Novel Measurement Technique of Gauge Block Without Wringing Using a Tandem Low-coherence Interferometer

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Gauge blocks are widely used as the practical standard of length-measuring instrument calibration. The high-precision length measurement requires more accurately calibrated gauge blocks as the reference standard. The length between upper faces of a gauge block and a platen, as defined in ISO 3650, is measured by using an interferometer. It is necessary to make wring of the gauge block onto the platen, which requires difficult labor process and takes time to get thermal stability. We have developed a novel tandem low-coherence interferometer to calibrate the gauge block with high efficiency. In this method, gauge block is only put on an optical parallel glass (platen) and then wringing of the gauge block onto a platen is not necessary. Using a triangle interferometric arrangement, the length of the gauge block is defined as the optical path difference between reflections from the both surface sides of the gauge block. By using this method, the length of gauge block can accurately be measured easily without any confusion due to fringe-order ambiguity.

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NOMENCLATURE

L= Length of the gauge block
A= Measured length the from bottom side of interferometer
B= Measured length from the upper side of interferometer

1. Introduction

More precision and better accuracy are highly demanded in the field of scientific metrology and industrial metrology to produce high quality products. Furthermore, a better and simple measurement method is also in high demand so that people who do not have enough skill can easily do the measurement tasks. In the field of length standard, gauge block as a practical standard of length is widely used to calibrate length measurement instruments such as CMM, micrometer, caliper, etc. To keep the chain of traceability, the length standard which is provided by the National Metrology Institute is disseminated to accredited calibration laboratories and industries through a calibration process [1-5].

The length of the gauge block is determined by the length between both of its surfaces [3,5]. Recently, interferometric method and comparison method are the major methods of gauge block measurement. Interferometric gauge block measurements based on several methods were introduced by several researchers. In the early 1980`s, Matsumoto proposed gauge block measurement method using single wavelength of a stabilized He-Ne laser [1]. The next generation of measurement method is the usage of multiple wavelengths and excess fraction method to get higher resolution and small uncertainty value of measurement [2-4,6-9]. The method to get a fraction value is one of the important roles on the gauge block measurement. Excess fraction methods based on several wavelengths also have been introduced to solve the problem of fringe-order ambiguity. Finally, only well established method can be accepted as the international standard. Based on ISO 3650, gauge block should be wrung on to the platen and measured by using interferometric method [5]. Wringing is a complicated process and only a well skilled person can do this task. A mistake on the wringing process can cause damage to gauge block surfaces. To solve this kind of problem, some measurement methods were introduced to eliminate the wringing process [3,4]. Generally, some stabilized lasers were directly applied to measure the length of the gauge block and the excess fraction method has important role in this method.

We are developing a new technique of gauge block measurement without wringing, by using tandem interferometer with a low-coherence light as a light source. The low-coherence interferometer has the capability to measure a surface profiling with high accuracy. Recently, technology of low-coherence light source also has been well developed and thus makes it possible to measure the profile of surface in nano level resolution. The use of low-coherence light source eliminates the fringe order ambiguity.

2. Measurement principle

2.1 Basic measurement principle

The basic idea of the proposed method is shown in a Figure 1. If lengths A and B are known values, then the length of the gauge block (L) is determined as B-A. It requires special interferometer to measure the length of A and B. By using low-coherence interferometer, it is easy to measure A and B values but it still require special arrangement. In the proposed method, the gauge block is put onto metal coated glass platen because the length A can be measured by using low-coherence interferometer if only the gauge block is placed on a transparent surface.

