MEASUREMENT OF MACHINE TOOL PRECISION BASED LASER EQUIPMENT

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Abstract:

This contribution deals with measuring and diagnostic laser system Renishasw XL 80, which is used in industry for monitoring and maintenance of machine tools and also for builders of progressive machines like 3 or 5 axis CNC machine tools. First part of contribution describes its physical principle following interferometry principle, the second part deals about complete measuring system, its performance and it shows its wide field of application possibilities.

1. INTRODUCTION

CAQ stands for Computer Aided Quality Assurance. This means the deployment of a computer system in Quality Assurance in order to plan and take quality assurance measures in a company. The aim of a CAQ system is to ensure support for company-specific processes. To make certain that the system functions effectively, it is therefore essential that operation of the software is aligned with work processes and sequences defined by the workflow of the user. Cross-module user navigation guarantees process-oriented work methods. A module is a component of an overall system which contains all the functions necessary for solving a defined task or supporting a quality management process (e.g. complaints management). This method ensures that the system is introduced efficiently. A CAQ system helps you to learn from your mistakes. All quality-related processes undergo permanent improvement. Enterprise-wide documentation and the tracking of corrective measures represent a central element of the continuous improvement process. Standards form the basis of every supplier-customer relationship. The requirements to be fulfilled by a functioning quality management system are laid down in standards. If a CAQ system is to be profitably deployed as a supportive tool for using and guaranteeing the quality management system, it is absolutely mandatory to take the stipulations of these standards into account. It is particularly important that the CAQ system conforms to all specifications laid down in the standards DIN EN ISO 9001:2000, ISO/TS 16949, QS 9000 and VDA 6.

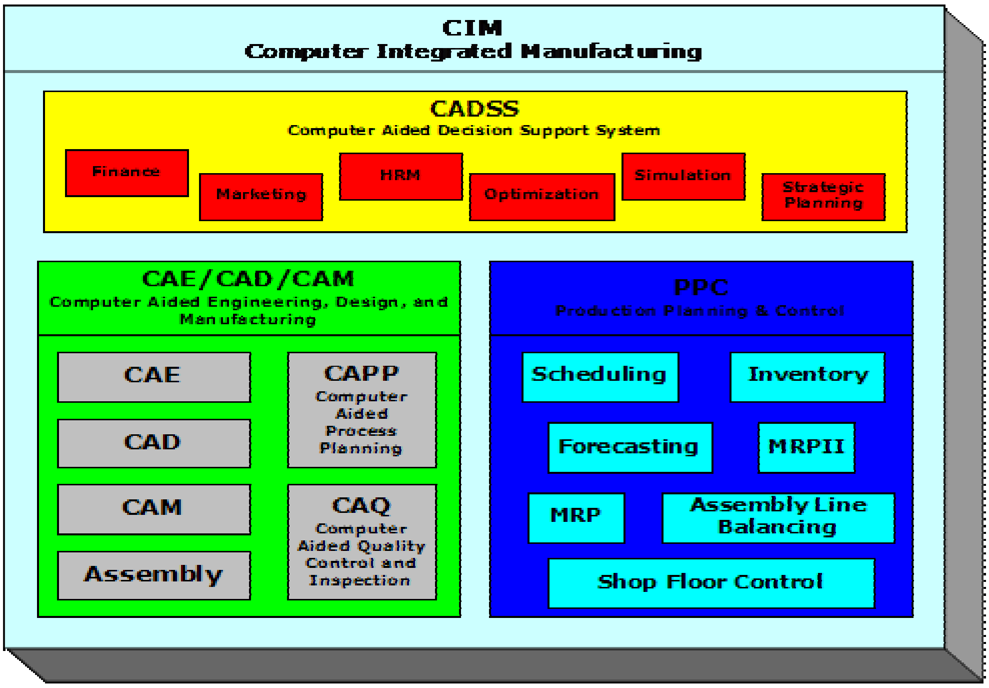


Fig. 1 *CAQ System in CIM (Computer Integrated Manufacturing)*

It will be not correct to supposed CAQ system as an independent unit, but as a part of complete CIM (Computer Integrated Manufacturing) system. Only with computer system interplay of additional domain are CAQ Systems able to show its benefits. Through the entire computer aid of all production segments and consequently integration of single elements date and information volumes which will be impossible without establishing of these communication ways.

