A dual-heterodyne laser interferometer for simultaneous measurement of linear and angular displacements

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I. Introduction

We develop a dual-heterodyne laser interferometer without DWS (Differential-front Sensing) which can measure picometer-level linear displacement and nano-radian-level angular displacement simultaneously. Due to a highly-symmetric optical path configuration, this dual-heterodyne laser interferometer has reduced sensitivity to the low-frequency noise mainly caused by the environmental fluctuations by means of common-mode noise rejection. This dual-heterodyne laser interferometer offers potentials for optical readout system of proof mass attitude metrology in space borne gravitational wave detection.

Ⅱ. Experiment Setup

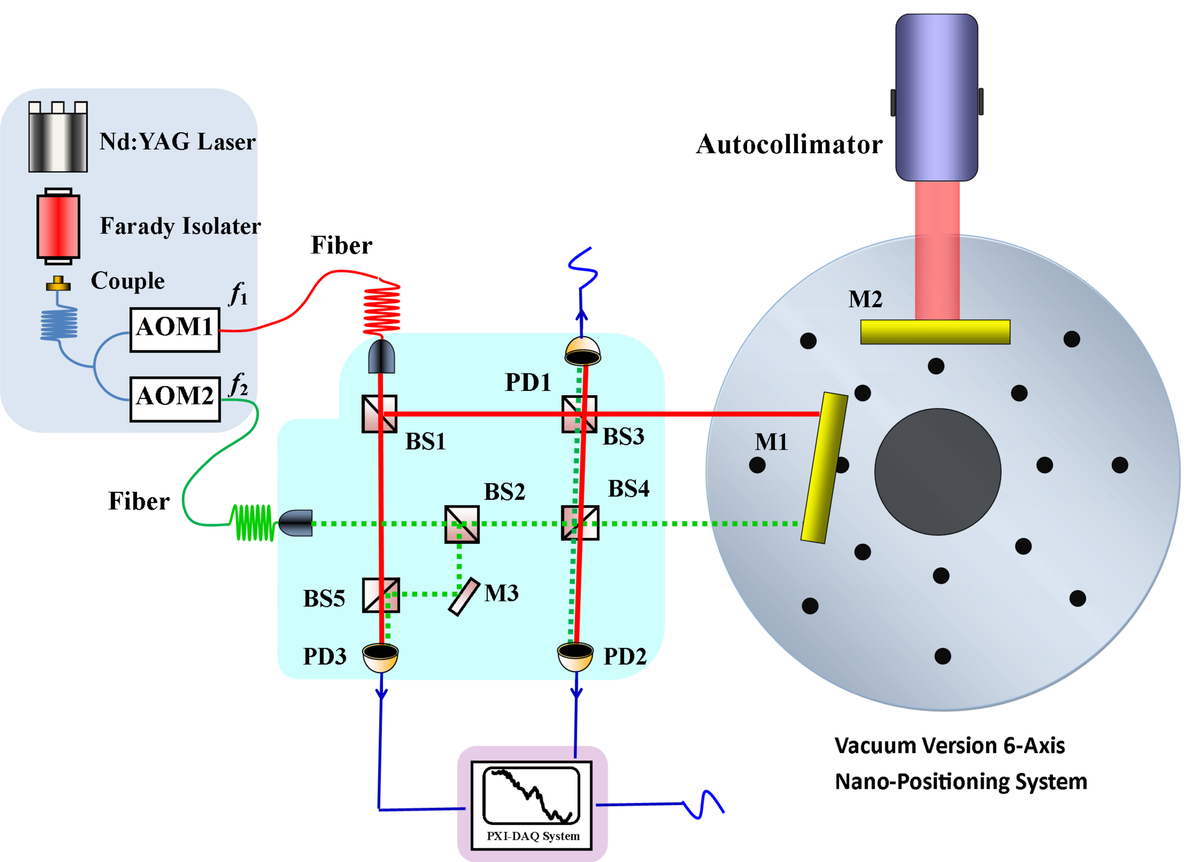
- **Laser : Nd:YAG , 1064nm**
- **AOM : Gooch & Housego , TeO_2**
- **Nano-Positioning System : PI , Hexapod Microrobot**
- **Acquisition System : NI-PXI-1112**
- **Heterodyne frequency : f_{het} = 20 kHz**
- **Laser Power (received by a single PD):200uW**

