

# 50 m LINEAR MEASURING INTERFEROMETER FOR CALIBRATION OF SURVEY TAPE

Don Young Jeong, Ho Suhng Suh, Jong Ahn Kim, Jae Wan Kim and Tae Bong Eom  
Korea Research Institute of Standards and Science  
Yousong, Daejeon, 305-340, S. Korea

## INTRODUCTION

Line standards such as survey tape and rigid rule still form important roles in the traceability chain for dimensional measurement. Their calibration is usually performed by a comparison method. The reference and measurement tapes are stretched side by side and the length difference of two graduations is measured. This comparison method requires a reference tape, which is traceable to length unit. Therefore the absolute measurement of the reference tape is required. Most of national metrology laboratories (NMLs) designed and constructed their own instruments.[1,2] Korea Research Institute of Standards and Science(KRISS) had designed and constructed a 50 m tape measuring system 20 years ago. Recently we modified it for automatic measurement. The image of the graduation of the tape is captured by the CCD camera of optical microscope and wireless-transferred to the computer. The computer determines the center of the graduation. And it also controls the stage position up to 50 m by wireless communication. In our system, the calibration of the tape is carried out by a comparison measurement as well as an absolute measurement traceable to SI unit of length and the long distance measuring instruments such as ultrasonic distance meter or lased distance meter can be directly calibrated by laser interferometer.

## SYSTEM DESCRIPTION

A 50 m linear measuring interferometer for the calibration of survey consists of a precision laser interferometer, a guide rail, a moving carriage, and optical microscope with CCD camera and an image processor. The entire instrument is housed in a 56 m tunnel where temperature is controlled. General view of the system is shown in Fig. 1.

### Rail system

The base of the system is a reinforced concrete pier, 51 m long, cast in 33 segments on the concrete floor. 32 steel plates, which cemented on the concrete pier, support the steel profile of

length 51 m which consists of rigidly bolted steel channel boxes, 3 m long, 0.1 m high and 0.35 m wide. The profile is constrained laterally but is free to move axially to accommodate the thermal expansion difference between concrete and steel. The track, on which the carriage moves and the surveying tape seats, consists of two rails which are made up of 42 ground rods of diameter 60 mm and length 3 m. 80 sleepers are rigidly fixed on steel profile at 0.65 m intervals. The sleepers support the rods and provide the lateral and vertical adjustments of rods for straight motion of the carriage.



Figure 1: Overview of the 50 m tape measuring system.

The straight motion of the carriage is very important. To obtain the good straight motion, two rails, which consist of ground rods, should be accurately aligned. First, using water level, the heights of both ends of the rails are adjusted to be same height. Using the laser beam and the position sensitive photodiode (PSD) fixed on the

carriage, the vertical and horizontal positions of the rails adjusted. Finally the electronic level is used to adjust tilting angle of the rails, which is related to the pitch and the rolling motion of the carriage.

### Carriage

The carriage, supported by 3 ball bushing bearings, is driven by a DC geared motor along the guide rail with rack gear. It is moved along the rail. On this carriage, a small translator with short moving range is fixed to provide a fine motion by micrometer. It also carries a corner cube of the laser interferometer and an optical microscope. The DC geared motor of the carriage is wireless-controlled by the computer. It has to be noted that the carriage can be manually driven by hand

### Tape support and tape tensioning system

In our system, the tape calibration is carried out by the comparison method or direct method by laser interferometer. In comparison method the reference and test tapes are stretched out side by side and the length of the test tape is determined in terms of the reference tape. This comparison method requires the reference tape traceable to meter. In order to reduce the friction between tape and tape supporting system, 80 round supporters are sat on the sleepers at 0.65 m intervals. The supporters are Teflon-coated to reduce friction and their height variations are less than 0.05 mm. Both ends of the tape are connected to hanging weights by wires.

### Detection of the graduation

At the absolute measurement by laser interferometer, the center of the line can be automatically determined. The line image of tape is captured by the CCD camera of the optical microscope and wireless-transferred to the frame grabber of the computer to calculate the deviation between the center of the line and the center of the field of view of the CCD camera. This deviation is used as error signal to control the motor. This signal is also wireless-transferred to control unit to serve the carriage until it reaches nearly zero. The distance between lines is calculated by the displacement of the carriage measured by laser interferometer and the deviation of the line center from the center of CDD. The rechargeable batteries at carriage supply the electric power for motor, CCD camera and lamp of microscope. This feature doesn't need the ducting for electrical

control signal and leads to a simple driving mechanism.

### Measurement of environment parameters

The temperature of tape is measured by 6 thermister probes. For calculating the refractive index of air, air pressure, humidity and air temperatures at 3 different positions were measured. The sensors are calibrated at laboratories of KRISS.