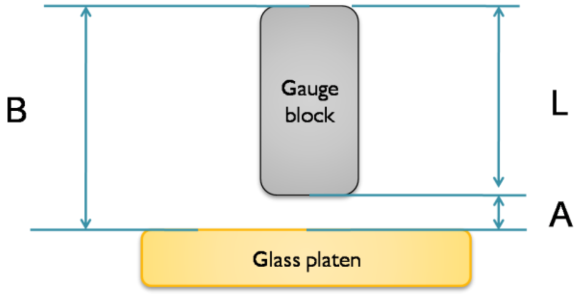

Fig. 1 Basic measurement arrangement

To get the L value, the length B is measured from the upper side of the gauge block and A is measured from the bottom side. Special interferometer based on a tandem low-coherence interferometer is modified to measure the A and B values. The detail of interferometric system will be explained in the next part of this paper

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2.2 Low-coherence tandem interferometer

Low-coherence interferometer provides some advantages for profiling measurement such as the possibility to measure the profile of surfaces in the nanometer scale. The interferometer is based on the Michelson interferometer design. Low-coherence interferences fringes are only be generated at around zero optical path difference, in this case, the interference fringes are only generated when the optical path differences between lights which are reflected from both mirrors is near zero. Tandem interferometer is combination of two interferometers where the one of the interferometer works as fringe scanner. Figure 2 shows the principle of low-coherence tandem interferometer which was introduced by Hirai and Matsumoto [6].

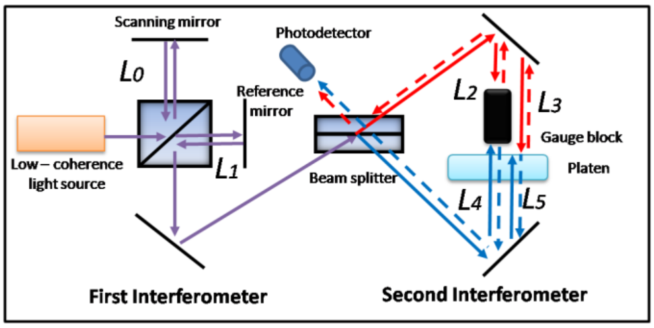

Fig.2 Tandem interferometer diagram

The first interferometer provides a low-coherence light which has an optical path difference equal to $2(L_0-L_1)$. The two light beams with the optical path difference $2(L_0-L_1)$ are then transmitted to the second interferometer through an optical fiber. The second interferometer has an optical path difference $2(L_2-L_3)$ or $2(L_4-L_5)$, in this case equal to the length of A or B. One of the mirrors of the first interferometer can be translated to forward and backward to scan the interference fringes. The interference fringes are generated when the optical path difference of first interferometer is zero, namely $L_0=L_1$. The interference fringes are also generated when the total optical path difference is around zero, in this case, the optical path differences of first interferometer and second interferometer should be the same. And then, one of the mirrors of the first interferometer is translated to compensate optical path difference between first and second interferometers. When both of interferometers have the same optical paths difference, then the low coherence fringes generate. In a simple equation, the interference fringes occurs when the absolute optical differences of first and second interferometer are same, $|L_0-L_1|=|L_2-L_3|$ or $|L_0-L_1|=|L_4-L_5|$. At least three low coherence interference fringes are generated during scanning process. One interference fringes is generated when optical path difference of first interferometer is zero, and two interference fringes are again generated when the optical path differences of the first and second interferometer are the same. Figure 3 shows the zero optical path interference fringe.

2.3 Experiment design

A modification of interferometer arrangement as shown in Figure 2 becomes the triangle interferometric arrangement as shown in Figure 4, and the low-coherence tandem interferometer is used to get A and B values which were already mentioned. The complete system consists of 2 set interferometer systems. First interferometer is low-coherence tandem interferometer called the main interferometer. Main interferometer consists of two interferometers which are connected each other by using a single optical fiber. The distance which is measured by using low-coherence interferometer is represented by the distance between two peaks of low-coherence interference fringes. The low-coherence interference fringe's peak can be detected but it requires an additional length measurement system to measure the distance between two peaks of low-coherence fringes. The interference signals of a He-Ne laser are used as a ruler to measure its distance. Figure 4 shows the optical arrangement of He-Ne interferometer system and then it is connected to the main interferometer. The usage of He-Ne light source provides traceability of measurement to the chain of measurement traceability. We used non stabilized He-Ne laser source, thus based on the advice from Consultative Committee for Length (CCL) on the use of an unstabilized laser as a standard wavelength, the He-Ne wavelength in vacuum is 632.9908 nm [10]. Two-side mirror which is placed on the table sitting on linear stage is used as a scanning mirror of first interferometer. One side of mirror is used to scan the low coherence interference fringes and the opposite side of this mirror scans the He-Ne interference fringes. Low coherence fringes and He-Ne interference fringes are detected by using photodetector and then recorded simultaneously by using an oscilloscope.