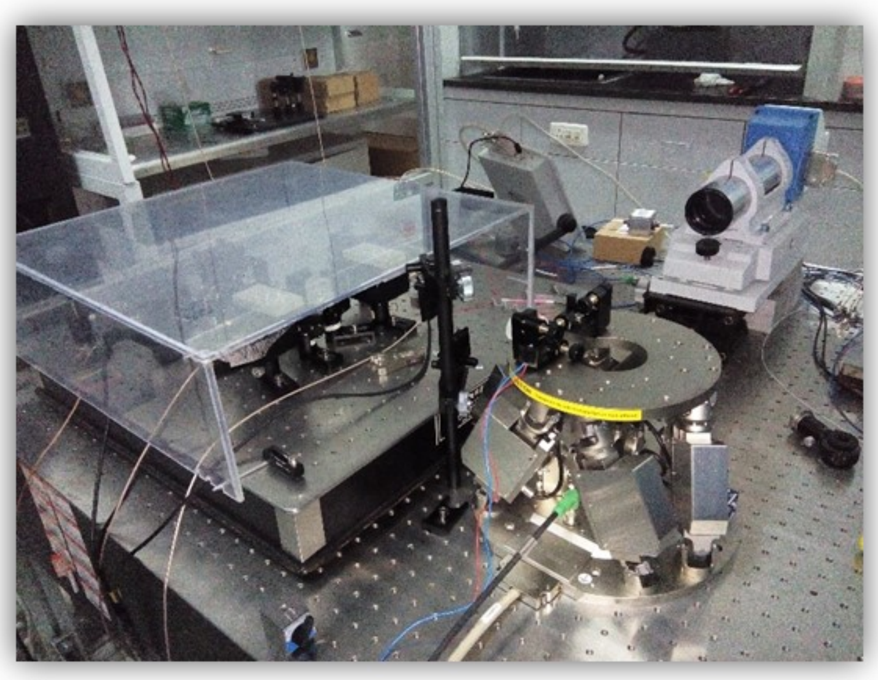
The experiment system is composed mainly of three parts :

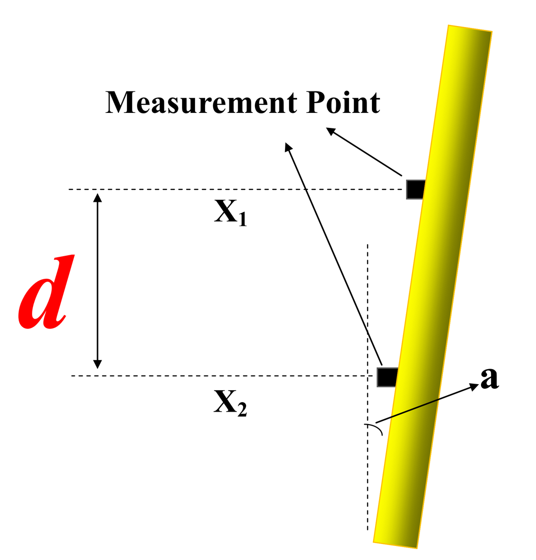
I. Generation system of heterodyne frequencies: Nd:YAG laser, Farady Isolater, Fiber Lens Couple , Acoustic-optical Modulator (AOM)

II. Optical bench: two fiber collimators, five beamsplitters, one mirror, three photodetectors (PD)

III. Calibration system: 6-Axis Nano-Position system, autocollimator







$$\begin{cases} \Delta x = \dfrac{\lambda}{8\pi}(\Delta\Phi^1 - \Delta\Phi^2) = \Delta(\dfrac{x_1 + x_2}{2}) \\ \Delta\theta \approx \dfrac{\lambda}{4\pi d}(\Delta\Phi^1 + \Delta\Phi^2 - 2\Delta\Phi 3) = \Delta(\dfrac{x_1 - x_2}{d}) \end{cases}$$

