A multi-purpose linear measuring system with laser interferometer

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Abstract
The paper presents a new linear measuring machine being designed and fabricated in the Korea Research Institute of Standards and Science. The main requirement of the machine is to achieve a flexibility to calibrate a variety of different standards such as step gages, line scales and gauge blocks with high accuracy. The main parts of the system are a precision linear stage, an alignment system for the specimen, a system for detecting measurement points, and a laser interferometer. Measuring range of the system is 1,000 mm, and target accuracy for 1,000 mm gauge block calibration is 0.35 um at the 95% confidence level.

Introduction
Most of demands on dimensional measurement are related to the linear measurement. The national metrology laboratories should maintain the primary standards such as end standards and line standards. These length standards are usually calibrated using the precise and accurate laser interferometers that are designed to operate in temperature-controlled chambers. Many kinds of interferometric calibration systems for gauge blocks or graduated line scales have been built at many national metrology laboratories. These systems need larger outlay of equipment and larger metrological effort. Recently demands of industry for the calibration of a step gauge, which can be used in calibration of CMMs, is increased more and more, so many metrology laboratories have developed special calibration systems for step gauge. Some laboratories modified commercial machine such as coordinate measuring machine or universal measuring machine for their purposes, and others specially developed their own systems. Generally these calibration systems are designed for calibrating one or two artifacts, so standard laboratories need several calibration systems as well as spaces in order to measure a variety of different artifacts. [1-4] For this reason, 4 years ago, we designed and constructed the universal measuring system that could calibrate many kinds of linear artifacts from industry. [5] However, this system was not designed for calibrating standard grade gauge block or primary standard line scale.

To calibrate standard grade gauge block, standard line scale and step gauge, Korea Research Institute of Standards and Science have designed a new linear measuring machine. On designing, we consider accuracy as well as flexibility to calibrate many kinds of different linear artifacts. The main parts of the system are a precision stage, a detecting system and a laser interferometer. To detect the measuring surface of gauge block or step gauge, we designed the special probing system with flexure structure. A double-pass plane mirror interferometers based on the heterodyne technique measure the displacement of the stage. The laser interferometer has Abbe' error free structure.
Design and fabrication of the linear measuring system

Fig. 1 shows the structure of the linear measuring machine. System consists of six main parts: machine body, linear translating system, alignment system for measuring artifact, laser interferometer, detecting apparatus, and electronic system. The granite surface plate (2,200 mm x 400 mm x 450 mm) is used as a base of the machine body and a vertical guide of the linear translator. The granite parallel bar is fixed on the granite surface plate and used as the horizontal guide of the linear translator. The translating system, which carries the alignment system for measuring artifact, reference gauge block and the interferometer reflector, makes relative displacements between the measuring artifact and the detecting apparatus. This translator, which incorporates air bearings for smooth movement, is driven by the micro-stepping motor and the lead screw. It has a traverse length of 1,100 mm. (the maximum range in gauge block measurement is 1,000 mm)

Fig. 1 Schematic diagram of the linear measuring machine

The alignment system for linear artifact consists of a horizontal translator, two vertical translators and a swivel system. The horizontal translator is driven by a micrometer with a DC geared motor and used for selecting the measuring gauge block. The vertical position and tilt angle of the artifact can be adjusted by two vertical translators.

The displacement measurement of carriage is realized by a heterodyne laser interferometer (HP5518 laser head and home-built plane mirror interferometer). The measuring axis of length standards is vertically and horizontally on same position with laser beam incident on moving interferometer reflector in order to reduce the Abbe’ error. The reference beat signal and the measurement beat signal are detected before and after interferometer, respectively. These are sinusoidal signals with frequency of about 1.8 MHz. When the linear translator (moving reflector) moves $\lambda/4$ (about 0.16 µm), the phase between two signals changes 360°. In order
to encode the phase difference between reference signal and measurement signal of the heterodyne interferometer, the phase-quadrature mixing technique is used. Two outputs of phase demodulating electronics become sinusoidal signals with phase quadrature. Whenever the plane mirror moves $\lambda/4$, sine and cosine signals change $360^\circ$. These are resolution-extended up to X20 electrically. (interpolator : X5 and counter : X4)

Therefore the resolution of $\lambda/80$ can be obtained. (optical : $\lambda/4$ and electrical : X20)

The detecting apparatus is used to detect the measuring point of linear artifact. Two detectors are generally used. For probing the measuring surface of gauge block, step gauge and ring gauge, parallelogram with an inductive probe and a spherical ball probe is used. The parallelogram of Invar is machined by a wire cutting machine. A solenoid coil and a permanent magnet make attractive and repulsive force. An inductive sensor measures the displacement of the hinge spring. However it is usually used as a zero detector. The measuring force is adjusted electronically by controlling the voltage applied to the solenoid. For observing the scale of line standards and detecting its center, an optical microscope with CCD camera is also used. The detecting apparatus and the reference interferometer reflector are attached to a vertical translator driven by step motor. The vertical translator is a fixed on a bridge which is also rigidly fixed on the granite surface plate.

Fig. 2 Schematic of parallelogram sensor    Fig. 3 Schematic of electronic system

The linear measuring system is controlled by a personal computer (PC). The schematic diagram of an electronic system is shown in Fig. 3. Two step motors are used for driving the main translator and Z-translator. For fine positioning of main translator, micro-translator with a PZT is used. Air temperature, pressure, humidity and concentration $\text{CO}_2$ are measured and the refractive index of the air is calculated using the
modified Edlen equation. And also material temperature is measured to compensate a thermal expansion.

**Operation of the system**
In order to reduce the dead path error and air turbulence effect, the measuring object is positioned as close as possible to the interferometer. And the measuring object must be aligned coaxially with center of laser beam to minimize Abbe’s error and cosine error. On measuring the step gauge, ring gauge or gauge block, a reference gauge block is used to calculate the effective probe diameter. The computer controls the position of a horizontal stage (main translator) and a vertical stage (Z-translator) to allow the electronic probe to touch the front or rear measuring face. On touching the measuring surface, the main translator is controlled to stop at zero position of the inductive sensor. For measuring the scale, an optical microscope with a CCD camera and an illumination system 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.

**Conclusion and future work**
In order to calibrate a variety of different standards such as step gages, line scales and gauge blocks with high accuracy, we have designed the new linear measuring machine. Its main feature is similar to old one. However its target accuracy for 1,000 mm gauge block calibration is $0.35 \mu m$ at the 95% confidence level. This value is about 3 times better than uncertainty of the old system. (Expended uncertainty (k=2) of the old system is $(0.2 + 0.63 \times L) \mu m$, where L is in m.) Now we are integrating the electronic system, and we will evaluate the performance of the system.

**References**