Absolute distance measurement with the fiber femtosecond optical frequency comb

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Abstract. The absolute distance measurement was experimentally demonstrated by using the fiber femtosecond optical frequency comb in air. The technique is based on the measurement of cross correlation between reference and measurement optical pulses. This method can achieve accuracy compared to the commercial laser interferometer.

Keywords. distance measurement, femtosecond, frequency comb, cross correlation

1 Introduction

High precision absolute distance measurement with the femtosecond laser has recently drawn increased attention in the noncontact measurement, and large scale manufacture. Research on the absolute distance measurement methods with optical frequency comb was first presented in the 2000; Minoshima obtained a high-accuracy optical distance meter with a mode-locked femtosecond laser and measured 240-m distance in an optical tunnel. In 2004 Ye proposed a scheme for high-precision and absolute length measurement. In this paper, we provided an experimental proof which used to measure a short distance in air with the femtosecond optical frequency comb and compared with the conventional laser interferometer.

2 Measurement Principle

Femtosecond optical frequency comb is composed of a phase-stabilized mode-locked femtosecond laser. It emits consecutive pulses train that called repetition frequency f_r. The group velocity and phase velocity are distinct because there is the phase shift Φ between the pulses. This phase shift is called f_0. We obtained the f_0 by using $f_0 = (f_i/2\pi)\ f_r$. Both f_0 and f_r are referenced to the clock. Therefore, the distance between the pulses l_{pp} is stable and fixed.

The Michelson interferometer has measurement arm and reference arm. When the path length difference of the two arms is a multiple of the adjacent pulses distances, it is position of maximum interference intensity. When the delay line adjustment range is over the $l_{pp}/2$, it can get the maximum position of pulse overlap in time-domain. The interpulse distance l_{pp} can be calculated by $l_{pp} = c_0/(n_g\, f_r.)$, where c_0 is light speed in vacuum and n_g is the group refractive index.

It was used a delay line in the arm to achieve overlap of the two pulse trains in temporal. The measurement of cross-correlation function can be obtained by using a piezoelectric transducer which is fixed on the reference arm. The position of the cross correlations peak can be found by using the Gaussian fitting. The difference of the two adjacent positions is the measurement distance. The purpose of this paper is to verify the measurement principle in a short distance in air. The precision and influence factors to this method will be discussed.

3 Experimental Method

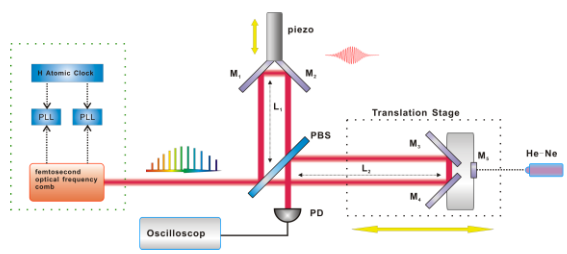

Fig. 1 The structure of the distance measurement

The measuring principle of the distance measurement method is shown in Fig.1. The light source is the Er-doped fiber femtosecond laser. The pulse width is 70fs. The length of reference can be adjusted by changing voltage of piezo-element. The measurement arm with a translation stage can be moved force and back. The lengths of reference and measurement are L_1 and L_2 respectively. The retro-reflector fixed on the piezo-element can be moved with different frequency. Finally the two reflected beams are recombined at the beam splitter and sent to the photo detector. The intensity of the interference fringe signals can be measured with an oscilloscope.

The key point is to verify the accuracy of the distance measurement and the conventional laser interferometer measurement. Firstly, the translation stage of the measurement arm is adjusted to keep the two arms' length equality and find the position of the maximum intensity of the brightest fringe. During the measurement, the PZT is translated with frequency of 5Hz. The maximum movement is 50μm. The cross-correlation signal is focused onto the photo detector. The intensity of the cross-correlation signal is measured with an oscilloscope. Secondly, the PZT is a closed loop and precision is 0.1nm. The PZT can be added initial voltage to produce distance shift. The cross-correlation was recorded in the same condition in the step 1. Thirdly, the translation stage is moved to make two arm lengths same and recorded the interferometer laser displacement distance. The correction term δ can be calculated by fitting the profiles of the cross-correlation with Gaussian functions. The distance of the PZT is obtained by calculated the displacement of the two peaks in the correlation function.

4 Results and Discussions

The peak shift between adjacent measurements can be measured by comparing the two cross-correlation function. The peak is obtained by using Gaussian curve fitting. Displacement L is $L = \delta/2$. The displacement is also measured independently with He-Ne laser interferometer. The temperature variation is controlled with 0.1 degree. The experiment measures a short displacement.

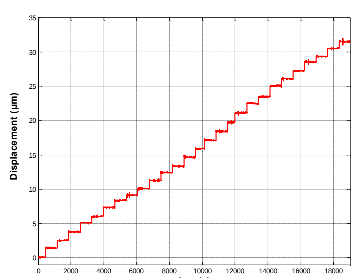

Fig. 2 Measurement by He-Ne laser interferometer

The translation stage was measured by the He-Ne laser interferometer that moved 1.25μm in a minute and the results are shown in Fig 2. The vibration and air flow lead to the time jitter. The average of the results in the relatively stable time was calculated.

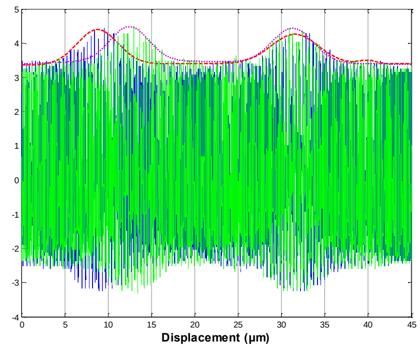

Fig. 3 Cross-Correlation curve

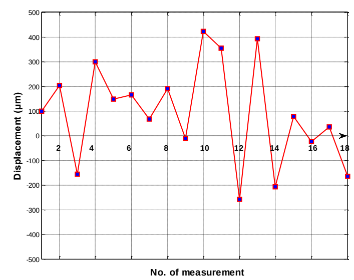

Fig. 4 The deviation of the experiment

The intensity of the cross-correlation which measured with an oscilloscope is fit by Gaussian function patterns in Fig.3. The real displacement can be calculated by finding the peak of the cross correlation. The experimental shows deviation is less than 500nm in Figure 4. It can be concluded that the precision attained sub-micron precision.

In conclusion, distance measurement with the fiber femtosecond optical frequency comb has a high accuracy in the short distance measurement. It is concluded that the precision by calculating the peaks between the two curves fitting of the cross-correlation agree within less 100nm and better to conventional laser interferometer.

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