A novel length measurement interferometer based on a femtosecond optical frequency comb introduced multi-pulse trains' interference

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Summary

A novel executable interferometric scheme based on a femtosecond optical frequency comb (FOFC) introduced multi-pulse trains' interference is proposed to achieve length measurement of meter order with an accuracy of nanometer order. The result of the length measurement experiment will be presented.

Introduction

In July 2009, an FOFC was adopted as designated standard equipment by the Japanese Measurement Law. In future meeting of the International Meter Convention, an FOFC is expected to be recommended as a tool for the "meter" and the "second" of the SI unit system. How to achieve the transformation for the length measurement from the length standard –the FOFC- is the urgent and significant task.

The purpose of our work was to study the temporal coherence function of an FOFC and its application to meter order length metrology with an accuracy of nanometer order. Based on previous works [1-4], the work presented here is of executable optical scheme to achieve the proposed concept.

Principle and Optical schematic

As shown in Fig.1, the proposed executable optical schematic consists of a mode-locked FOFC, a modified Michelson interferometer, and system controls. The pulse trains from the FOFC are expanded and collimated by a collimator lens and introduced into the modified Michelson interferometer. The modified Michelson interferometer is a combination of an ordinary Michelson interferometer and an unbalanced optical-path Michelson interferometer. The ordinary Michelson interferometer is composed of a beam splitter, a reference mirror M_{ref}, and an object mirror M_{obj1} (or $M_{obj1'}$). The unbalanced Michelson interferometer is composed of the same beam splitter and M_{ref}, and a different object mirror M_{obj2} to vary the relative delay between the two pulse trains, which are reflected by the mirror M_{obj1} and M_{obj2}. During the measurement, by moving the common reference mirror M_{ref} of the two interferometers, we could observe the following two interference fringes, which are formed for the ordinary and unbalanced Michelson interferometer.

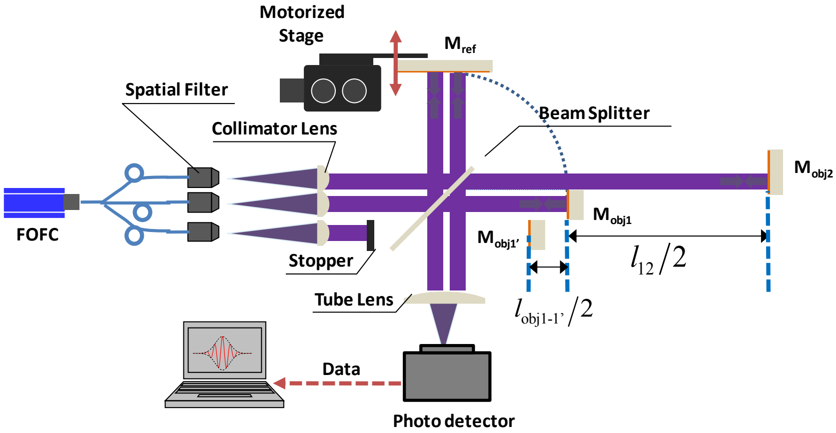

Fig 1. Optical schematic.

$$I(l_1) = a_1 + b_1 \times \exp\left[-\left(2\sqrt{\ln 2}\, l_1 / L_{\mathrm{coh}}\right)^2\right] \times \cos(k \times l_1)$$
$$+ a_2 + b_2 \times \exp\left[-\left(2\sqrt{\ln 2}\,(l_1 + \Delta_{12}) / L_{\mathrm{coh}}\right)^2\right] \times \cos(k \times (l_1 + \Delta_{12}) - h_{12} \times \Delta\varphi_{\mathrm{ce}}). \quad (1)$$

where $a_n = I_{\mathrm{ref}} + I_{\mathrm{obj}\text{-}n}$, $b_n = 2\sqrt{I_{\mathrm{ref}} I_{\mathrm{obj}\text{-}n}}$, $I_{\mathrm{ref}}, I_{\mathrm{obj}\text{-}n}$ are intensities reflected by the reference mirror and the nth object mirror, l_1 is the optical path difference between the object mirror M_{obj1} and the reference mirror M_{ref}, L_{coh} is the temporal coherence length of one pulse from the FOFC, T_{R} is the pulse repetition period, $\Delta\varphi_{\mathrm{ce}}$ is carrier phase slippage per T_{R} . The distance between two object mirrors is $l_{12} = h_{12} \times c \times T_R + \Delta_{12}, (\Delta_{12} > L_{\mathrm{Rey}})$, L_{Rey} means the Rayleigh limit. To avoid that two interference fringes overloped each other, it is needed to select one from the object mirrors M_{obj1} and $M_{obj1'}$, which are set with the optical path difference $l_{\mathrm{obj1\text{-}1'}}$ ($l_{\mathrm{obj1\text{-}1'}} > L_{\mathrm{Rey}}$). The Eq. (1) means that one can presume the distance between interference fringes' peaks Δ_{12} and the measured length related carrier phase slippage of the interference fringes $h_{12} \times \Delta\varphi_{\mathrm{ce}}$ from the observed interference fringes.

The analysis indicates that, with the values of f_{CEO} and f_{rep} (namely, $\Delta\varphi_{\mathrm{ce}} = 2\pi f_{\mathrm{CEO}} / f_{\mathrm{rep}}$ and $T_{\mathrm{R}} = 1/f_{\mathrm{rep}}$ are known), one can perform high accuracy distant evaluation by calculating h_{12} and Δ_{12} from the obtained interference fringes.

Summary

In summary, the executable optical schematic of an FOFC-based multiplex Michelson interferometer was proposed. The results of analysis show that the multi-pulse trains' interference based method can be used as a powerful length measurement tool. Finally, the present concept and analysis pave the way for multi-pulse trains' interference based metrology.

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References

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