2. ACCURACY OF CNC MACHINE TOOLS

The quality of a machine tool is expressed in terms of the dimensional accuracy and surface finish of the parts produced by the machine. The most important factor, the dimensional accuracy of machined components, depends on the accuracy of the machine tool used. Traditional defect detection concepts of machining parts and then inspecting them to see if they are acceptable are fast becoming obsolete. Instead, an emphasis is being given to defect prevention, i.e. making the product right the first time. To implement defect prevention, quality control actions must be built into manufacturing systems that actively monitor and correct the error sources of manufacturing processes rather than passively inspecting machined parts. Machine tools are the most important means of production for the metalworking industries. Without the development of this type of machine, the high living standards of the present time would be unthinkable. In some of the most highly industrialized nations, approximately 10% of all machines built are machine tools, and about 10% of the work forces in machine manufacture are concerned with machine tools. Numerically controlled (NC) machine tools have been widely used for various purposes, such as for flexible automation, to improve machining accuracy, to reduce lead-time, to cut cost etc. Therefore, the ability of NC machine tools should be improved in order to meet the various needs. The most desirable improvement is the ability to achieve high efficiency and high precision machining. Compensation for errors gains its importance because design and operating specifications are either difficult to implement or contradictory. Moreover, compensation is considered an effective measure for overcoming the machine aging factor, which shows as a gradual and minor deterioration in its performance. Compensation for error correction has the advantages of the cost reduction of error correction and avoidance, and increasing machines accuracy by approaching its level of resolution.

In a typical machine tool, there are multiple error origins including geometric, static and dynamic loading, thermal, mismatches between servo-loop parameters, interpolation etc. Geometric errors of machine tools come from manufacturing defects, machine wear, and static deflection of machine components. Geometric errors are especially significant with medium-size and large-size machine tools where rigid machine structures are difficult to achieve.

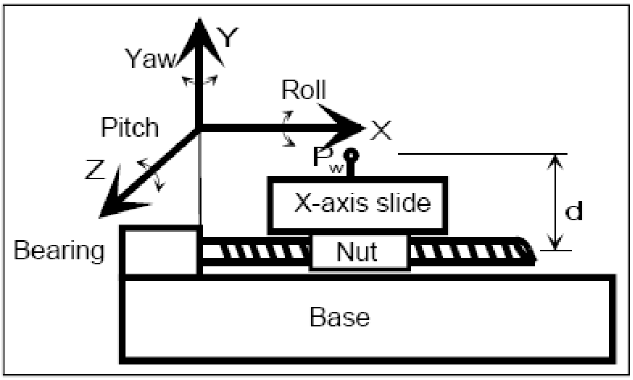


Fig. 2 *Offset distance from axis to the worktable that magnifies the error at control point*

Geometric errors are regarded as the machine errors which exist under cold and warm up conditions and that and which do not change with time (they have good repeatability). 75% of initial errors of a new machine tool arise as a result of manufacture and assembly. Major geometric errors are roll, pitch, yaw and squareness errors. All three axes are prone to these errors, thereby causing 21 common geometric error terms. These types of errors originate from the manufacturing or assembly defects of different parts of the machine. These errors include link length error, angular error, straightness error, squareness error, parallelism, perpendicularity error and zero position error. Time to time collisions may destroy the work piece and change the geometry and drive elements of the machine. These types of errors vary with time slowly. This means that the machine repeats the same error again and again for some duration. In the case of assembling the machine tool, the designed state and assembly state exerts an important effect on the accuracy of the machine tool. All sliding components of machine tools show roll, pitch and yaw (RPY).

