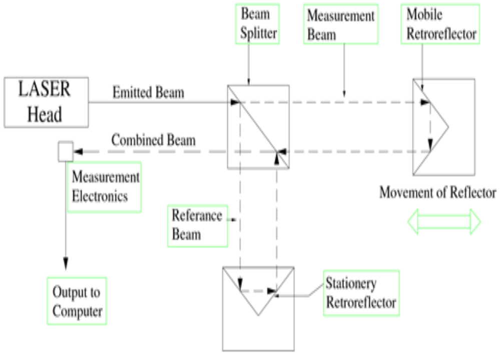


Figure 3.1 General Arrangements for Laser Interferometer

3.2Calibration of Laser Interferometers

Laser interferometer systems are widely employed in the manufacturing and metrology industries for direct precision measurement of length and displacement, particularly in relation to CNC machine tool and co-ordinate measuring machine (CMM) calibration. Many technologically based countries have their own National Metrology Laboratories—see an abridged list of them at rear of this book, that can offer an end user/customer a laser calibration service, such as that provided by The NPL within the UK, or for certain industrial/metrology companies which are suitably accredited to undertake such calibration, or periodic re-calibration. Typically within the UK, The NPL offers a routine-service for the verification of interferometer system accuracy, which includes the following:

- Calibration of a stabilized laser source wavelength.
- Verification of displacement measurement—to30m
- Calibration of environmental compensation transducer compensated system calibration—to 2 parts in 107.
- UKAS accreditation/ISO 9000 compliance.

Such essential periodic laser interferometer calibration confirms the traceability measurement chain to the absolute standard for the metre, as basically depicted. Typically, laser interferometers of the homo, or heterodyne-types, are frequently utilized by manufacturing industry at large, and in calibration laboratories for displacement-measurements in a very wide-range, from just 0.1 nm up to that of 50 m distance. The accurate and traceable operation of a laser interferometer requires calibrations and checks of several specific factors.

3.3 Air pressure sensor

Air pressure sensor is a device equipped with a pressure -sensitive element that measures the pressure of a gas or a liquid against a diaphragm made of stainless steel, silicon, etc., and converts the measured value into an electrical signal as an output. Air temperature sensors are compared against calibrated reference Pt100- sensors, inside a climate chamber.

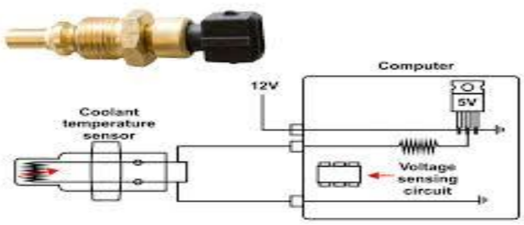


Figure 3.2 Air Pressure Sensor

3.4 Metal temperature sensor

A metal temperature sensor is a device, typically, a thermocouple or RTD that provides for temperature measurement through an electrical signal. A thermocouple (T/C) is made from two dissimilar metals that generate electrical voltage in direct proportion to changes in temperature. An RTD (Resistance Temperature Detector) is a variable resistor that will change its electrical resistance in direct proportion to changes in temperature in a precise, repeatable and nearly linear manner. Material sensors of the instrument and reference Pt100-sensors are attached to a steel block and inserted inside a climate chamber.

Figure 3.3 Metal Temperature Sensor

3.5 Laser receiver

The Spectra Precision DR400 Digit Rod digital rod is a versatile, revolutionary tool that eliminates the need for grade rods when checking grades with a rotating laser. The combination of a laser receiver with digital readout, laser distance meter, and built-in tilt sensor provide the information required to take rod-less, accurate grade readings, even at tilt angles up to 30 degrees.

Various grade rods can be emulated including direct elevation rods, cut/fill rods and indirect reading rods. Units of measure are selectable with the press of a button in meters, decimal feet or fractional inches.

Figure 3.4 Laser Receiver

3.6 Magnetic base

A magnetic base is a magnetic based on a magnet that can effectively be turned "on" and "off" at will; they are often used in optics and metalworking, e.g., to hold a dial indicator. The vertical post, side arm (as shown in the image at right) and the dial indicator (not shown) are connected by two swiveling connectors. These connectors allow free movement of the arms so that the indicator can be presented to the work in a suitable orientation. The magnetic base may have a "V" cut into the bottom of the base or the back. This "V" allows the base to be attached to a round bar such as the column of a drill press.

Figure 3.5 Magnetic Base

3.7 Dial gauge

A dial indicator aims at comparing measurements between two objects in order to check the conformity of one of the objects, the second one being the reference.

