Improvement of Gauge Block Measurement Without Wringing Using Tandem Low-coherence Interferometer

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Abstract

Development of a novel gauge block measurement method without wringing onto platen using a tandem low-coherence interferometric system is currently in progress. In this method, the gauge block is placed between a pair of beam splitters to form a Fizeau interferometer, which renders wringing unnecessary. To measure the length of the gauge block, two interferometers are connected by a single-mode optical fiber and optical path difference is compensated using a linear translation stage with a resolution of 10 nm. Moreover, the optical path difference is scanned by a piezo-electric transducer (PZT) for generating the low-coherence interference fringes. The scanning length is measured by using the interference fringes with a He-Ne laser as a reference standard. Gauge blocks with nominal lengths of 1.5 mm and 5 mm have been measured with a standard deviation of 30 nm.

1 Introduction

More precision and better accuracy are in high demand in the fields of scientific and industrial metrology to produce high-quality products. Gauge blocks as a practical standard of length are widely used in industry and calibration laboratories. Lower grades of gauge block are calibrated using the mechanical comparison method, while higher grades of gauge block are calibrated using the interferometric method. Under the interferometric method, it is necessary to wring gauge blocks onto a platen[1], which requires a complicated process and a high level of operator skill. Furthermore, mechanical contact between gauge block and platen may also create several error sources and physical damage to the surface of the gauge block, the platen, or both. Therefore, non-wringing techniques should be considered to improve accuracy and reduce operator skill requirements by simplifing the measurement process.

Matsumoto and Hirai[2,3,4] introduced using a tandem low-coherence interferometer for the remote measurement of length standards. In our previous work[5,6], we devoleped a novel gauge block measurement method without wringing onto platen by using a tandem low-coherence interferometric system. Our system consists of two interferometers connected by a single-mode optical fiber. Previous interferometer work has been improved in three novel ways. First, we placed the gauge blocks between a pair of beam splitters to improve envelope shapes of interference fringes. Second, we increase the resolution of our scanning system by adding a piezo-electric transducer (PZT). Third, we replaced our previous linear translation stage with a 10 nm resolution linear encoder scale to simplify measurement.

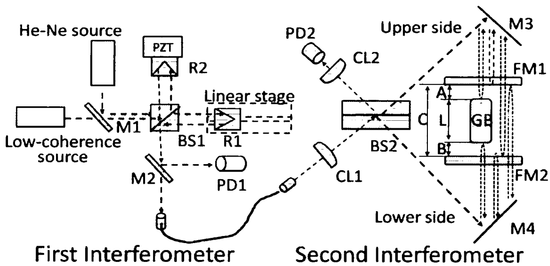


Figure 1: A schematic of experimental setup

2 Experimental setup

2.1 Tandem low-coherence interferometric system

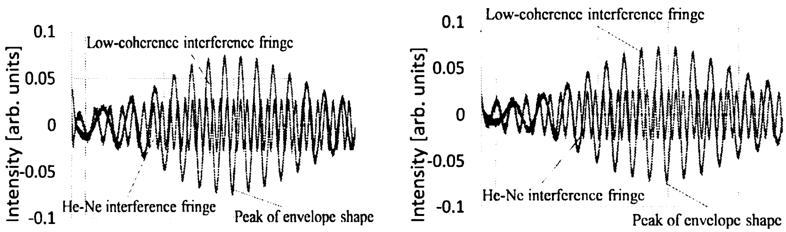
Our experimental setup (Figure 1) is similar to that of our previous work[5,6]. The first interferometer is a Michelson interferometer that has two light sources, a super luminescent light diode (SLD, Amonics, ASLD-CWDM-3-FA) with a center wavelength of 1544nm and a He-Ne laser with a wavelength of 632.9902nm[7], which is used as a wavelength standard. The second interferometer is a Fizeau interferometer in triangle interferometric arrangement, connected to the first interferometer by a single-mode optical fiber. The optical path difference of the second interferometer is compensated by a corner-cube reflector (R1 in Fig. 1), while the other corner-cube reflector (R2 in Fig. 1) used for fringe scanning is driven by a PZT (Thorlabs-AE0203D04F).

2.2 Measurement

The length of gauge block (L) is calculated by subtracting the distances (A and B) from the upper and lower Fizeau mirrors (FM1 and FM2) to the gauge block from the cavity length (C). The light beams from the low-coherence (SLD) and He-Ne light sources incident to the first interferometer are divided into two directions by a beam splitter (BS1). The light beams are then reflected back by the corner-cube reflectors (R1 and R2), and focused onto the optical fiber, and the beams that have the optical path difference of the first interferometer are collimated by a collimator lens (CL1) and then divided into two directions by a second beam splitter (BS2). Returned beams from the upper and lower sides of the second interferometer are focused by a collimator lens (CL2) and then detected by a photodetector (PD2).

Using this arrangement, the length of the cavity (C) and the distance from the upper Fizeau mirror (A) are measured from the upper side of the second interferometer, while the lower side is used to measure the distance from the lower Fizeau mirror (B). We measure the distance between the peaks of the gauge block interference fringe and the platen intereference fringe. Gauge block interference fringes and platen interference fringes are generated by moving a cormer-cube reflector (R1) on a linear translation stage (Sigma Tech, PC-501A) to compensate for the optical path difference of the first interferometer. The interference fringes are then slowly scanned using the PZT. Its expansions and peak positions of low-coherence interference fringes are measured precisely by using He-Ne interference fringe signals.

3 Experimental results



(a)Platen interference fringe (b) Gauge interference fringe

Figure 2: Obtained interference fringes; they correspond to the distance from lower platen and lower surface of gauge block (B).

The non-wringing method has been applied to measure gauge blocks of nominal lengths 1.5 mm and 5 mm. Figure 2 shows gauge block and platen interference fringes taken from the lower side of the second interferometer with the linear translation stage position He-Ne interference fringe signals. Envelope shapes of interference fringes were easily disturbed by some sources such as vibration and fluctuations in environmental conditions. Therefore, the peak positions of the envelope pattern of low-coherence interference fringes scanned by the PZT were observed to ensure a scanning stability with a standard deviation of 5-10 nm. Our measurement results for 1.5 mm and 5 mm gauge blocks were 1.5000123mm and 5.000170mm respectively, with a standard deviation of 30 nm. They are corrected by about 80 nm which is 2 times of the conventional depth of optical penetration on the gauge block. Therefore, the difference between our results and values precalibrated by the Japan Quality Assurance Organization (JQA) was around 90 nm.

4 Conclusions

The non-wringing gauge block measurement system has been improved by the use of a Fizeau interferometer, a 10 nm resolution linear translation stage, and by applying interference fringe scanning with a PZT. The experimental results show the achieved measurement of gauge blocks up to 5 mm with a standard deviation of 30 nm. However, the experimental values have a small difference of 80 nm. In order to reduce the difference from the conventional method, we plan a further improvement of the new method and some error resources, and then long gauge blocks are measured in future work.

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