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Application of laser in machine tool and metrology measurements, calibration and testing

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Abstract. Significant increase in demands on machine tool accuracies has imposed stringent requirements on quickness and accuracy of measurements and calibration. More so with the increasing application of sophisticated control system such as NC (Numerical Control) in the Metalworking Industry, resulting in higher repetative accuracy, laser has come in as a very versatile measurement tool, satisfying the stringent requirements of accurate measurement and with quickness, which with conventional measurement systems is almost an impossibility.

The Delphi system of forecasting on Engineering technology predicts that demands for increased accuracy and resolution of machined workpieces are going to reach within a few more years such orders as to call for machine tools with positioning accuracies of the order of microns and fractions of microns (micron = 0·001 mm.) Highly reliable, technology rich modern machine tools having sophisticated control, systems such as N.C., C.N.C. designed to operate reliably, continuously, with automatically monitoring and adjusting devices, are gradually being introduced in the manufacturing industry. Requirements of measurement on such sophisticated machine tools are finer measurement accuracies associated with fast calibration and measurement techniques.

Parameters, like positional accuracies of slides and coordinate tables, angular measurements including pitch and yaw, straightness of movement, guide alignments etc., constituting geometrical properties, controlling the workpiece accuracy produced by machine tools can be measured very accurately with the help of Laser, associated electronics and optics and at rates much faster than conventional measuring equipment.

The needs of production technology on machine tool accuracies and thereby demands on measurement engineering capabilities are far reaching. They call for a total revitalization of calibration and inspection standards and equipment. It is in this context that the advent of laser interferometer together with digital electronics and data acquisition system, has emerged as a powerful measurement tool assisting the dimensional metrologist and the machine tool builder to check for higher accuracies.

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Hitherto the calibration and testing of machine tool was done using conventional gauges and equipment such as gauge bars, slip gauges, dial indicators, mandrels, levels, autocollimator, encoders, travelling microscope, taut wire and an assortment of electronic and electromechanical gauging systems. No doubt some of these are quite accurate and they cannot also be (overruled under circumstances) discorded totally but considering the time factor they have proved inadequate to meet the demands of complicated machine tools. Added to the time factor, the periodic calibration of the gauging system themselves. due to wear and tear and other factors like susceptibility to thermal dilatation, handling etc., deters one to adopt the conventional gauging or measurement systems It does not mean that these systems have to be totally discarded it is simply that they are good for most of the general purpose applications and for higher accuracies and high speeds of measurement the Laser Interferometric measurement system, described in this paper offers high degree of versatility and capability.

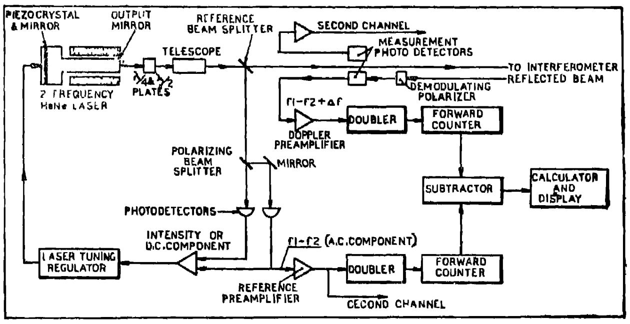

Figure 1. Laser measurement system

2. The principle of operation of the laser system

A low-power helium-neon laser operating at 6328 Å emits a coherent light beam composed of two slightly different optical frequencies, f_1 and f_2 obtained by Zeeman splitting by passing the beam through an axial magnet (Figure 1). The two beams are of opposite circular polarization. After conversion to orthogonal linear, polarizations the beam is expanded and collimated, then directed to the reference beam-splitter where a small fraction of both frequencies is split off.

This portion of the beam is used both to generate a reference frequency and to provide an error signal to the laser cavity tuning system. The difference in the DC levels of f_1 and f_2 is used for continuous cavity tuning to hold the center frequency constant corresponding to 6328 Å i.e., atomic transition in neon gas. The cavity design of the laser satisfies the requirement of low reflection loss by using a sturdy plasma tube with very small coefficient of thermal expansion in the laser tube. The tuning is controlled by a servo-loop which includes mirror on a piezo-electric wafer transducer and electronic circuitry. The loop monitors the intensities of Zeeman split lines and keeps them equal by varying the voltage on the piezo-electric element on which the mirror is mounted, thus varying the cavity length. The ac component of the difference between f_1 and f_2 (about 2 MHz) is used for internal reference and goes to a counter in the Laser display.