Though these angular errors are very small, they magnify the final tool tip error due to the abbe effect. If *x a* is roll error at any point on X-axis, the positioning error in the Z direction is *Z a d x* D = × with small angle assumption. If the X-axis has a roll error of .001 degree (CW negative direction) and the distance is 500 mm (d, from center of nut to work piece), the positional deviation in the Z direction is 8.73 micrometers. It has the of rotating a line on the YZ plane with an angle *x a* in the CCW direction. That means, if the angular error is in the CW direction the location of W P will be in the negative Z direction. These types of positional error always exist if the machine tool is not calibrated properly with time to time and the error is not taken into account. The major reasons for these types of errors are the profile and form errors of the saddle, base and guide surfaces and thermal distortion. Additional factors such as wear and foundation effects may also influence the errors.

3. ORIGINS OF MACHINE TOOLS ERRORS

Numerous error origins affect tool tip position. Among the key factors that affect the accuracy of this relative position are the geometric errors of the machine tool and thermal effects on the machine tool axes. Other error origins are the resolution and accuracy of the linear measuring system, elastic deformation of drive components, inertia forces when braking/accelerating, friction and stick slip motion, the servo control system and cutting force and vibration. For a multi-axis machine, the calibration should include each axis and its roll, pitch, yaw, squareness and positioning error in the workspace. The static working load and the mass of the work-piece being machined produce distortions that result in positioning errors in the machine tools.

In general, CNC machine tool inaccuracy is caused by:

- Geometric errors of machine components and structures,
- Errors induced by thermal distortions,
- Friction in drive system,
- Deflection caused by cutting force,
- Servo control system,
- Random vibration.

Machine tools error origins can be divided into two classes, systematic and random errors from an analysis point of view. Systematic errors are those, which we are able to describe and predict the amount in machine tools workspaces. On the other hand, random errors are difficult and complex to describe. Geometric errors dominate in systematic errors and the major origins are ball screws, guide ways, bearings etc. Ball screw pitch error, inaccurate production, wear in guide ways etc. are factors that contribute to geometric error. Geometric error has good repeatability and changes gradually with time. A machine tool operates also in non steady state due to thermal distortions. Different parts of machine tools are deformed based on thermal flux. There are two majors kinds of heat sources for machine tools: external, for example, room temperature, sun rays etc. and internal which are generated by internal friction among different components of the machine. Uneven dynamic characteristics will lead to the generation of vibrations. There are two kinds of vibrations,: self excited vibration and externally excited vibrations. The control system and measuring system of the machine itself affects positioning error. For semi closed loop type there is no direct measuring system. On the other hand, for a closed loop there is a direct measuring system. For semi closed loop, the pitch of the ball screw is used to calculate the position of the table, while closed loop measuring system gets the measured variable directly from the scale.

