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A REVIEW OVER ELECTRICAL METHODS FOR MEASURING THE MACHINE TOOLS' PRECISION

BY

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Abstract. There is always an influence between the quality parameters of a machine tool and the quality parameters of the machined parts. Constant measuring the precision of the machine tool is an important aspect in maintaining the quality of the entire manufacturing process. Accuracy inspection using laser interferometer and linear encoders are two methods for giving information about machine tool status and thus permitting to predict the finished machine product quality.

Key words: laser interferometer, linear encoder, machine tools' accuracy, non contact measuring, precision manufacturing.

1. Introduction

The precision of each machine tool it's characterized by the machine ability to produce machined components in respect with the imposed geometry, dimensioning and surface roughness, conditions imposed into the manufacturing documentation of each desired part.

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Because with a single machine tool are usually produced different surfaces of a component with different geometrical features, it is absolutely necessary to respect the precision of the basic constituent elements which compose the machine tool assembly, such as:

- planarity and linearity of the guiding surfaces;
- colinearity of the clamping fixtures and of the clamping devices;
- parallelism between the machining axes and the guideways of the moving elements;
- perpendicularity/ parallelism between machining axes and machine table, depending on the type of machining and machine.

The initial acceptance condition for the dimensional and geometrical precision control of the machine tools was initially established in 1927 by dr. Georg Schlesinger, professor at Technical University from Berlin and now are stated into the ISO 230 1-13 standard.

2. Measuring the Precision of Machine Tools

2.1. The Reason for Knowing Machine Tools' Precision

There is always an influence between the quality parameters of a machine tool and the quality parameters of the machined parts (tolerances, roughness etc.). It is very important to maintain the stability of the quality parameters for the machined parts, this being a key factor in ensuring the quality of the entire production process.

Also, any machine tool or machining center is a part of a larger and more complex manufacturing assembly. Therefore, it can be the situation when a machine tool is programmed to behave in a way but to perform in another undesired way, due to external influences such as temperature, vibrations, power supply fluctuations etc.

Another factor which needs to be taken into account in order to ensure a high quality for the machined parts and which makes the measuring of the machine tool's precision very important is that a specific component of the machining tool can influence one or more different components of the same machine tool, affecting by this the manufacturing precision and thus the quality of the finished part.

In essence, by constant measuring the precision of the machine tool can be considered a huge step forward in maintaining the quality of the entire manufacturing process and thus increase the level of satisfaction of the clients in relation with the desired product.

2.2. Methods for Measuring the Machine Tools' Precision

The measurement of the machine tools' precision can be made in two ways, according to the design of the measurement systems involved:

- Measurement with physical contact with the probes;
- Measurement without physical contact with the probes.

The second way of measurements it is the purpose of this paper.

Among the type of contact between the measurement device and the probes, there are also two types of measurement of the machine tools' precision, depending on the machining process which is used:

- Measurement with the machine actually performing a cutting operation and the measurement devices record it's performance;
- Measurement without the machine being into a cutting operation but only simulating one.

For the second type of measurement, having a simulated cutting process, in this paper there will be treated two electrical methods of accuracy inspection of the machine tool:

- Measurement with laser interferometer;
- Measurement with linear encoder;

3. Measurement of Machine Tools' Precision Using Non-Contact Measurement Methods

3.1. Measurement with Laser Interferometer

Measuring the precision of a machine tool with a laser interferometer device allows the possibility to measure a large number of dimensional and geometrical characteristics, such as: coaxiality, angularity, perpendicularity, planarity, rotation etc. of the machine tool elements.

The measurement is always performed without the machine being into a real cutting process and the result of the measurement will consist from:

- A graphical representation of a detected error along one of machine's axis;
- A table/list containing the measured values;
- Precision state of which the machine founds out on the respective measured axis;
- Possible recommendations to be followed up in case of errors are found.

The measurement principle with laser interferometer is described up in Figures 1 and 2.

Measurement of gauge adjustment including corrections: the beam from the laser project enters into the linear interferometer, where it is split into two beams. One beam (known as the reference beam) is directed to the reflector attached to the beam-splitter, while the second beam (the measurement beam) passes through the beam-splitter to the second reflector.

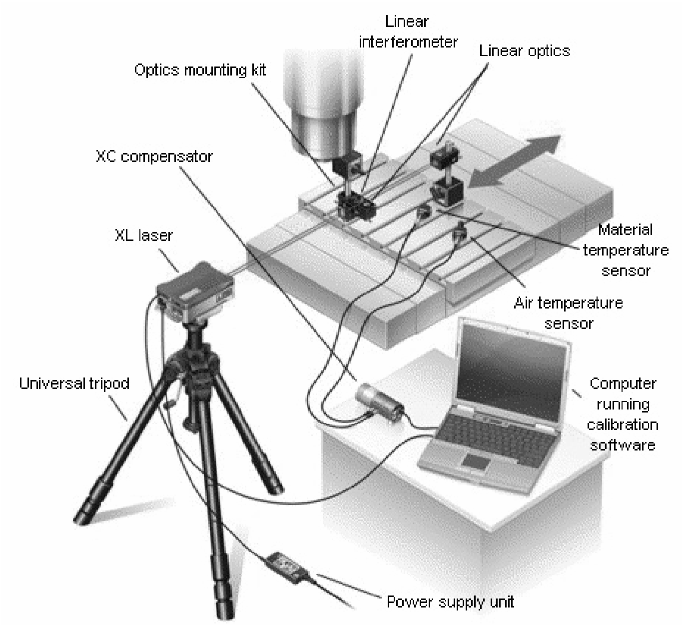

Fig 1 – The measurement equipment with laser interferometer.