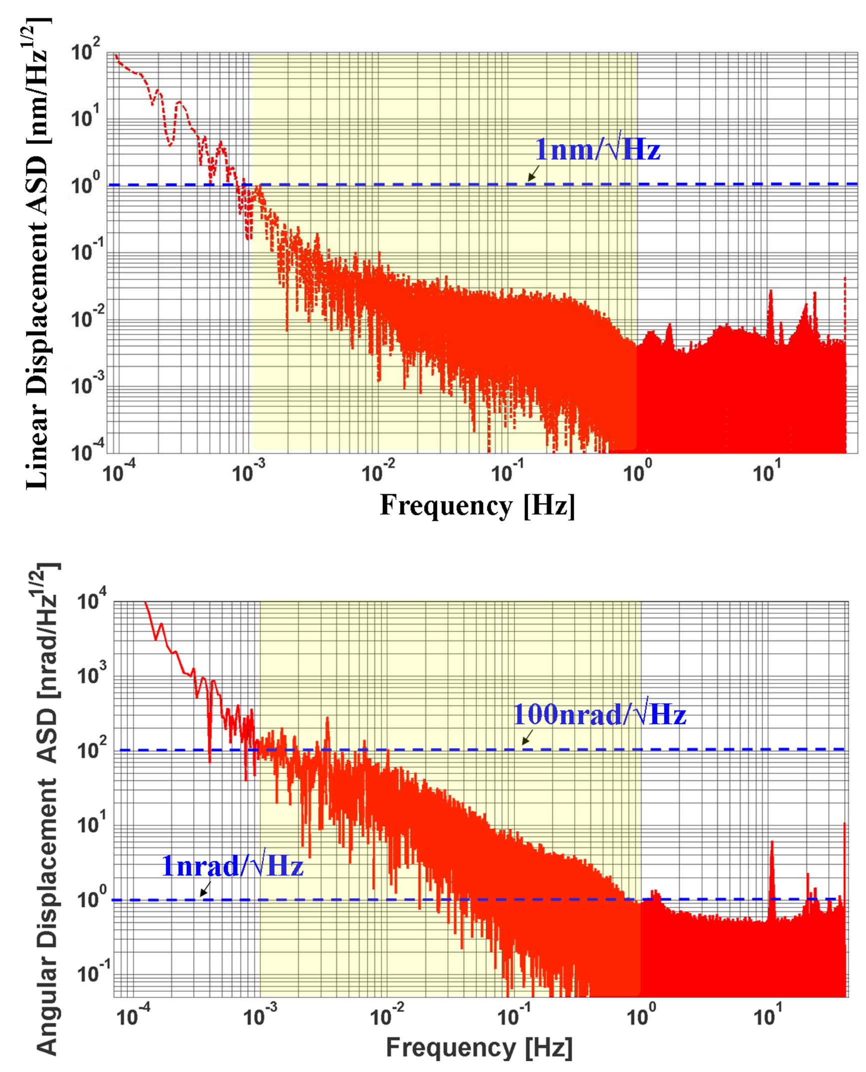
The translational displacement of two parallel measurement points on surface of the testing mirror (M1) is measured, so information of two degrees of freedom of M1 is known: translational displacement along the measurement laser axis and tilt in the laser plane.