The major portion of the beam passes out of the Laser Head to an interferrometer. Interferometers (Michelson type Ref. figures 2 to 4) measure relative displacement of two objects by splitting the beam into two legs (f_1 and f_2), directing them to two retro-reflectors or Wollaston prism and inclined mirrors for straightness measurement (Ref. figures 2 to 4) and returning the resultant signals to a photodetector in the Laser Head. Relative motion between the retro-reflectors causes a difference in the Doppler shifts $\Delta f, \Delta f_1, \Delta f_2$) in the return frequencies, thus creating a difference between the frequency observed by the measurement photodetector and that seen by the reference photodetector. This difference is monitored by a subtractor and accumulated in a fringecount register.

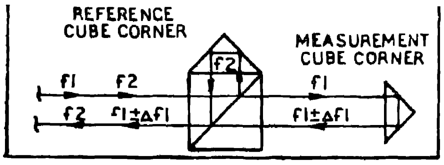

Figure 2. Linear displacement interferometer

A digital calculator samples the accumulated value and performs a two-stage multiplication, one for refractive index correction and the other for conversion to inches or milli-meters. The resultsing value is updated and displayed.

Accuracy of interferometric measurements is limited to only the laser frequency and wavelength. Laser is basically a frequency standard. This frequency standard could be used as a length standard through the well established laser wavelength.

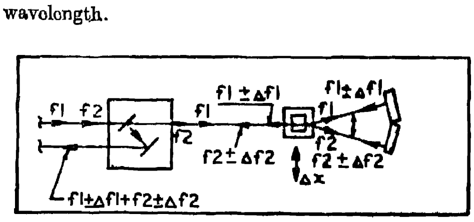

Figure 3. Straightness interferometer

A measure of an interferometer's ability to operate under adverse conditions is the maximum loss of intensity. The two frequency interferometer using double frequency laser tolerates more than 90%. This additional margin of safety also frees the two-frequency interferometer from periodic electrical adjustments. There are no adjustments for beam intensity or triggering threshold. Furthermore, the interferometer tolerates signal variations produced when the reflector is rotated enabling it to take measurements such as dynamic growth of a lathe spindle resulting from bearing self-heating.

3. Applications

The primary application of the described system (Ref. figures 5 to 7) is in calibration of numerically controlled machine tools in the machine shop and coordinate measuring machines in metrology labs. The Laser beam can be aligned parallel to the axis of a machine tool or measuring machine in a few minutes.

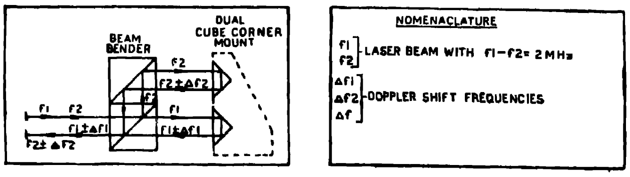

Figure 4. Angular/flatness interferometer

Because the laser head requires no warm-up, calibration may begin immediately. Complete calibration of a three axis machine tool with a printed record and or graph of errors against command position can be accomplished in a fraction of an hour, compared with several days required by conventional methods. In addition conventional methods do not offer scope for automatic error ploting.

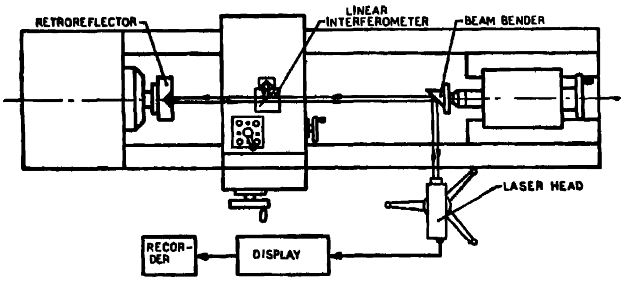

Figure 5. Positional accuracy of N C lathe carriage movement

A word on the capability of the described laser equipment, from the personal experience of the authors will not be out of context. This equipment was used to calibrate a number of boring machines six in all, fitted with digital read-outs and Moire fringe gratings. Resolution of these grating scales was 0·002 mm and expected machine positioning accuracy was 0·01 mm. The axes to be calibrated were 1·5 metres long each. In all eleven axes were calibrated in eight days adopting NMTBA (National Machine Tool Builders Association, USA) specifications involving statistical analysis of errors over a minimum of seven calibration runs per axis. Apart from this, scales on two axes horizontal and vertical, on an imported jig-boring machine were readjusted to realise the original accuracy ±·007 mm of the machine, which had been lost over a period of use. This entire work, by conventional methods, would have consumed three man months as against eight days of using Laser.