Both beams are then reflected back to the beam-splitter where they are re-combined and directed back to the laser head where a detector within the head monitors the interference between the two beams.

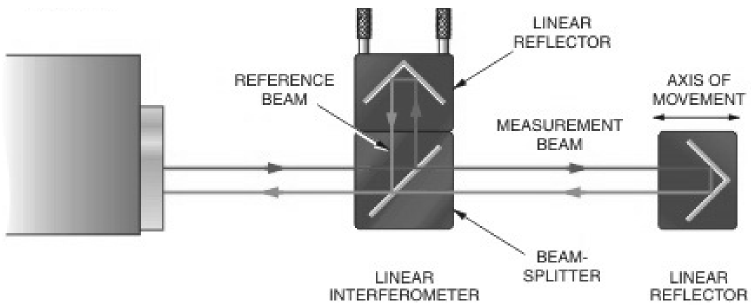

Fig 2 – Functioning principle for laser interferometer's optical sensor.

Captured data can be analyzed in accordance with a number of international standards. When carrying out any analysis of the captured data, it must be ensured that the analysis selected is suitable for the type of machine which is tested and the test requirements. Data capture is carried out by moving the machine to a number of different positions (or 'targets') along the axis under test and measuring the machine's error.

Measurements are taken during each pause. When choosing the target positions for a calibration of a machine's axis, the target positions should usually span the entire working zone of the axis.

3.2. Measurement with Linear Encoder

The linear encoder measurement systems serve for acceptance testing, inspection and calibration of machine tools and measuring equipment.

In addition to determining the position error, this type of measuring system also measures guideways error orthogonal to the traverse direction of the machine axis. The resulting error values can then be used in the subsequent electronics (display unit or control) for electronic error compensation and some models, like Heidenhein VM182 can download the error compensation values directly. Linear encoders measure the position of linear axes without additional mechanical transfer elements. The control loop for position control with a linear encoder also includes the entire feed mechanism.

Transfer errors from the mechanics can be detected by the linear encoder on the slide, and corrected by the control electronics. This makes it possible to eliminate a number of potential error sources:

- Positioning error due to thermal behavior of the recirculation ball screw;
- Reversal error;
- Kinematic error through ball-screw pitch error.

Most linear encoders operate using the principle of photoelectric scanning. Photoelectric scanning of a measuring standard is contact-free, and as such, free of wear. This method detects even very fine lines, no more than a few microns wide, and generates output signals with very small signal periods. The finer the grating period of a measuring standard is, the greater the effect of diffraction on photoelectric scanning.

As example, the linear encoders from producer Heidenhein uses two scanning principles with linear encoders:

- The **imaging scanning principle,** for grating periods from 20 μm and 40 μm;
- The **interferential scanning principle,** for very fine graduations with grating periods of, for example, 8 μm.

3.2.1 *Measurement with linear encoder with imaging scanning principle*

The measurement with linear encoders using imaging scanning principle functions by means of projected light signal generation: two scale gratings with equal or similar grating periods are moved relative to each other—the scale and the scanning reticule. The carrier material of the scanning reticule is transparent, whereas the graduation on the measuring standard may be applied to a transparent or reflective surface.

When parallel light passes through a grating, light and dark surfaces are projected at a certain distance, where there is an index grating. When the two gratings move relative to each other, the incident light is modulated. If the gaps in the gratings are aligned, light passes through. If the lines of one grating coincide with the gaps of the other, no light passes through. An array of photovoltaic cells converts these variations in light intensity into electrical signals. The specially structured grating of the scanning reticule filters the light to generate nearly sinusoidal output signals.