3.7.1 The Dial indicator can be used in

Manufacturing processes, to check the flatness of a surface before machining it. In metrology, to check the dimensional conformity of a part. In that case, the dial indicator is combined with a checking fixture, used to position the part.

3.8 Software set up

The Renishaw Laser Interferometer system is controlled by software on a standard laptop. Renishaw software package was used to collect information from the laser interferometer system. The software was setup to capture the reading of data from the system with the motion of the machine work table.

The motion of the machine table was under automatic control of a part program written for this purpose. Setting up the software for linear motion measurement was done by filling in the entries on the setup screens for the control of the XL-80 laser system.

3.9 Split gauge

Figure 3.6 Split Gauge

To check the accuracy of a carpenter’s type level, a perfect horizontal surface is not needed. The level is placed on a flat and roughly level; surface and the reading on the bubble tube is noted. This reading indicates to what extent the surface is parallel to the horizontal plane, according to the level, which at this stage is of unknown accuracy. The spirit level is then rotated through 180 degrees in the horizontal plane, and another reading is noted. If the level is accurate, it will indicate the same orientation with respect to the horizontal plane. A different implies that the level is inaccurate.

3.10 Axis Table

The 3-axis CNC machining centers still have place in modern manufacturing. Whether a 3 axis milling machine is the right solution for your business depends on a myriad of factors relation to the size of the production run, work piece properties, accuracy and finish requirements, materials costs, stock holding capabilities, etc.. At Geo Kingsbury, we have the knowledge and expertise to analysis all these variables and determine if 3axis milling is still the most profitable option for you. If so, we can recommend the best machine and provide a turnkey service for installation, setup and programming. All our 3 axis machines are aviable with siemens or heidenhain controls.

3.11 Hand Remote

One of the primary benefits of a cnc machine is the hands-off operation. Once you’ve programmed the machine to mill part you need, you can sit down, grab a crossword and enjoy your coffee. Well, may be it’s not that hands off, but you certainly don’t have to control the machine manually through the entire operation. Computer control speeds up production of many simple parts as well as makes machining complex shapes faster and more accurate.

The remote control enables basic milling operation on the CNC machine without needing to start up your computer to create or edit a CNC program.

Figure 3.7 Hand Remote

3.12 Alignment of the Interferometer

Before the start of the experiment the interferometer has to be aligned. Though the initial alignment of the interferometer is generally not disturbed from one experiment to the other, periodic fine tuning is essential to ensure that the interferometer is operating at its highest sensitivity. The initial alignment of the interferometer is carried out as per the following steps:

1. The light output of the spatial filter is adjusted so that the diffraction rings, which appear with the expanded beam, vanish. This requires adjustment of the screws on the spatial filter. In most experiments, the diffraction ring formed a complete circle and remained outside the periphery of the expanded beam.
2. The laser power output is measured using a light meter. The laser-power output is generally not a stable quantity and changes with time. This change in power output is generally not a stable quantity and changes with time. This change in power output is not a transient phenomena. Instead, it decreases steadily with the hours of operation. During the present work, the laser output was in the range 30-32 mW over two years.
3. The convex lens is adjusted from the pinhole of the spatial filter so that the distance of separation is the focal length of the lens. This produces a parallel laser beam needed for the experiments.

IV. WORKING PRINCIPLE

The working principle of interferometry is discovered in 1880 by Albert Michelson. Michelson's interferometer comprises the source of monochromatic light, semitransparent mirror and Renishaw laser system measures accuracy of straightness and repeatability of machine movement by measuring deviation of target points from reference axis.

Using RENISHAW laser 10 system straightness of main shaft movement of CNC mill DM 60 mono BLOCK in direction of Y axis is performed. Measurement is performed on a length of 490 mm from outmost position towards machine bed. According to machine producers specification this deviation should be less then 0.02 mm on 300 mm length.

Laser source on this laser system is positioned on a tripod outside of a machine, while interferometer is positioned on a movable part and mirror is positioned on a stationary part of a given machine. Deviation of target points from reference axis, which is positioned between laser source and mirror on a stationary part of a machine, is measured.