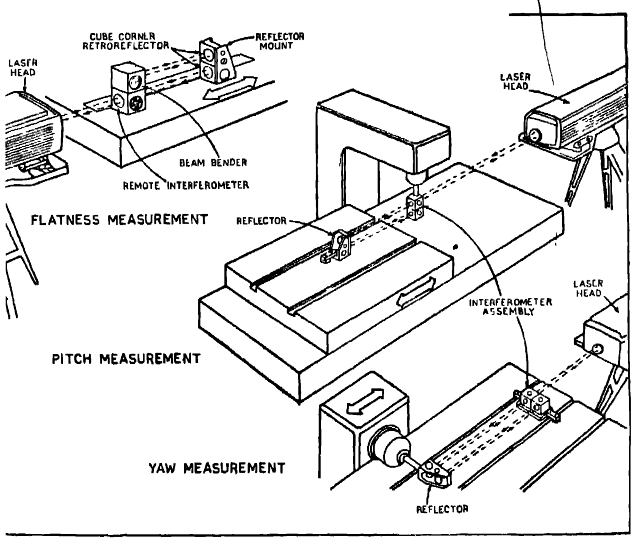

Figure 6. Set-up for flatness, pitch and yaw measurement

It is also possible to measure on inclined axis positional and other measurements quite easily with this equipment using a beam deflector mirror or prism.

Since the laser interferometer also measures velocity, it is possible to calibrate machine tool feed rate simultaneously while positioning accuracy is being measured.

It is particularly noteworthy that metrological calibrations may be performed continuously rather than in discrete steps as required with gage blocks. The error plotting option generates a continuous plot of leadscrew error versus position that allows the metrologist to see short-term variations in lead (leadscrew drunkenness) which otherwise might be obscured by the 'synchronous sampling' of gage blocks. Also the error incurred by transferring a measurement from a part to a stack of gauge blocks can be avoided.

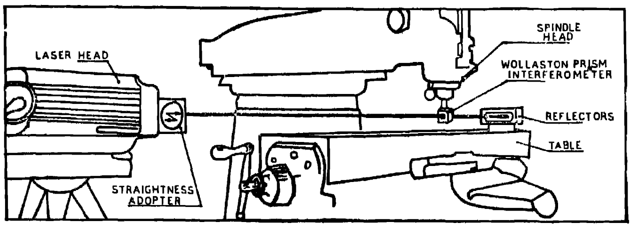

Figure 7. Straightness set up on a milling machine

Laser interferometers are already in use as a precision option on conventional NC machine tools that have their own built-in position transducers. With this arrangement it is possible to machine to normal tolerances with NC. Then for precision machining, the controller turns the machine over to the operator who manually positions one axis at a time using the laser interferometer. An example of such a use is the precise location of dowel holes in a large part.

Apart from machine tool calibration, Laser is used in Metrology applications such as calibration of line standards, slip-gauges, flatness of surface-plates etc. In large scale metrology (6, 7), it has been reported that Laser has been used along with spherical axicons and quadrant detectors for alignment and angle measurements over distances as large as 10 meters and above.

Scanning type Laser levels along with ranging rods fitted with active detectors (7) capable of searching and locking on to generated laser beam plane have been used to generate true virtual planes, with respect to which deviations of actual (real) planes could be measured. Such a system has been used, along with computerised data logging and estimation, by National Bureau of Standards USA, forc alibrating volumes of huge tanks on ships used for international custody transfer of Liquified Natural Gas (LNG Tanks) to an accuracy of around 0·1%. In custody transfer the most important factor happens to be "faith" in the accuracy of measurement, which has been possible with the advent of Laser, associated optics and digital electronics.

In conclusion, the Laser measurement system is a unique device (an off spring of electro-optic and digital electronics) which has capabilities of multi-purpose measurement like positional accuracies, angles, straightness, flatness, feedrate movement etc., Ref. figures 5 to 7 and with measurement accuracies and speed of measurements unheard off before. It is a new tool for measurement. Although Laser Interferometer measures distance and velocity with higher range and increased accuracy, it is nevertheless practical and economical to use it even for making gross low-accuracy measurements, since it is fast and easy to use.

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