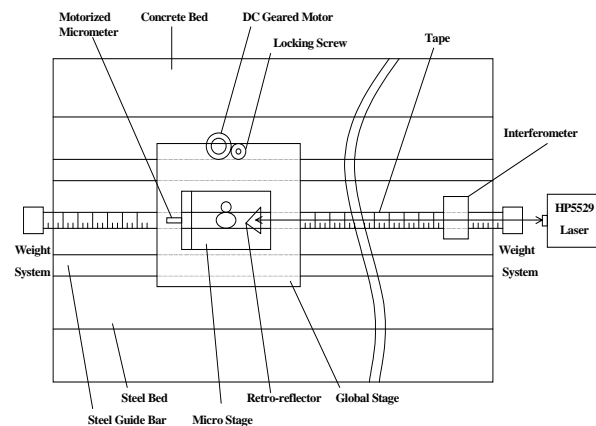


Figure 2: Schematic diagram of the tape calibration system.

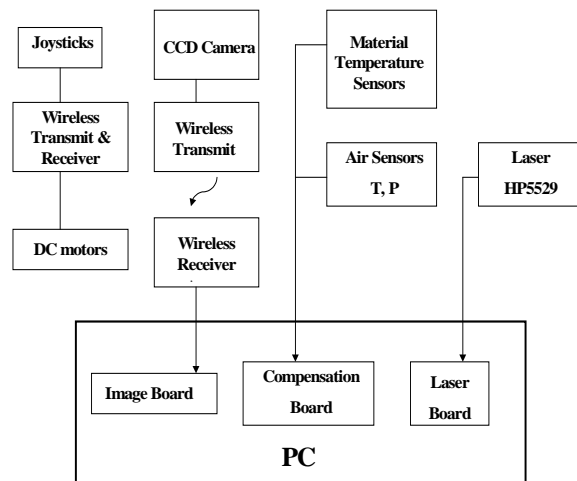


Figure 3: Electronic control of the tape calibration system.

## **MEASUREMENT SOFTWARE AND SYSTEM PERFORMANCE**

The software to control the system and determine the center of the graduation is written in LABVIEW. The software controls the DC motor to drive carriage, and it reads the data from laser interferometer and environmental

parameters such as air temperature, pressure and humidity. The displacement of the carriage is determined. The image of the graduation is captured by CCD camera and transferred to a frame grabber of the computer. The computer calculates the image profile and determines the center of the graduation. Finally the distance between the measuring graduation and the reference graduation is determined. In order to determine the center of the graduation, we use three different algorithms. First, the image profile over specified threshold level is fitted in even order 6<sup>th</sup> polynomial and the axis of the polynomial is used as the center of the line. Second, the left side and right side areas at the center of the image profile are calculated so that two areas are same. Third, the left and right edges of the image profile are determined at every intensity level of the image and the center of the graduation is calculated as an average of the centers of the left and right edges at all intensity levels. The difference between distances determined by three center detection algorithms depends on image quality and is usually less than 10  $\mu\text{m}$ .

Sources of uncertainty	Standard Uncertainty
Determination of center of graduation	11.6 $\mu\text{m}$
Abbe error (Pitch)	2.6 $\mu\text{m}$
(Yaw)	0.8 $\mu\text{m}$
Dead path error	0.2 $\mu\text{m}$
Laser frequency	$0.6 \times 10^{-8}$
Refractive index of air	$8.0 \times 10^{-7}$
Cosine error	$2.0 \times 10^{-8}$
Temperature measurement	$3.1 \times 10^{-6}$
Friction force	$1.0 \times 10^{-6}$
Drift	2.0 $\mu\text{m}$
Combined standard uncertainty	$(12.2 + 3.3 \times 10^{-6} L) \mu\text{m}$ , L: m
Expanded uncertainty (k = 2)	$(24.4 + 6.6 \times 10^{-6} L) \mu\text{m}$ , L: m

Table 1: Uncertainty evaluation in measurement of tape.

The Abbe offset in vertical direction can not be avoided in our system, so it is required to reduce the pitch error motion. In our system, the Abbe offset in vertical direction and horizontal direction are less than 25 mm and 4 mm respectively. Pitch and yaw error along

movement range of 50 m were determined using automatic autocollimator. Roll error was also measured by electronic level. Fig. 5 illustrates the angular error motions of the carriage during travel of 50 m in 1 m intervals.

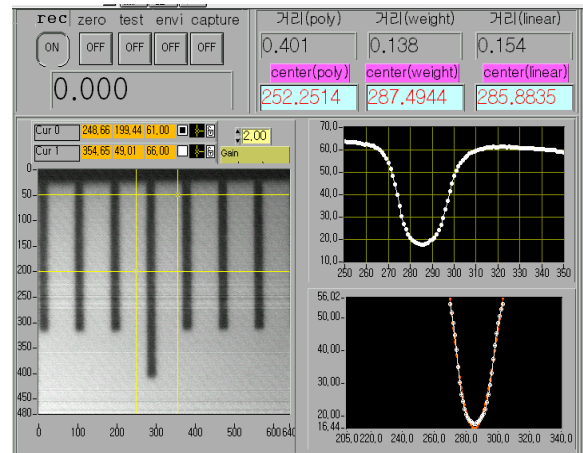


Figure 4: Output window of the software.

