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Investigation of yaw errors in measuring tape calibration system

Wanchai Chinchusak, Vittaya Tipsuwanporn*

Faculty of Engineering, King Mongkut's Institute Technology Ladkrabang, 1 Soi Chalong Krung 1, Ladkrabang Subdistrict, Ladkrabang District, Bangkok 10520, Thailand

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ABSTRACT

Yaw error measurements using a new designed yaw sensor were carried out to determine the characteristics of yaw errors and analyze the behavior of the structural guide. Laser interferometers have generally been used in calibration laboratories for the angular measurement of measuring tape calibration systems, and their performance must be verified to determine whether it meets the laboratory specifications. The yaw sensor technique is identical to the error compensation used in a measuring tape calibration, and also has some special parameters. Although the yaw error observation period is very short, it is sufficiently accurate for a carriage yaw sensor. The results of a yaw error measurement comparison between a yaw sensor and the angular measurement system of a laser interferometer were satisfactory. The measurement uncertainty of a yaw sensor calibration was approximately $U = 40$ arcsec at a confidence level of 95%.

1. Introduction

Several design solutions for improving a measuring tape calibration system have been developed, such as a motorized 5 m tape comparator [1,2], an automatic calibration of surveying tapes using wireless communication [3], and a laser interferometer for the calibration of surveying tape [4,5]; these solutions are very different from the conceptual design of the original system. There are also some problems in the constructive design of the carriage's guide system, which causes an insufficient straightness, such as errors in the yaw and pitch. Since 2011, the length and dimensional calibration laboratory of the Department of Science Service (DSS) in Bangkok, Thailand has been improving the standard tape measuring system. The Measuring Tape Development Project (MTDP), the main purpose of which is to set up an appropriate and complete traceable calibration of a 50 m long measuring tape, has been developed to serve customers from both industry and public organizations. At present, this project still does not provide a complete alignment of up to 50 m. However, it is operable up to 20 m. The MTDP calibration and verification technique requirements for a long-distance measuring system were proven through an inter-laboratory comparison with the National Institute of Metrology (NIM), China. The performance follows the reference document, International Organization of Legal Metrology (OIML), R35 [6]. There are several constructive solutions for an improvement of the tape calibration system, which differ from the conceptual design of the original system. There are also some constructive solutions regarding the installation of the guide, which causes an insufficient level of straightness, such as errors in the measured yaw and pitch. Generally, an angular measurement uses a laser interferometer, which is a highly accurate application. However, in many cases, the original method is expensive and its potential is limited. The angular measurement application of laser measurement is limited to a measurement range of up to 15 m according to the manufacturer's specifications, and is only suitable for use in a high-level laboratory such as a National Metrology Institute (NMI) or legal metrological laboratory. In addition, it is impossible to observe an angular measurement at the same time as a linear measurement owing to the different optical devices used, meaning that the real-time monitoring of a yaw measurement is not possible. At present, a more suitable high-resolution yaw sensor for investigating yaw errors is needed [7]. A yaw error measurement using a yaw sensor would also resolve the investigation problem. An investigation into yaw error measurements requires a yaw sensor that is capable of angular measurements rotating around the Z-axis. A yaw motion is a rotating movement of the plane from side to side, while the carriage is moving along the guide. If a yaw sensor is mounted on the carriage, then instead of taking only angular measurements, it could detect any yaw errors and compensate them in real time. The rotary encoder is normally a standard instrument used for angle measurements. Generally, the design of an encoder sensor for a roll and pitch angle measurement is relatively simple. The angular investigation of a measuring tape calibration system employs a laser angular measurement system and an electronic level for the long-term stability of the pitch error measurement. This research challenged to develop a high-resolution rotary encoder that is also applicable to measuring the yaw angle. The main purpose of this research is to

* Corresponding author.
E-mail addresses: wanchai@dss.go.th (W. Chinchusak), ktvittay@staff.kmitl.ac.th (V. Tipsuwanporn).

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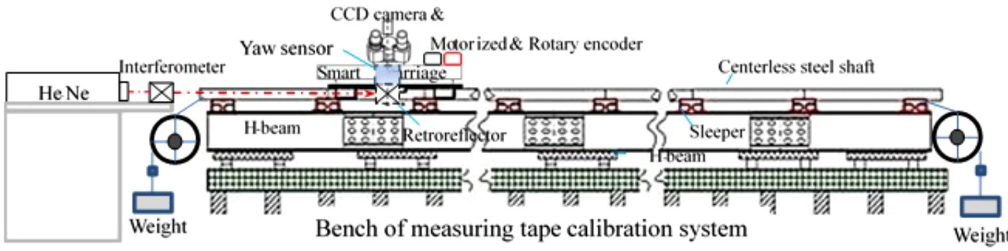

Fig. 1. Designed structure of measuring tape calibration system.

investigate yaw error measurements using a yaw sensor, and to indicate the characteristic factors of the guide alignment and installation.