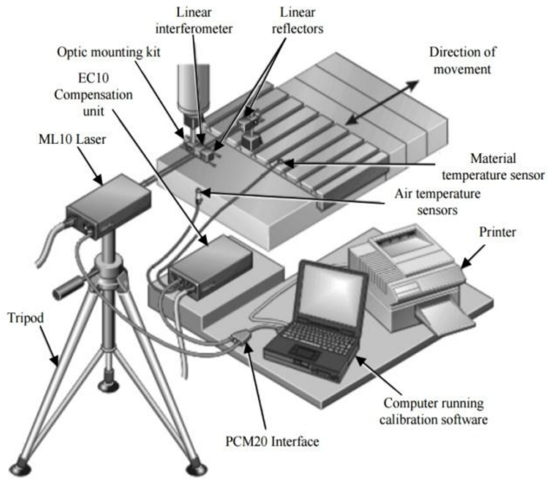
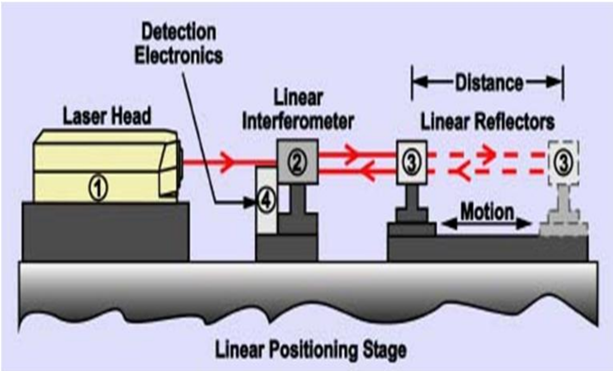


Figure 4.1 Experimental set-up

After optics are positioned and connected with laser management software the main shaft is moved from point to point 8 times on a 490 mm length. This procedure is repeated 3 times. The distance between target points is 70 mm. Measurement results are given. Analysis of measurement results according to German standard VDI 2671. Maximum deviation on a given length is Umax=0.00436 which is considerably less from allowable 0.02mm. This machine is calibrated upon its installation using dial gauge and length gauge. Length gauge is of 300 mm and overall deviation is 0.006 mm, what is in accordance to allowable deviation of 0.02 mm on a 300 mm length.

On a semitransparent mirror light beam is split in two parts. One part goes towards movable mirror and the second part is reflected under 90° angle towards fixed mirror. Mirrors are placed in such a way so that recombined light beam goes towards observer. If both mirrors are on the same distance from semitransparent mirror then both beams reflected towards observer will be in phase which will result in amplification of the light intensity. If the movable mirror is placed ¼ wavelengths away from fixed mirror, then the return beam is 180° out from the phase of base light beam and that results in so called "destructive interferometer" which produces dark on a screen. PDS detector is a silicon film sensitive to light.



In comparison to digital camera in which the resolution is defined with the camera design these detectors are analog and can have almost unlimited resolution.
When laser beam hits silicon film electrical current begin to flow from point of impact towards electrode. The intensity of current is proportional to distances of an impact point from each electrode. Based on intensity of current exact location of laser beam is calculated.

4.1 Uses of Laser Interferometer

The uses of a laser interferometer are as given below.
(a) Since laser interferometer produce very thin, straight beam, they are used for measurements and alignment in the production of large machines.
(b) They are also used to calibrate precision machine and measuring devices.
(c) They can also be used to check machine set ups. A laser beam is projected against the work and measurements are made by the beam and displayed on a digital readout panel.
(d) Laser interferometers can also be used in glass feature measurements.

V. ADVANTAGES AND APPLICATIONS

5.1 Advantages

- Highly durable optics
- Improved dynamic response
- Quick thermal acclimatization
- Easier long-range alignment.
- It facilitates to maintain long range optical path (60 m).
- Laser interferometers are easy to install.
- There is no chance deterioration in performance due to ageing or wear and tear.

5.2 APPLICATIONS

- It is used to improve the component surface finish. It is used to analysis the 3-axis of the table.
- It improves the tool life.
- It increase the position accuracy of axis the machine performance is improved.
- Measure angles, flatness, straightness, velocity and vibrations, etc.

VI. CONCLUSION

The need for very precise measurements has emerged with evolution of automatic and CNC machine tools. Precision and accuracy are amongst main requests on modern machine tools. To define and know this characteristic of machine tools standard measuring procedures have been used for many years. Yet, others more advanced approaches and equipments, like laser measuring systems, are also available for measuring machine parameters like straightness of movements, repeatability, surfaces flatness, parallelism etc.

This paper presents some examples of measurements of different deviations for different machine tools. These are measurement results of CNC lathe (deviation from linear motion), CNC milling machine (dynamic behaviour), deep drilling machine (straightness), CNC milling machine (comparative measurement straightness according to two different methods of measurement: interferometry and CCD method). Presented results can gave significant help in regular machine shop maintenance activities. Hence, the correct choice of measuring device and method in that sense can save time and decrease costs of machine maintenance.

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APPENDIX