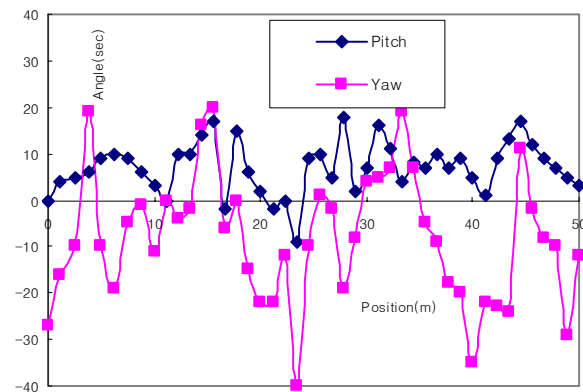


Figure 5: Angular error motion of the carriage over travel of 50 m.

The measurement uncertainty of the system was estimated according to the ISO guide for the expression of uncertainty in measurement. Details in uncertainty contributions are outlined at Table 1. As shown at table, main contributions are from determination of center of graduation, temperature measurement and friction force.

#### OTHER TASKS : TESTING EDMs

The system can be adapted to several other tasks. For example, ultrasonic distance meter and laser interferometer can be calibrated in this system. And also the short-range performance

of electronic distance meter (EDM) is tested in the tape measurement system.

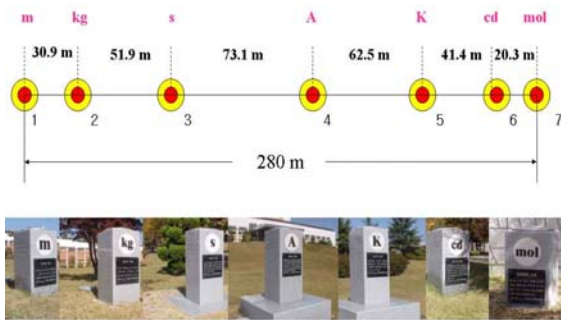


Figure 6: KRIS 280 m baseline for calibrating the electronic distance meter.

The EDMs are normally used for measuring large engineering structures such as ships, dams and tunnels and still have a key role for establishing the position in surveying. The EDMs can generally measure the distance up to a few km with resolution better than 0.1 mm. Usually we calibrate its scale factor and cyclic error.[3] In KRIS the scale factor of EDM is calibrated using 280 m baseline. (see Fig. 6) To calibrate the cyclic error of the EDM, we use the tape calibration system. The calibration is straightforward. The EDM is set on other side of the tape bench and a corner cube for EDM is fixed at opposite side of a corner cube for laser interferometer. And the reading of the EDM is compared with the reading of the laser interferometer. Fig. 7 is the calibration result of an EDM. The figure shows the cyclic error with period of 3 m.

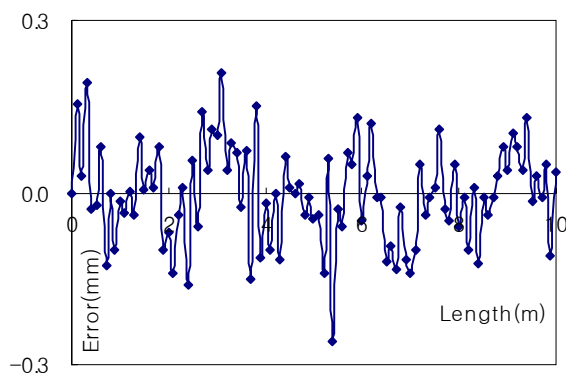


Figure 7: Cyclic error of an EDM.

## CONCLUSION

Laser interferometric measurement system for calibration of tape up to 50 m had been

constructed and was recently modified for automatic measurement. It consists of a precision laser interferometer, a guide rail, a moving carriage, and optical microscope with CCD camera and an image processor. The calibration of the tape is generally carried out by a comparison measurement as well as an absolute measurement traceable to SI unit of length. The system can be adapted to several other tasks. For example, ultrasonic distance meter and electronic distance can be calibrated in this system.

## REFERENCES

- 1.P. E. Ciddor, K.H. Edensor, K.J. Loughry and H.M.P. Stock, 1987, A 70 metre Laser Interferometer for the Calibration of Survey and Mapping, *The Australian Surveyor*, 33: 493.
- 2.Rosenberg C.B., Munteanu C.S., and Ferguson R.A., 1997, Calibration of the Flexible Tapes to ppm Accuracy Level, *OIML Bulletin*, 38: 25-29.
- 3.R.A. Veugen, 2002, Cause of Cyclic Error at the Calibration of EDM Devices with a Laser Interferometer, Report number PE 2002-083 Eindhoven.