Ⅲ. Results

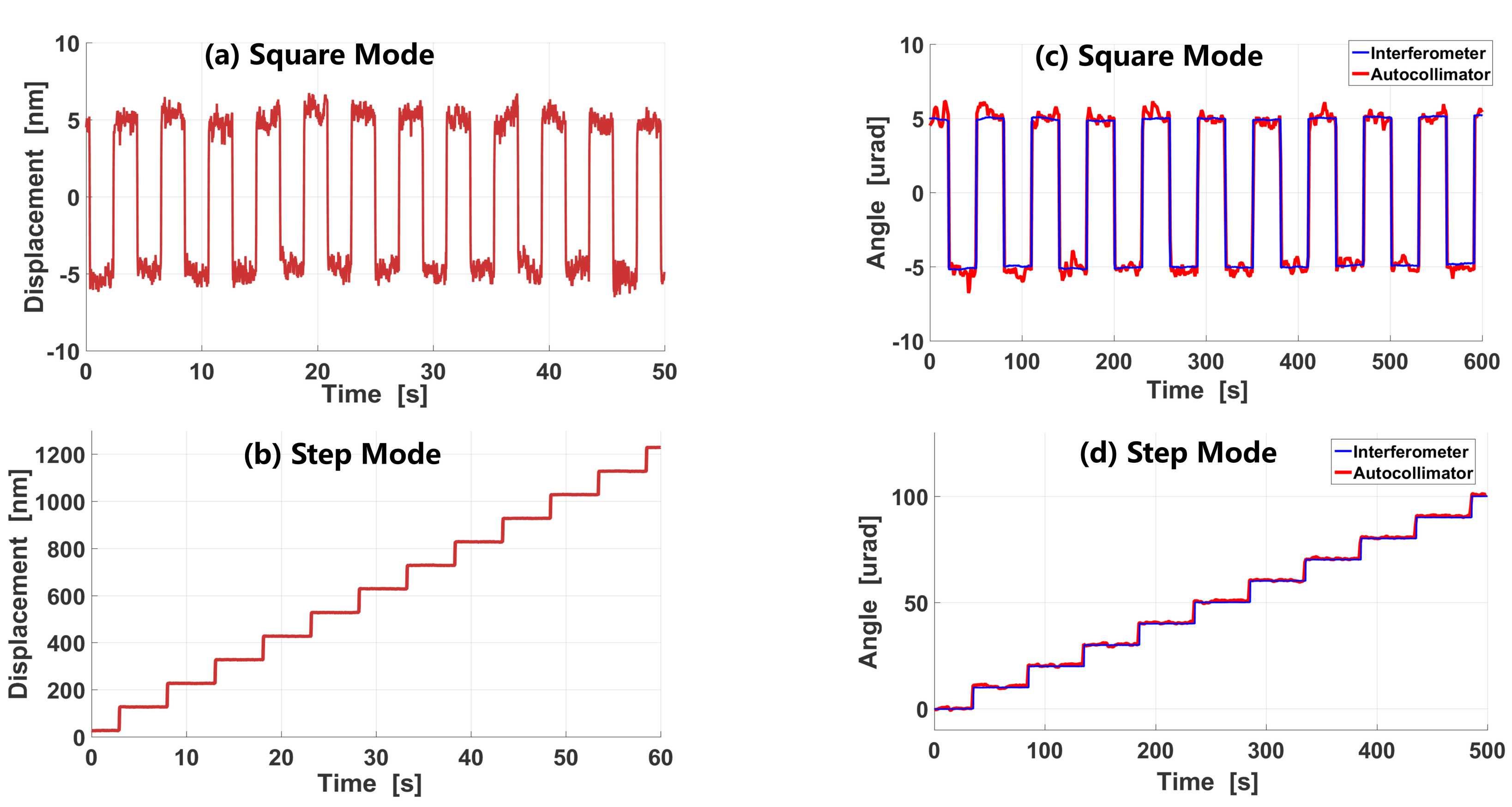
A. Noise Level

Translation noise	20 pm/√Hz @ 0.1 Hz 100 pm/√Hz @ 2 mHz
Tilt noise	6 nrad /√Hz @ 0.1 Hz 100 nrad/√Hz @ 1 mHz

Figures on the right show the noise levels of the linear and angular displacements measurements are 50 pm/√Hz and 50 nrad/√Hz at 10 mHz, respectively. The noise with frequency above 6 Hz is likely attributable to mechanical vibrations.



B. Calibration



Translation Calibration

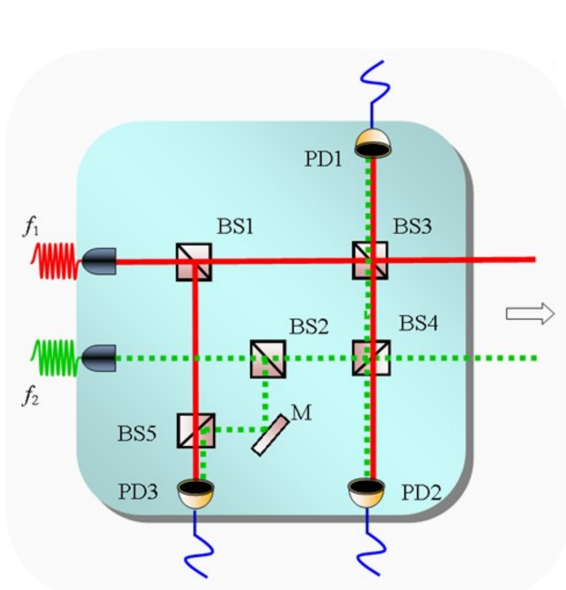
- **Actuator : 6-Six Miniature Hexapod**
- **Calibration : Miniature Hexapod**
- **Square Mode : 10 nm @ T=4s**
- **Step Mode : 100 nm @ T=5s**
- **Nonlinearty : <1 %**
- **Travel Range : >200um**

