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Remote Measurements of Lengths by Excess-Fraction Method Using Optical Fiber Networks and Tandem Interferometer

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Abstract: Practical lengths are remotely measured by excess fraction method using a tandem low-coherence interferometer through optical fiber networks. Interference fringes of high S/N are generated when the path difference between two interferometers is equal.

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1. Introduction

In the metrology fields of science and industry, in-situ and precision length measurements are strongly demanded for extending the reliability of experimental measurement data and improving the quality of production devices and systems. In the case of practical length standards, the high-grade standards should be calibrated in standard metrology institutes using a conventional interferometer with an accuracy of 10^{-7} order. At present, the length standards are supplied on the basis of the Japan Calibration Service System (JCSS) with a series of standards, ranging from "the national standards", followed to "a practical stabilized He-Ne laser", and artificial standards. Currently, the practical length standards under calibration are sent to the standard metrology institute or calibration laboratories. This is time-consuming and there is possible loss and damage of the practical length standards, and therefore this system is not efficient.

Remote measurements of practical length standards were carried out by use of technology based on a tandem low-coherence interferometer through an optical fiber networks between the AIST in Tsukuba-city and a calibration laboratory in Tsuchiura-city, Ibaraki Prefecture [1,2]. We used a dark optical fiber of about 20 km long for conventional communication fiber networks. In this case, the optical fiber network as complete common path for probe and reference beams of one interferometer, and therefore the spectral chirping and polarization effects for these beams is the same. We can obtain the symmetrical interference fringe pattern, even if we use an optical fiber of 103-km long [3].

We propose a new technique using the method of excess fractions in a tandem interferometer with a low-coherence light source for achieving remote measurements of length, in which two low-coherence interferometers are connected by a single-mode optical fiber in the wavelength range of 1500 nm. One in the tandem low-coherence interferometer used is compared with the optical path

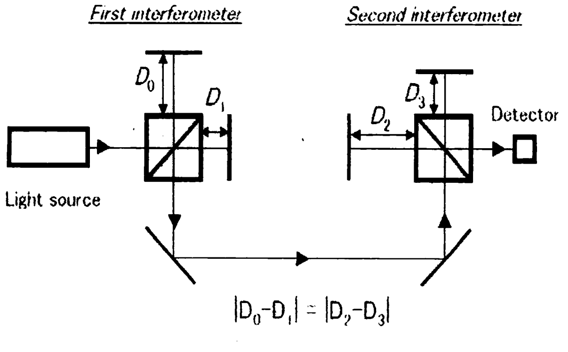

Fig. 1. Tandem low-coherence interferometer

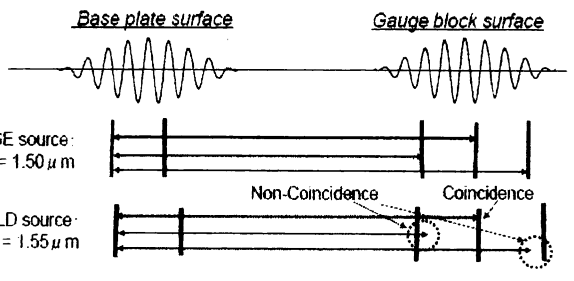

Fig. 2. The method of excess fractions

difference of the other interferometer through the communication optical fiber networks. The length standards are remotely measured within a high accuracy using the excess fraction method on low-coherence interferometry at the calibration laboratory.

2. Principle of Measurement

Remote measurements of practical length standards were carried out using a tandem interferometer with two low coherence interferometers, as shown in Fig. 1. Interference fringes are generated when the optical path difference of the first low-coherence interferometer, $|D_0-D_1|$, is equal to the path difference of the second low-coherence interferometer, $|D_2-D_3|$. Here, the optical path difference of each interferometer is set to be longer than the coherence length of the light source used. Next, two low-coherence interferometers are connected by a single mode optical fiber. The effect of the fiber is cancelled due to the principle of common path of interferometer, so we may use a long optical fiber such as 103 km because the loss is very low. Moreover, this technique may use optical amplifiers for amplifying weak light [3].

In this study, we propose the excess fractions method in order to resolve the problem of the light source used. In general, it is required to use the light source with broad band spectrum in order to determine the central interference fringe of the fringe pattern, uniquely. However, the light source used in practical optical networks doesn't have broad spectrum, and sometimes light sources of nallow spectrum are used. We apply the method of excess fractions to the low-coherence interferometry as shown in Fig. 2. Using this method, the length of practical standards is determined, uniquely.