2. Description of measuring tape calibration system

The structure consists of H-shaped beams that are designed for use on a steady-base measuring machine. These beams are placed on 51 foundation supports over a smooth concrete bench 51 m long, 900 mm tall, and 900 mm wide. Eighty-five adjustable sleepers are placed on the H-beams to support 17 centerless steel shafts with a guide diameter of 40 mm. The tape calibration technique will be developed for absolute measurements using a He-Ne laser with a wavelength of 633 nm, as shown in Fig. 1.

The measuring tape calibration system is designed for a controlled environment with a temperature of 20 ± 1 °C, humidity of 50 ± 10%, and an overall length of 50 m. The sleepers are placed on the H-beams, as shown in Fig. 2, in order to finely adjust the level of tolerance to ± 0.1 mm. The tape support is made of steel rods mounted on the sleepers and has a cylindrical roller design to reduce the friction from the tension force while the tape is stretched.

2.1. Rotary encoder and motorized driver carriage

The carriage consists of the following five components: three ball bearing brushes supporting the base of the carriage, an X-Y translator, a DC driving motor, and a microscope on the carriage. The carriage is a single optical measuring probe, and is slightly moved by hand with motorized control along the guide. A motorized driver is used to connect each carriage, and to directly drive a DC servomotor coupling with the shaft without the use of rack gear. A wireless joystick control is available for long distance use. The driving motor and wheel are symmetrically designed to provide force equilibrium while the driver moves smoothly along the guide rail, as shown in Fig. 3. Three-point balancing of the roller with a friction adjustment makes it very stable. The first roller drive uses a driving motor, and another one is used for the rotary encoder, with the friction adjusted using a force adjustable knob, as shown in Fig. 4.

3. Yaw and pitch error investigation with angular interferometer

For the angular measurement both yaw and pitch error are very important parameters, a laser interferometer, which is a highly accurate device, is traditionally used. As mentioned above, the pitch and roll measurement can be measured by using other devices such as, a high

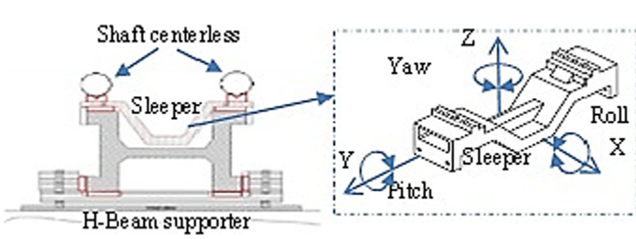

Fig. 2. Design of H-beam and sleepers for guide rail support.

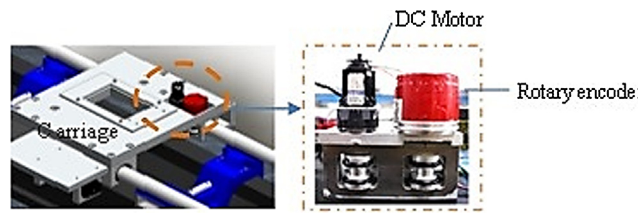

Fig. 3. Carriage of measuring system with driving motor.

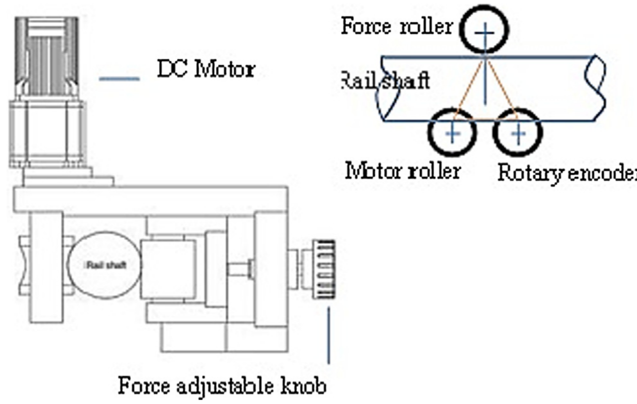

Fig. 4. Design of motorized carriage.

precision electronic level, rotary encoder, capacitive sensor, optical devices, etc. Hence, the yaw error measurement with angular interferometer is more interesting for solving the limiting of range or manufacturer's specification.

3.1. Principle of yaw error measurement by using interferometer

The axes of the positioning carriage are considered to have six degrees of freedom as shown in Fig. 5, three for the linear directions along the x-, y-, and z-axes, and three for rotations along the same axes. These motions are described based on the right-hand principle. The cross product of the x- and y-axes (second and third fingers) is the z-axis (thumb). In addition, if the thumb of the right-hand points in the positive direction of the axis, the fingers will wrap around the axis in the direction of the positive rotation about that axis.

All movements consist of translations along, and rotations around, the coordinate axes. The x- and y-axes are on the horizontal plane, the traveling direction of the first or bottom stage being aligned with the x-axis, and the z-axis is on the vertical plane.

The case of straightness measurement [8] is actually a measurement of the traveling path of perpendicular motion in the horizontal plane, $y(x)$ and as a reference is defined as a straight line passing through the initial, $y(0)$ and end points, $y(L)$, L: length.

That is, $y(0) = y(L) = 0$. The local slope is given by

$$\frac{dy}{dx} = \tan\phi \tag{1}$$