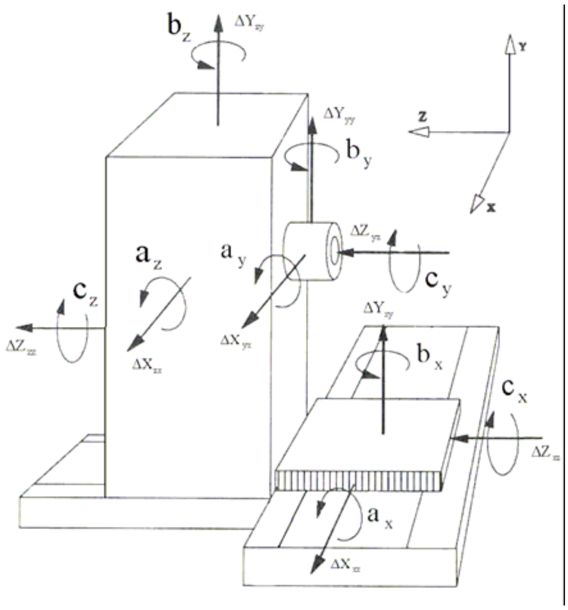


Fig. 3 *CNC machine's geometric error*

4. LASER MEASURING OF CNC MACHINE TOOLS

A laser interferometer can measure the whole working space with the desired interval selected by the users. Intermediate measurement values can be obtained by interpolation. By laser methods, using different optics one can measure linear error as well as angular errors. One can compare one axis with another and find which axes cause error for a particular problem. With a laser it is easy to detect local error such as pitch and yaw at a particular point of the working space. The laser interferometer is based on the principles of the Michelson interferometer. The major drawbacks of laser measurement systems are that we obtain information about an axis at one time and it takes quite a long time to achieve the results of the whole working volume. The measurement does not tell any information about the dynamic behaviour of the machine such as cross coupling effects (effects of simultaneous movements of two or more axes at a time), squareness error between two axes that are quite common for medium to large size machines. By special optics, it is possible to measure squareness error between axes. Also, the measurement is done without a real working load. Significant motion error depends on the cutting processes. These could be the material being cut, feed rate, depth of cut, cutting tool, cutting lubricant, fixture etc. Laser measurement is still a popular measuring system despite the drawbacks. The laser interferometer is an old technique, and has been used extensively in the past to observe a machine tool's motion error conditions. It may take up to two days to measure a medium size machine for all error components. In this method, each axis (which one is being measured) moves independently while the others are kept in a fixed position. A process computer can take measurement results with a certain interval, which it can plot on the computer screen, where we can see the results visually. The information about the intermediate point is calculated based on interpolation if necessary. It is not possible to predict from this result the behaviour of dynamic error without proper analysis of the machine tools and the measurement results.

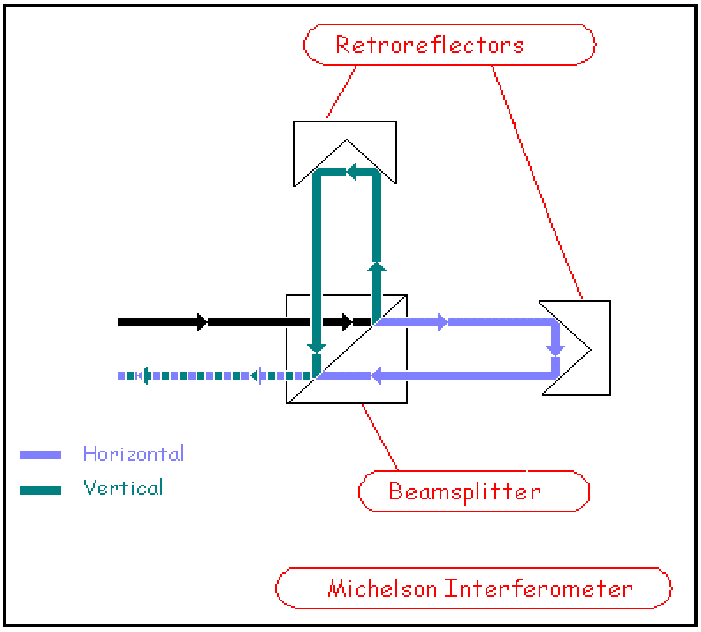


Fig. 4 *Michelson interferometer - principle of laser measuring*

With a laser interferometer we are able to detect the following errors for a particular axis:

- Positioning error,
- Pitch error,
- Yaw error,
- Squareness error with special optics.

An individual axis is measured at a time while keeping the other axis in a fixed position. This means that the errors of other axes do not affect the result of the measured axis. A laser measuring system is static in nature.