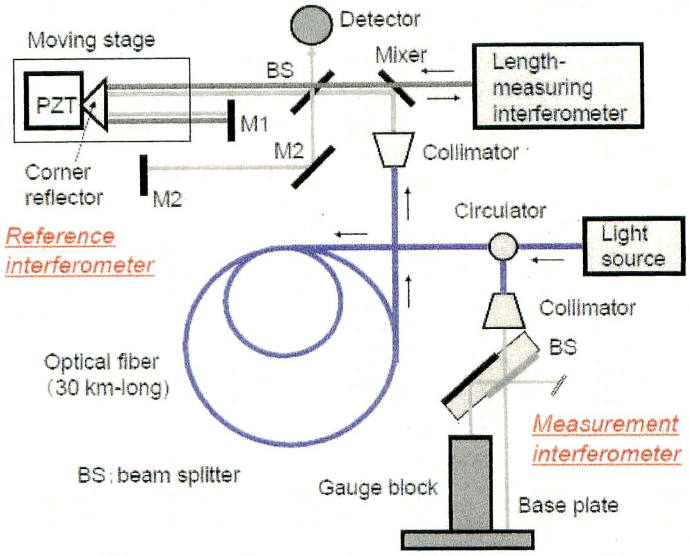

Fig. 3. Experimental setup

3. Experiments and results

The experimental setup of the new tandem interferometer is shown in Fig. 3. They consist of two Michelson type low-coherence interferometers (measurement interferometer and reference interferometer) which are set in well air conditioned room. Their interferometers are connected by a single-mode optical fiber of 30 km long in the wavelength range of 1500 nm, and the overall optical path difference of the tandem interferometer are compensated by the optical path differences of the two low-coherence interferometers (tandem interferometer). The low-coherence interference fringes are generated when the overall optical path difference of the tandem interferometer becomes zero. A light beam is introduced through a single-mode optical fiber and an optical-fiber circulator from the light source and is collimated to a diameter of about 5 mm in diameter. The light beams through the beam splitter are incident on a gauge block of nominal length 15 mm and a base plate, which are connected by wringing.

One of the light source used was generated by the ASE (amplified spontaneous emission, SOA240), whose center wavelength is 1500 nm and its output power was about 5 mW. Other is the SLD (super luminescent light emitting diode, ASLD15-100) with a center wavelength of 1550 nm and an output power of 10 mW. The experiments were performed using the single-mode optical fiber of 30 km long. The optical beams from the measurement interferometer are transmitted to the reference interferometer through the optical fiber. The optical path difference in the reference interferometer was changed by moving the corner reflector using a linear stage (FS3150) and a piezoelectric transducer (PZT, PI-621.1CL). The peak position of the envelop pattern of the low-coherence interference fringes may accurately be determined. The phase of the center interference fringe is obtained with a standard deviation of 5-10 nm in length. Measurements are achieved when the optical path difference of the reference interferometer is equal to the optical paths of the measurement interferometer on the surface of the gauge block, and then the optical paths of the reference interferometer difference on the surface of the base in the measurement interferometer. The displacement of the corner reflector of the reference interferometer was measured using an HP length-measuring interferometer (Agilent 517B) with a resolution of 1 nm.

The experimental results are shown in Figure 4. The signal-to-noise ratios of the interference fringes are high. The phases of interference fringes are accurately measured with a relative accuracy of several nanometers for the positions on the surfaces of the gauge block and base plate. The length of the gauge block was uniquely determined using the wavelengths of 1500 nm and 1550 nm, whose difference is only 50 nm. This technique can utilize conventional light sources which are used in the optical communication networks, because no excess fraction method requires broad-band spectral sources. Moreover, this technique may extend the optical path difference of each interferometer depending to the coherence length of the light source used.

Sources	$\lambda_1=1.50\,\mu m$ (ASE)	$\lambda_2=1.55\,\mu m$ (SLD)	Difference (μm)
Max+λ	15001.482	15001.528	-0.046
Max+λ/2	15000.732	15000.753	-0.021
Max	14999.982	14999.978	0.004
Max-λ/2	14999.232	14999.203	0.029
Max-λ	14998.482	14998.428	0.054

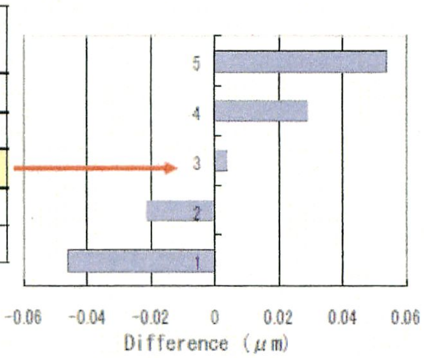

Fig. 4. Experimental results by the method of excess fractions.

4. Conclusions

We have realized transmitting of the information of practical length standards through an optical fiber network for communications of 30 km long between the two places in the experimental room. The length of the gauge block as practical length standard was uniquely determined with a relative accuracy of several nanometers using the two light sources with the wavelength difference of 50 nm, only.

The success in the remote calibration technology will allow users to acquire a length value traceable for a national standard through the optical fiber networks while keeping their own length standards in the laboratory. Therefore, this technique can be applied to a conventional optical fiber networks.

5. Acknowledgements

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6. References

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