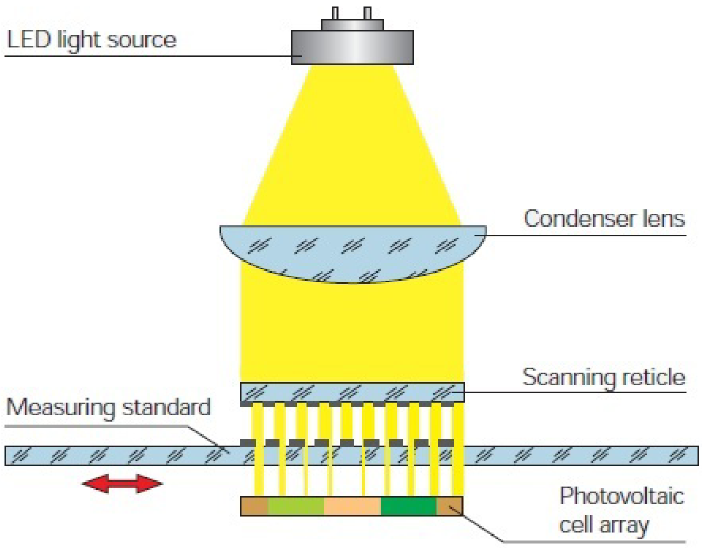

Fig 3 – Measurement with linear encoder using imaging scanning principle (acc. VM182 linear encoder technical data from Renishaw GmBH).

3.2.2. *Measurement with Linear Encoder with Interferential Scanning Principle*

The interferential scanning principle exploits the diffraction and interference of light on a fine graduation to produce signals used to measure displacement.

A step grating is used as the measuring standard: reflective lines 0.2 μm high are applied to a fl at, reflective surface. In front of that is the scanning reticule—a transparent phase grating with the same grating period as the scale. When a light wave passes through the scanning reticule, it is diffracted into three partial waves of the orders –1, 0, and +1, with approximately equal luminous intensity.

The waves are diffracted by the scale such that most of the luminous intensity is found in the reflected diffraction orders +1 and –1. These partial waves meet again at the phase grating of the scanning reticule where they are diffracted again and interfere. This produces essentially three waves that leave the scanning reticule at different angles.

Photovoltaic cells convert this alternating light intensity into electrical signals.

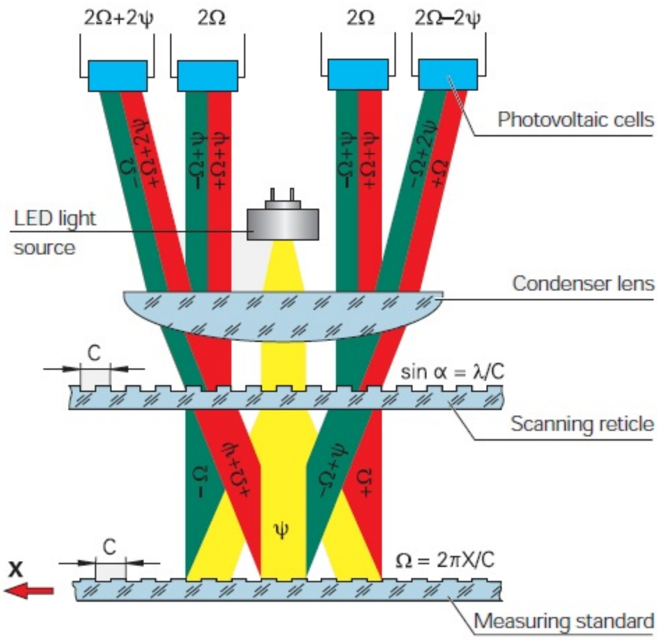

Fig 4 – Measurement with linear encoder using interferential scanning principle (acc. VM182 linear encoder technical data from Renishaw GmBH).

A relative motion of the scanning reticule to the scale causes the diffracted wave fronts to undergo a phase shift: when the grating moves by one period, the wave front of the first order is displaced by one wavelength in the positive direction, and the wavelength of diffraction order –1 is displaced by one wavelength in the negative direction.

Since the two waves interfere with each other when exiting the grating, the waves are shifted relative to each other by two wavelengths. This results in two signal periods from the relative motion of just one grating period. Interferential encoders function with grating periods of, for example, 8 μm, 4 μm and finer.

Their scanning signals are largely free of harmonics and can be highly interpolated. These encoders are therefore especially suited for high resolution and high accuracy.

4. Conclusions

Machine tool performance from the point of view of compliances to tolerances, surface definition, etc., is determined essentially by the accuracy of machine movement. For precision machining it is therefore important to measure and compensate for deviations in motion, according to the standards ISO 230-2,3, 4 and VDI/DGQ 3441.

This paper is helpful for researchers in need to use a real time diagnostic tool for inspecting and enhancing the precision of a machining center and also with the will to interfere as little as possible into the physical machining operation. This way, the two presented electrical non-contact measurement systems, together with the author's review of their performance and suggestions of use can be considered a helping hand in determining the accuracy of machining processes investigations.

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ANALIZA METODELOR ELECTRICE DE MĂSURARE
A PRECIZIEI MAŞINILOR-UNELTE

(Rezumat)

Lucrarea de faţă prezintă două metode de determinare a preciziei maşinilor unelte utilizând aparate de măsură fără contact fizic, şi anume interferometrul laser si traductorul liniar. Totodată, se prezintă analiza autorilor asupra performanţelor celor două sisteme de măsurare, precum şi modul optim de utilizare ale celor două sisteme prezentate.