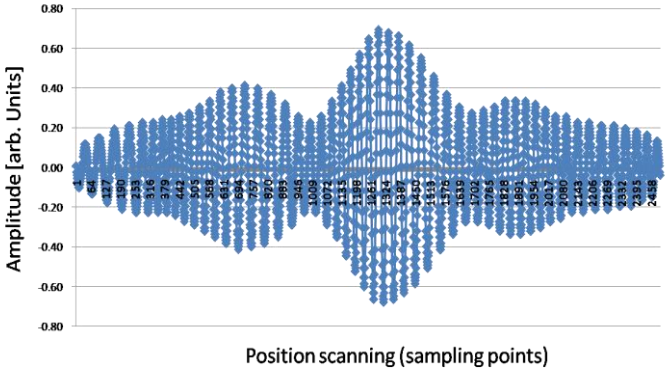

Fig.3 Zero optical path interference fringe

The Low-coherence light sources used are a superluminescent diode (SLD, Amonics, ASLD-CWDM-3—FA) whose center wavelength is 1544.25 nm and an amplified spontaneous emission (ASE,Fiber Labs,ASE-FL7210) whose central wavelength is 1479 nm. The beams from the first interferometer go to the second interferometer through the single mode optical fiber, and are thence collimated. The beams are divided into two parts by using a beam splitter, BS_3. The beam is directed to the upper side and incident to the topside of gauge block and glass platen, and they are reflected back to the beam splitter, BS_3. The reflected beams return back to the beam splitter, directed to the focusing lens, introduced to the optical fiber and finally detected by a photodetector. The length of B is measured by using the beam which is directed to upper side of second interferometer and the length of A is measured by using the beam which goes to the lower side of second interferometer.

3. Experiment and result

3.1 Scanning procedure

In this experiment, the lengths A and B were measured separately. Ideally, the gauge block is only put onto the glass platen, but the A is small and thus the gauge fringe of the A was very close to the zero optical path interference fringe. To make measurement easier, the gap is about 1 mm. Two additional gauge blocks which have 1 mm nominal length were placed on the glass platen and separated by about 10 mm each other to make 1 mm gap between the glass platen and the gauge block. After the gauge block is placed on the platen, the second interferometer has an optical path difference equal to the lengths of A and B. The optical path difference of the first interferometer which was introduced into the second interferometer was longer than the optical path difference of the second interferometer, $|L_1-L_2|>A$ or $|L_1-L_2|>B$. Then, the reference mirror M_1 was translated along its axis to scan the low coherence interference fringes. First interference fringe is generated when (L_1-L_2) is equal to A or B, and let call it gauge interference fringes. Another interference fringes occurred, and let call it the zero optical path interference fringe, at the position where L_1 is equal to L_2. Low coherence interference fringes occur again at the position (L_2-L_1) was equal to A or B. Figure 3 shows the zero optical path interference fringes that occurred when L_1 and L_2 are in the equal distance.

