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Femtosecond Laser based Phase Locked Synthetic Wavelength Interferometer for Absolute Distance Measurement

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A synthetic wavelength interferometer (SWI) with a long period wave generated through interference of waves which have similar frequencies has an advantage of avoiding 2π *phase ambiguity in long distance measurement. However, during measuring the distance, a cyclic error occurs that deteriorate the resolution and accuracy. In this study, the synthetic waves having frequencies from tens of MHz to a GHz are generated by employing an Acousto-Optic Modulator (AOM) and a femtosecond laser. In addition, a phase locked method is proposed to remove cyclic error. The phase locked method is locking a difference of phase between measurement arm and reference arm of the SWI to a constant value. This can be implemented by utilizing a P-I controller to maintain voltage resulting from the phase difference between arms at a certain value. An output voltage from the P-I controller was converted to oscillation frequency using Voltage-Controlled Oscillator (VCO) principle. This oscillation frequency was input in the AOM as a modulation frequency. As a result, it is possible to lock the phase to a constant value by modulating the frequency of synthetic wave. It can also be used to measure the absolute distance by selecting a specific frequency of the synthetic wave. The advantage of this method is that the SWI can have high resolution over a wide range of distance measurement depending on the frequency, as well as eliminate cyclic error.*

NOMENCLATURE

L= one-way distance to the retroreflector
c = speed of light
n = refractive index
f = frequency of the synthetic wavelength
$\Delta\emptyset$ = phase difference between reference arm and measurem-ent arm
m= integer number

1. Introduction

In this article, the absolute distance is measured using a femtosecond laser as a light source and a synthetic wavelength interferometer (SWI) that one of the interferometers for measuring distance. Measure the distance using a conventional phase meter method and phase locked method and compare them. The phase measurement method uses a superheterodyne receiver to down-convert the frequency and then measures the phase difference between reference arm and measurement arm through Lock-in amplifier (LIA). This method causes a cyclic error. The cyclic error is attributed to partial beam splitting and recombination in the optical interferometer or signal leakage in the electronics. Cyclic error deteriorates the accuracy of distance measurement. On the other hand, the phase locked method is a way to measure the distance by measuring change of the frequency while the phase difference between the reference arm and measurement arm is fixed. Since the cyclic error occurs depending on the phase difference, this method can remove the cyclic error. Therefore, the accuracy of the measurement distance can be improved. Also, since the resolution is determined by the frequency stability rather than digits of the LIA, using this method can enhance resolution.

2. Experimental Setup (SWI)

2.1 Interferometer Configuration

Fig. 1 (a) shows the configuration of the SWI system. This is double path system. According to operation of the stage, the distance to retroreflector on the measurement arm changes, which causes changes of the phase. Therefore, the distance can be obtained by measuring the phase difference between the measurement arm and the reference arm.

(a)
(b)
(c)