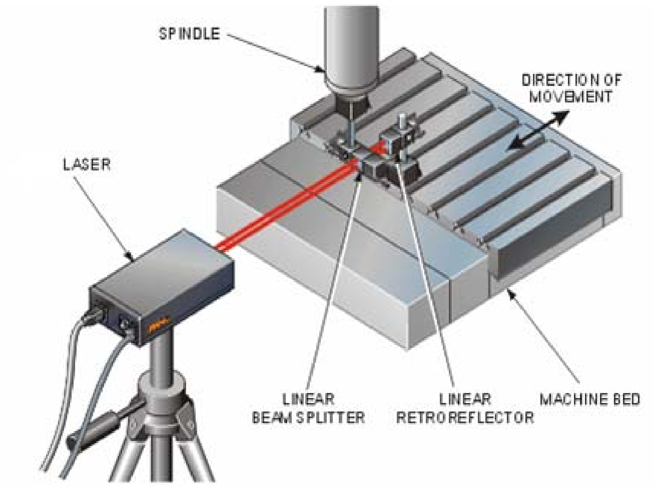


Fig. 5 *Standard set up by laser measuring of machine tool*

5. XL-80 LASER MEASUREMENT SYSTEM

The new Renishaw XL-80 laser measurement system offers high performance calibration for motion systems, including CMMs and machine tools**.** Renishaw has been designing, manufacturing and supplying Laser Interferometer Systems for over 20 years. The new XL-80 laser system available from MD Calibrations offers greatly increased portability, system accuracy and improved dynamic measurement performance. It is quicker and easier to use, while retaining the benefits of a pure interferometer based system, a proven technology that has made Renishaw Laser Systems the preferred choice worldwide Renishaw's laser interferometer systems are used for comprehensive accuracy assessment of machine tools, co-ordinate measuring machines CMM and other position-critical motion systems. The XL-80 laser produces an extremely stable laser beam, with a wavelength that is traceable back to national andinternational standards. The laser frequency stability is specified as ±0.05 ppm oveyear and ±0.02 ppm over 1 hour. This excellent performanceis achieved by dynamic thermal control of the laser tube length to within a few nanometres. The XL-80 laser produces an extremely stable laser beam with a wavelength that is traceable back to national and international standards. The laser frequency stability is specified as ±0.05 ppm over 1 year and ±0.02 ppm over 1 hour. This excellent performance is achieved by dynamic thermal control of the laser tube length to within a few nanometers. Linear measurement accuracy is an assured ±0.5 ppm over the whole environmental range i.e. from 0 °C - 40 °C and 650 mbar - 1150 mbar. Readings are taken at 50 kHz, with a maximum linear measurement speed of 4 m/s and a linear resolution of 1 nm; even at maximum speed. As the XL system uses interferometry as the basis for all its measurement options (not just linear), you can have confidence in the accuracy of all your measurements. With integrated USB there is no requirement for a separate laser-to-PC interface. The laser also features an auxiliary analogue signal output as standard, with quadrature output a factory option. The same socket also accepts a trigger signal input for data capture synchronization. LED status lights, indicating laser status and signal strength provide back-up to the software's "on-screen" indicators. Together with a switchable long range mode (40 m - 80 m) and a warm-up time of less than 6 minutes, these features make the XL-80 quick and easy to use. An external, switch mode power supply ensures 90 V - 264 V

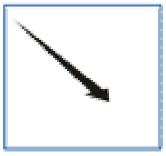
Fig. 6 *Workplace of Renishaw XL 80 with integrated PC and compensator unit XC 80*

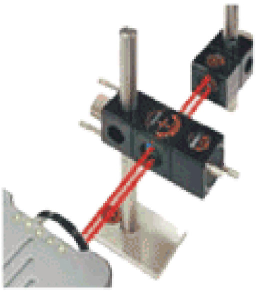
The accuracy of a laser distance measurement system is primarily dependant on how well the system can compensate for the effects of air refraction changes on the wavelength of the laser. Without this compensation, accuracy of any system is significantly compromised. The XC80 compensation unit continually monitors the surrounding environment by collecting data from highly accurate sensors which measure the ambient air temperature, pressure and humidity. From this data, the unit calculates the true laser wavelength using Edlen's equation. The XC-80 compensator is a key factor in your XL system's measurement accuracy. Featuring 'intelligent sensors' that process the readings at source, the compensator very accurately measures air temperature, air pressure and relative humidity. Up to three material temperature sensors can also be attached to the XC-80 compensator to allow linear measurements to be normalised to a standard material temperature of 20 °C.