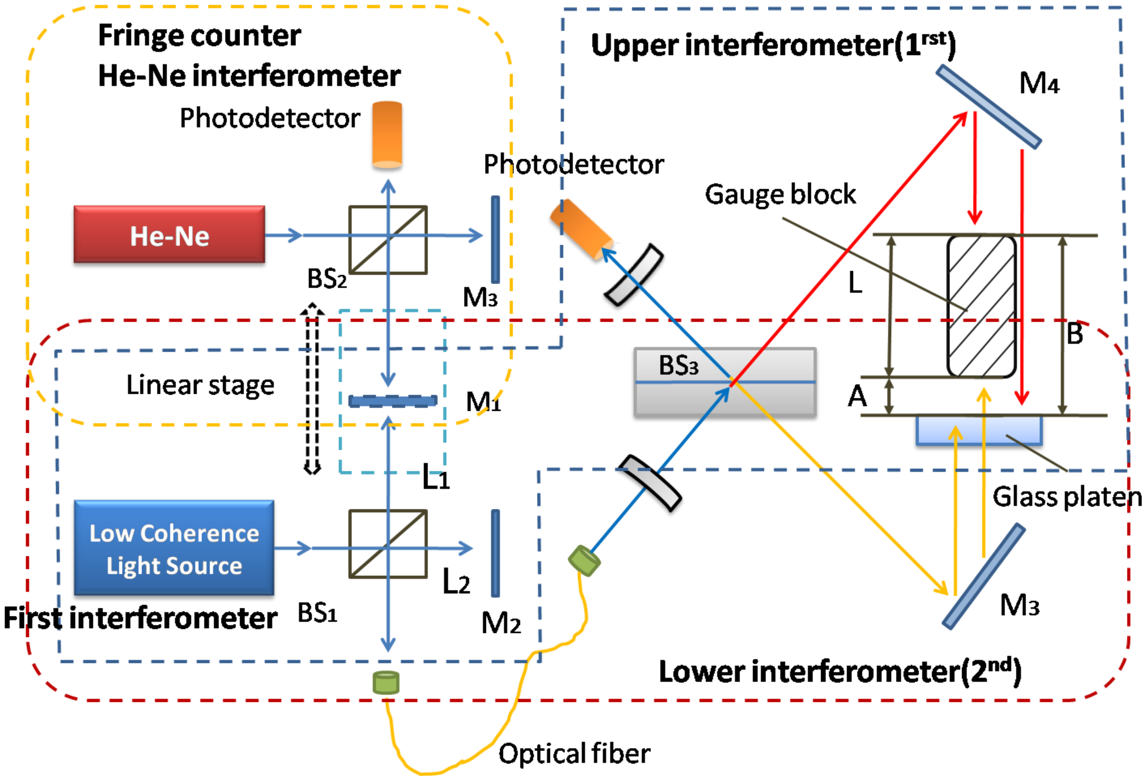

Fig.4 Overall design of triangle interferometric system

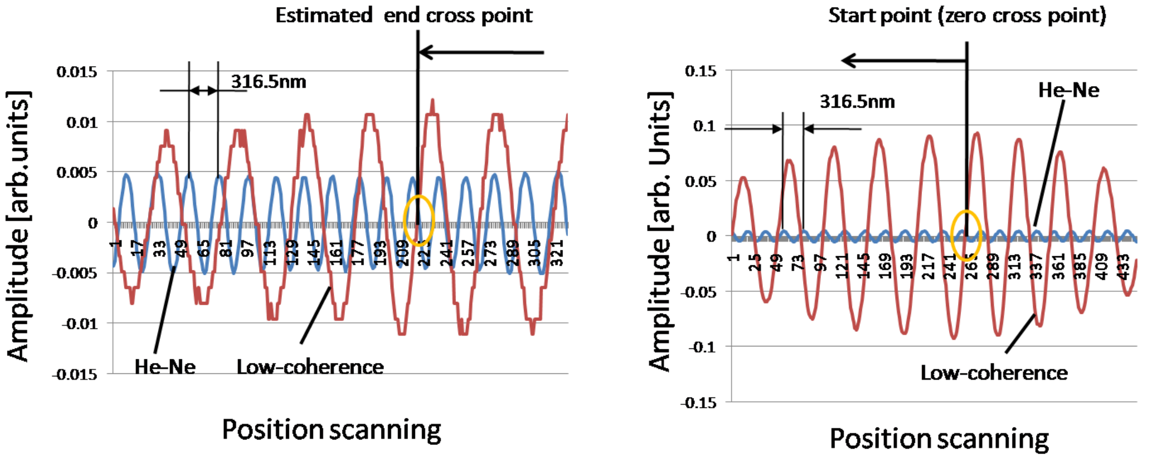

Fig.5 pair of zero optical path interference fringe and gauge fringe

3.2 Signal detection

Interference signals from the main interferometer (the low-coherence interferometer) and the He-Ne interferometer were recorded simultaneously by using a 2-channel digital oscilloscope. Output power of the SLD from the first interferometer is about 1 dBm, and the SLE is about -07 dBm. Output from first interferometer is then directed to the second interferometer through single mode optical fiber. After the beam passing the collimator (diameter 50 mm), are reflected by the glass platen and the gauge block surface, and finally are focused again, the output power from second interferometer was about -45dBm. We use a New Focus 2011 photoreceiver to detect the output interference signal from the second interferometer before recorded by the oscilloscope. The signal intensity which was reflected by the gauge block was high enough but the signal which was reflected by the glass platen was too low because we used a glass platen that only has 4 percent reflection.

3.3 Data analysis

Some disturbances, such as vibration and temperature fluctuation, give influences to the shape and position of interference fringes. Because of this kind of disturbances, the center of fringes does not correspond to the maximum amplitude of the fringes. Considering this situation, we applied an excess fraction method to calculate the length of the gauge block which was introduced by Matsumoto and Hirai [8]. In this case, it is important to make sure that central wavelength of the low coherence light around the zero optical path interference fringes and the gauge interference fringe does not change. Central wavelength was calculated by using the He-Ne interference fringe signal as a ruler. Unfortunately, measurement environment of the preliminary measurement was not well controlled. Temperature and humidity data were recorded by using simple equipment. The refractive index of air was calculated by the Edlén`s equation [11,12]. Length of the gauge block is equal to the distance between the zero optical path interference fringe and the gauge fringe, or a half of distance between two gauge interference fringes. As shown in Figure 5, start and end points were determined, and then by calculating the number (including the fraction) of He-Ne interference fringes, the length of the gauge block was calculated. We used two low-coherence light sources which have the difference central wavelength around 65 nm, so that it has the effective measuring range 17.43 µm in an excess fraction method. The measurement results of preliminary experiment are shown in Table 1.