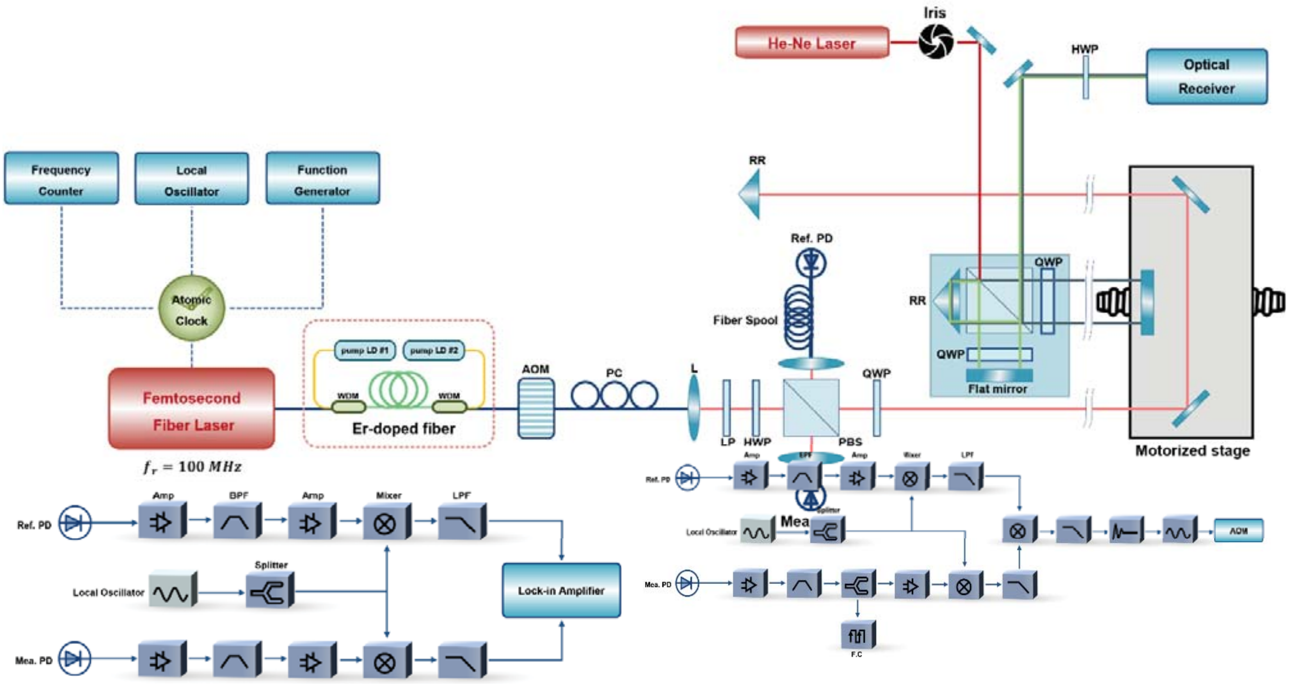


Fig. 1 (a) SWI system configuration (b) Circuit configuration of the phase measurement method (c) Circuit configuration of the phase locked method. AOM: acousto-optic modulator, PC: polarization controller, L: lens, LP: linear polarizer, HWP: half wave plate, PBS: polarizing beam splitter, QWP: quarter wave plate, PD: photodetector, RR: retroreflector, Amp: Amplifier, BPF: band-pass filter, LPF: low-pass filter, FC: frequency counter.

2.2 Phase Measurement Method

Fig. 1 (b) is the configuration of the phase measurement method. In the phase measurement method, the superheterodyne receiver was used to down-convert to the frequency range that LIA can measure. In the LIA, the phase difference between the reference arm and the measurement arm is measured, and the distance is calculated using the following formula.

$$\Delta L = \frac{c}{4\pi n f}\Delta\emptyset$$

2.3 Phase Locked Method

Fig. 1 (c) is the configuration of the phase locked method. The phase locked method is locking a difference of phase between measurement arm and reference arm of the SWI to a constant value. In this experiment the constant value is 90°. Therefore, the distance is calculated using following formula

$$\Delta L = \frac{(m + 0.25)c}{2nf}$$

This formula mean that the distance can be known by measuring the frequency of the synthetic wavelength utilizing a frequency counter. In this experiment, by utilizing optical comb of the femtosecond laser and the AOM, it is possible to generate synthetic wavelength of a wide range of frequencies based on the principle of beat. In addition, the modulation frequency of the AOM can be controlled by using the principle of voltage-controlled oscillator (VCO) which converts DC voltage corresponding to the phase difference into oscillation frequency. Therefore, in order to lock the phase difference, it is mandatory to make the DC voltage constant. This is implemented by the P-I controller.