Fig. 7 *Compensation unit XC 80 with two sensors*

6. MEASURING POSSIBILITIES

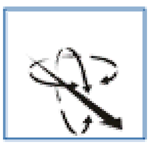
Linear

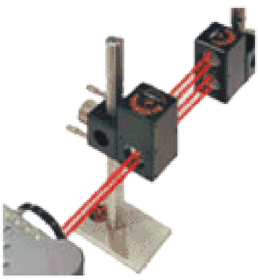




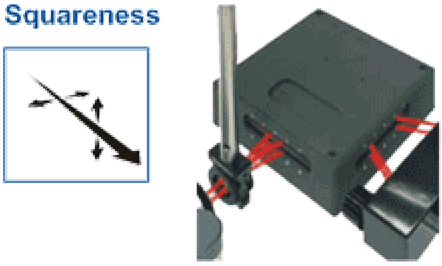
This is the most common form of measurement performed on machines. The system measures linear positioning accuracy and repeatability by comparing the position displayed on a machine’s readout with the true position measured by the laser. These values can then be viewed, printed and statistically analysed by the system’s software to national and international standards. On many of today’s machine tools, it is also possible to take this process one step further and automatically download the measured data to a compensation table in the machine’s controller. In this way, a machine’s positioning accuracy can be verified and significantly improved, quickly and easily.

Angular

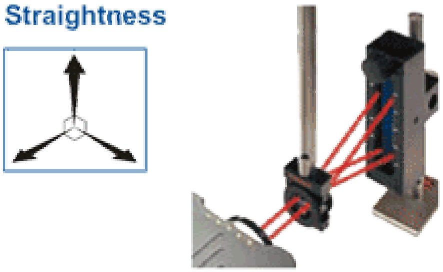




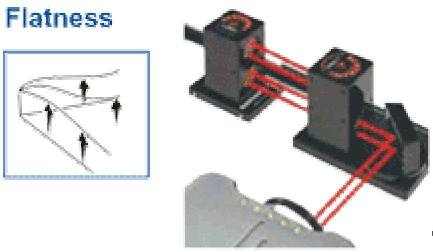
Pitch and yaw angular errors are among the largest contributory factors to positioning inaccuracy in machine tools and measurement accuracy errors on CMM.



Squareness measurement determines the out of-squareness of two nominally orthogonal axes, by comparing their straightness values. Squareness errors could be the result of wear in machine guide ways, an accident which may have caused damage, poor machine foundations or misaligned home position sensors on gantry machines. Squareness error will have a direct effect on the positioning accuracy and contouring ability of a machine.



Straightness measurements highlight any bending component or overall misalignment in the guide ways of a machine. This could be the result of wear in these guide ways, an accident which may have damaged them in some way, or poor machine foundations that are causing a bowing effect on the whole machine. Straightness error will have a direct effect on the positioning and contouring accuracy of a machine.



This measurement is performed to check the accuracy of CMM table sand all types of surface plate. It determines whether any significant errors in form exist and,
in turn, quantifies them. If these errors are significant to the application of the flat surface, then remedial work, such as further lapping, may be required.

7. CONCLUSION

The new XL-80 laser measurement system offers high performance calibration for motion systems, including CMMs and machine tools. The size of the XL-80 laser and XC-80 compensator means that a complete linear system can fit into a 'wheelie-case' and weighs only 12 kg. The legacy continues with key virtues of accuracy, reliability and durability in day-to-day use and with advanced software solutions and superior performance. Of course all measuring are done with a help of newest software. This makes the measuring more practical, quicker and more accurately for all technicians and researches in industry.

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