

A DIAMETER MEASURING SYSTEM WITH LASER INTERFEROMETER

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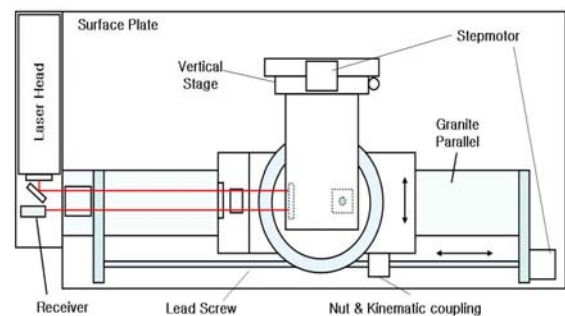
INTRODUCTION

The diameter measurement of ring, plug and sphere is very important in dimensional metrology. The measurement of diameter is generally carried out by a comparison method using a ring gauge comparator. Recently the commercial comparators using laser interferometer or precision linear encoder were introduced. The accuracies of these instruments are larger than $0.5 \mu\text{m}$. A laboratory uses the coordinate measuring machine cooperating a laser interferometer and a precision probe. It provides good performance but has a limitation on operation as coordinate measuring machine. However the comparison method requires a reference gauge block, which is traceable to meter unit. So this method is time-consuming due to wringing gauge block. And it is not accurate comparing to the absolute method. So several national metrology laboratories (NMLs) designed and fabricated their own equipment using a laser interferometer.[1,2]

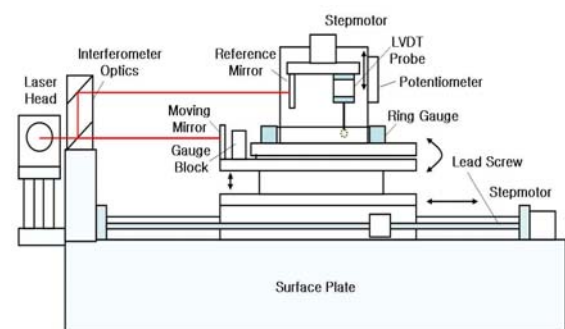
Korea Research Institute of Standards and Science developed a multi-purpose linear measuring interferometer to calibrate step gauge, end bar and diameter of ring or plug gauge.[3] Even if it can measure the diameter, its main purpose is to measure a step gauge. Therefore, in measurement of diameter, it can not provide good performance. For this reason, we designed and fabricated a new comparator which can measure a diameter of ring and plug up to 300 mm diameter. In addition to diameter measurement, the system measures a short line scale such as stage micrometer.

SYSTEM FABRICATION

The principal requirement is achieve a measurement uncertainty in the order of $0.05 \mu\text{m}$ to $0.2 \mu\text{m}$. On designing the system, we mainly consider the simple structure and the small size. Fig. 1 shows the structure of the diameter measuring system. The instrument is an Abbe-type comparator. The base of the instrument is a granite table (940 x 460 x 200 mm). All components are sat on this table.



(a) Top view.



(b) Side view

Figure 1: A schematic diagram of the diameter measuring system.

Translation system

An air bearing linear stage, which has a moving range of 400 mm, is installed on granite table. It is horizontally driven by a backlash-free lead screw with a step motor and its position is controlled by the laser interferometer. The lead screw is not perfectly parallel to the linear guide, even more there is a natural deflection on the lead screw caused by its own weight. Then the movement of the nut should be transmitted to the carriage in one direction. This is achieved using a flexure type coupling which is machined by a wire cutting machine. The stiffness of the flexure is high enough in the direction of the movement and provides an accurate movement to carriage, but in perpendicular directions to the movement it can be deformed and can reduce the transmission of distortions to the carriage.

The adjusting facility, which specimen is sat on, is fixed on the carriage. It provides the vertical and horizontal displacements and the angular motion to align the specimen. This stage is operated by hand. The moving mirror for interferometer, the reference gauge block for calibration of probe ball diameter and the specimen are sat on the adjusting table.

The vertical stage with an inductive probe and a reference mirror is fixed on a granite table and used to move the inductive probe to other measuring surface of the plug or the reference gauge block without crashing. It also is driven by a ball screw with a step motor. It also carries the reference mirror for laser interferometer. Its position is controlled by a linear potentiometer because it does not require accurate position. In our system, the motion accuracy of the vertical translator is not important because it only provides the vertical positioning of the probe, so we use a cheap commercial translator.

Displacement measurement

Measurement of the displacement of the air bearing stage is realized by the laser interferometer that consists of a commercial laser head (HP 5517C) and a home-built interferometer with the double pass arrangement. The laser interferometer provides a resolution of 5 nm. The system has a configuration to avoid the Abbe offset between the measuring line of a specimen, the axis of the laser beam and the center of the inductive probe ball. Thanks to this arrangement, the Abbe offset can be minimized. To compensate the wavelength of the laser, air pressure, temperature and humidity are measured. And two thermister sensors are used to measure the temperature of the specimen and correct the thermal expansion of the specimen.