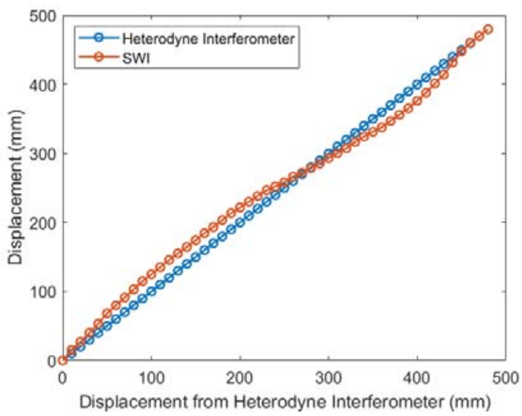
3. Results

Fig. 2 (a) shows the result of distance measurement using the synthetic wavelength with a frequency of 400 MHz and Heterodyne interferometer. In this experiment, the angle of QWP was adjusted to generate the cyclic error. As a result, in the Fig 2. (b), the cyclic error occurs exceeding about 20 degrees. On the other hand, Fig. 2 (c) and (d) are the results of measuring the distance using the phase locked method. Fig. 2 (c) exhibits the result of distance measurement using synthetic wavelength with frequencies of 137.7 ~ 139 MHz. By fixing the phase difference value, Fig. 2 (c) shows that the maximum error has been reduced to about 1/10 and the cyclic error caused by the change of the phase difference is removed.

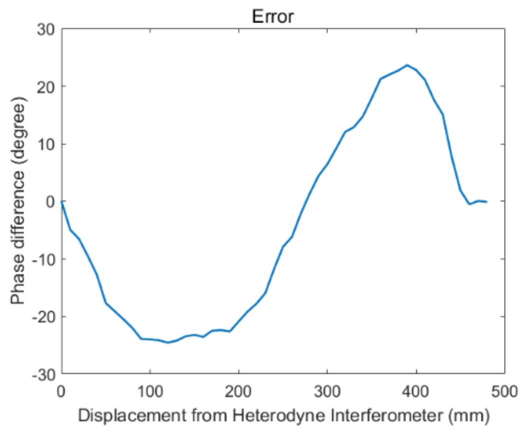
4. Conclusion

This paper shows that the cyclic error occurring during the distance measurement is eliminated using the phase locked method. Moreover, if we can the SNR of the electronic circuit, it is possible to implement

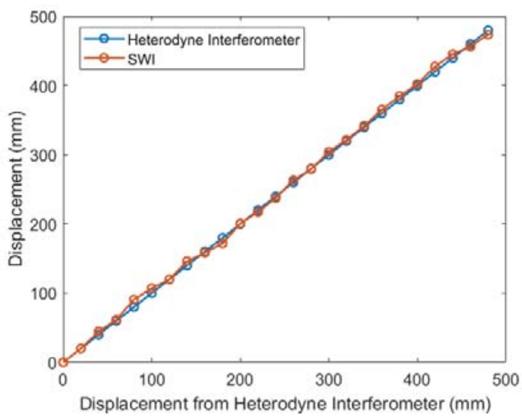
(a)



(b)



(c)



(d)

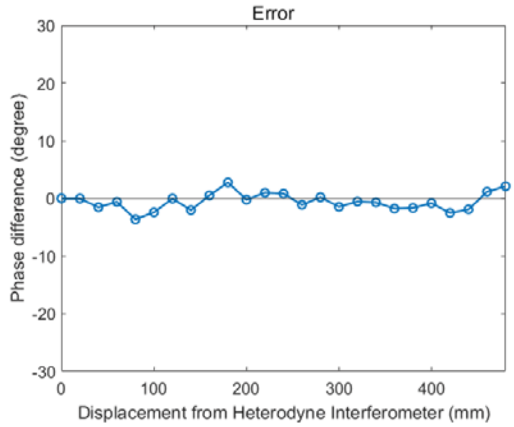


Fig. 2 (a) Distance measurement result using phase measurement method (b) The result of converting the error value of the distance measured by the Heterodyne interferometer and the SWI into the phase difference value (c) Distance measurement result using phase locked method (d) The result of converting the error value of the distance measured by the Heterodyne interferometer and the SWI into the phase difference value

the system which has better resolution.

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