Table 1. Experiment result
(difference value from nominal length)

Nominal Length (mm)	JQA (uncertainty 40nm) result (µm)	Wringing method (µm)	Without wringing method (µm)
1.5	-0.043	-0.068	-0.261
2	-	-0.012	-
5	-0.001	-0.262	-

4. Discussion

To connect the measurement result to the chain of traceability system, the gauge blocks were calibrated by Japan Quality Assurance Organization (JQA). The measurement result from several gauge blocks shows that our measurement is near to the JQA measurement result, but it has some notes and attention. We done an experiment based on wringing method and non wringing method by using the same machine. The wringing method gave results close to the JQA result, but the difference was a little far for the 5 mm nominal length. From the nominal length 1.5 mm data, wringing method result is still covered by the uncertainty of JQA result, but the non-wringing method has a difference about 250 nm. Our preliminary experiment of without wringing method gave a result little far from wringing method but the repeatability is good. The best repeatability is about 23nm. We consider that unstable room condition and imperfect optical alignment are the main sources of the far displacement result. We consider also that phase correction should be calculated due to the different material between gauge block and platen. The position of some optical parts such as mirror was drifted, therefore the procedure to check an optical alignment every time before measurement become important. The other problem comes from the interference signal that was too weak. The weak signal is very easy to be influenced by external noise such as stage vibration and air conditioner. The zero optical path interference fringe was strong enough but the gauge block interference fringe was too weak. To solve the problem, the use of higher reflective index of glass platen is important to get better resolution of gauge interference fringe.

4. Conclusion

We have realized the gauge block measurement system without wringing onto the platen based on the tandem low-coherence interferometer. We confirm that the system worked properly with some limitations due to imperfect alignment and uncontrolled environment condition. Now we are working on accuracy improvement such as re-alignment of optical component, put a bigger collimator lens of the He-Ne, and some other works. The success of the measurement of gauge block without wringing process will allow people who do not have wringing skill to measure the gauge block easily. This method makes the measurement of the gauge block more effective and efficient.

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