Tilt Calibration

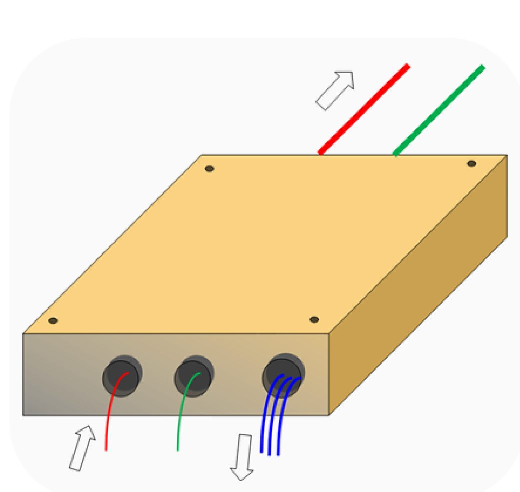
- **Actuator : 6-Axis Miniature Hexapod**
- **Calibration : Miniature Hexapod , Autocollimator**
- **Square Mode : 10 urad @ T=60s**
- **Step Mode : 10 urad @ T=50s**
- **Nonlinearity : <1 %**
- **Travel Range : >±100urad**

Ⅳ. Future Work

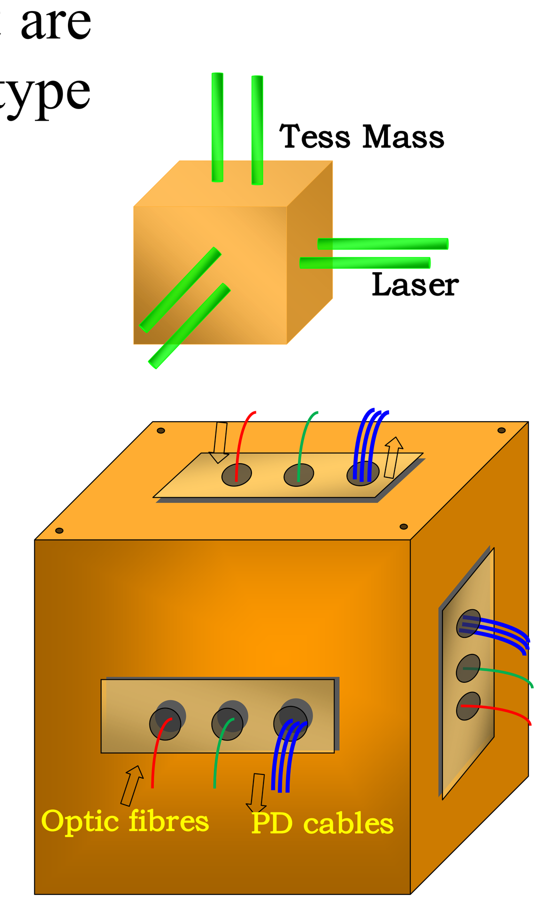
A dual-heterodyne laser interferometer with displacement resolution of picometer-level translation and nano-radian-level tilt are demonstrated. It can be used as optical readout system prototype for proof mass attitude metrology.



I. Optical Bench



II. Compact 2-DOF Interferometry



III. 6-DOF Optical Readout System

Challenges :

- **Desired resolution (@ 10 mHz): 10 pm/√Hz, 10 nrad/√Hz**
- **Cross-Coupling effects between six DOFs**
- **Compact packaging of 6-DOF Optical Readout System**

reference :

H. Yan, H. Z. Duan, L. T Li, Y. R. Liang, J. Luo, and H. C. Yeh, "A dual-heterodyne laser interferometer for simultaneous measurement of linear and angular displacements," Rev. Sci. Instrum. 86, 123102 (2015).