Probing system

The probing system is sketched in Fig. 2. For the probing system, a home-built parallelogram with a spherical ruby ball probe is used. It is made of Invar and machined by a CNC wire cutting machine. The displacement of the parallelogram is measured by a LVDT. The probe is bi-directional and measuring force adjustable. The measuring force is proportional to the deflection and the force at 0.5 mm deflection is about 0.1 N. Its measuring range is about ± 0.5 mm. By controlling the current of the solenoid coil, the measuring force can be

also adjusted. Due to solenoid coil, the probe can be used as a real zero detector because it can generate pre-force. It has to be noted that probing is performed in real zero position on left and right contact in case of using the solenoid coil. However in this probe, we can detect the measuring surface and adjust the measuring force without the solenoid coil. The difference between probe output and target is used as error signal to control the motor of air bearing stage.

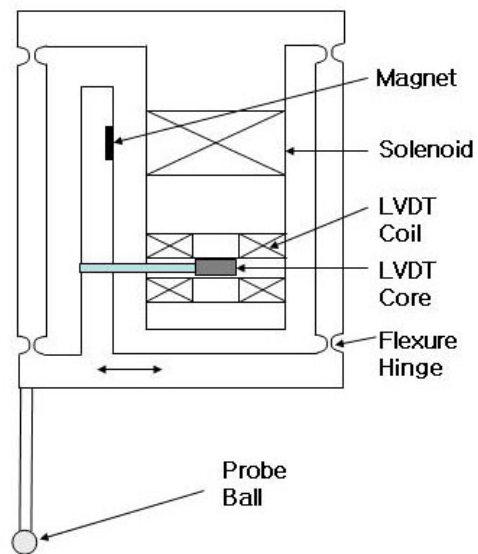


Figure 2: Probing system.

Electronic controller

Fig. 3 shows the schematic diagram of the electronic controller. The system is fully controlled by a PC. The position data is obtained through a HP laser board and it is corrected by compensating the vacuum wavelength. The temperature, pressure and humidity of the air are measured by VAISAL PTU 200 and the refractive index of air is calculated by Edlen's formula. The image of the line scale is captured by CCD camera and is processed to determine the center of the graduation at image board. (see chapter "Operation system") The signals from two material temperature sensors, LVDT probe and potentiometer are changed into a digital signals by a 24 bit AD converter. The measuring force of the probe is generated adjusting the current of the solenoid through a 16 bit DA converter. Two step motors are driven by a microstep driver (46,080 step/1 revolution) through digital IO port of the data acquisition board.

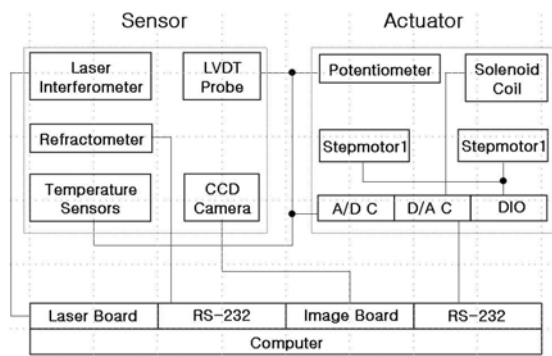


Figure 3: Schematic of an electronic control system.

OPERATION SYSTEM

The system is in the environmental controlled laboratory. The air temperature and relative humidity are controlled at 20 ± 0.5 °C and below 50 % respectively. The variation of the air temperature in the laboratory is below ± 0.05 °C per one hour. Usually the linear artifact to be measured has temperature variation of 20 ± 0.15 °C.

In order to reduce the dead path error and the effect of the air turbulence, the artifact is positioned as close as possible to the interferometer optics. And also it must be aligned coaxially with the center of laser beam to minimize the Abbe error and the cosine error. In the system, artifact can be easily aligned within Abbe offset of 1 mm and cosine deviation of 1 minute. To determine the Abbe error, pitch and yaw error of the carriage are measured. Fig. 4 illustrates the angular errors of the carriage during travel of 400 mm. The figure shows the pitch error is about ± 2 ". This results in 0.01 μm Abbe error.

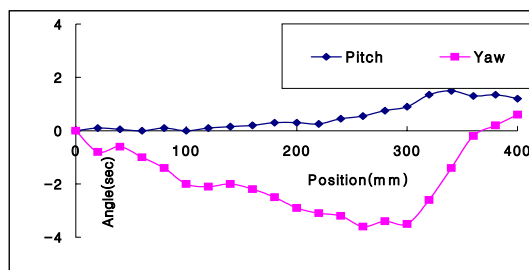


Figure 4: Angular motion errors of the horizontal stage.

Before and after each measurement, the air temperature, pressure and humidity are measured and the refractive index of the air is calculated using the modified Edlen's equation. And also material temperature is measured to compensate a thermal expansion. On measuring the diameter, a 20 mm reference gauge block is used to calculate the effective probe diameter. The stylus constant (effective diameter of stylus), which is the difference between left and right probing, is given by the diameter of the sphere of the stylus, compression of the sphere and the specimen to be measured, and asymmetry of the bi-directional probing system. This gauge block has been measured on a gauge block interferometer with an uncertainty of 25 nm. The computer controls the position of a horizontal stage and a vertical stage to allow the electronic probe to touch one measuring face and move to other measuring face. In order to detect the measuring face of artifact, the horizontal stage approaches to the measuring face with speed proportional to the output of the LVDT probe. And it stops when the absolute value of the probe reading is smaller than about 0.5 μm . Then a computer latches and takes the probe reading and the laser interferometer reading. The position of the measuring face is determined by the laser interferometer reading, the probe reading and the effective probe diameter. The system measures the front and rear faces of artifact in sequence automatically.

We have a 2 m line standard interferometer. It is accurate and precise enough to measure a standard scale, but it is very difficult to install and align the short line scale. So we modified the diameter measuring system to measure the short line standard such as a stage micrometer. For the measurement of line scales, an optical microscope with a CCD camera is used. The image processor board captures the image of the scale marker and displays it on the CRT monitor with reference cross line, which is generated by computer. The coincidence of the scale marker with the reference cross line is carried out observing the image of scale marker displayed onto CRT monitor. After the position of the reference scale marker is determined, the horizontal stage is automatically moved to the predefined position for measuring the next line. In the system, we can automatically determine the center of the line using the image processing technique.

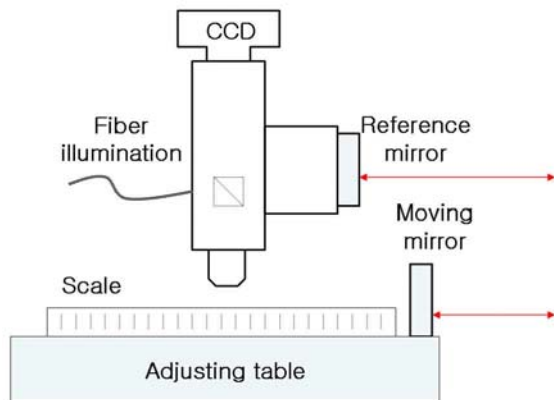


Figure 5: Measurement with optical microscope for the calibration of short line scale.

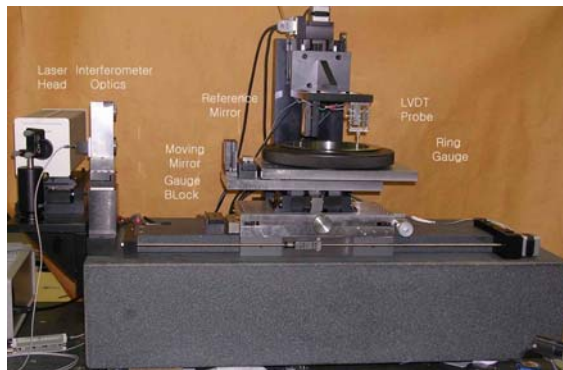


Figure 6: Picture of a diameter measuring laser interferometer.

Conclusion

The diameter measurement of ring, plug and sphere is very important in dimensional metrology. Traditionally diameter is measured by comparing with master gauge block or absolutely measured by the laser interferometer. Korea Research Institute of Standards and Science designed and fabricated the diameter measuring system traceable to SI unit. The principal requirement of the system is achieve a measurement uncertainty in the order of $0.05 \mu\text{m}$ to $0.2 \mu\text{m}$ for diameter up to 300 mm. It has the simple structure and the small size. The instrument is an Abbe-type comparator which can reduce Abbe error. The system is fully automatically operated. The system can be also used for measurement of short line scale up to 400 mm. Now we are testing the performance of the system and evaluating the measurement uncertainty.

ACKNOWLEDGMENTS

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REFERENCES

- 1.M Neugebauer, F Ludicke, D Bastam, H Bosse, H Reimann and C Topperwien, 1997, Uncertainty of Diameter Calibrations with the Comparator for Diameter and Form, *Meas. Sci. Technol.*, 8: 1053-1058.
- 3.R. Thalmann, 1997, A New High Precision Length Measuring Machine, *8th Congress International de Metrologie*, 1-4.
- 3.TaeBong Eom and Jin Wan Han, 2001, A Precision Length Measuring System for a Variety of Linear Artifacts, *Meas. Sci. Technol.* 12: 698-701.