Characterization of a Bimorph Piezoactuator to apply in Laser Interferometer Control Vibration

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Abstract
Measurements of small displacements up to some nanometers by laser interferometry needs noise ambient reduction. Some expensive techniques are applied to this control. In this work, it is shown an alternatively low cost laser interferometer vibration control applying a bimorph piezoactuator. At first, experimental and simulated tests are done to characterize this actuator. Laser interferometry is applied to obtain displacement frequency response of actuator and electrical impedance curve is obtained to determine resonance frequency and phase of this actuator. All experimental results are compared with numerical simulations by using finite element model.

Introduction
Laser interferometry is widely applied to measure displacements generated by piezoelectric transducers [1,2]. However, there are many difficulties to make these measurements applying a simple and low-cost interferometer, because the ambient noise (below 1 kHz) is larger than piezoelectric displacement, which is in the range of nanometers. To implement a precision interferometer is necessary to reduce these low frequency noise to an acceptable level. Several techniques are applied to insulate the interferometer from ambient noise [2,3], such as a heterodyne technique [4] or double detection signal [5]. However, the heterodyne technique needs a hard electronics and both need expensive optical components such as wave plates, polarized beamsplitter etc [2]. In this work, a bimorph cantilever piezoactuator to stabilize laser interferometers is characterized and implemented with a low order bandpass filter.

A bimorph piezoactuator is built by bonding two pieces of piezoceramic together or to a thin metal sheet, as shown in figure 1a, so that differential changes in length of the two pieces can produce relatively large movements. Therefore, a voltage applied to the electrodes causes the plates to deform in opposite directions, resulting in a bending action, as illustrated in figure 1b. Bimorphs cantilever provides larger displacements at low voltages than other piezoelectric transducers, typically in excess of 10 µm per volt at static excitation and 50 µm per volt at resonance frequencies. Because of this, it is an excellent actuator to apply to laser interferometer vibration control [4], in mirror scanning etc. Other advantage of this actuator is a fast displacement response to voltage applied.

![Figure 1: (a) rest bimorph; (b) excited bimorph](image)

Before applying the bimorph actuator to laser interferometry vibration control, the bimorph actuator is characterized by using experimental and computational techniques. A laser interferometer and a commercial optical system (MTI-2000) are applied to characterize bimorph displacement. An impedance analyzer (HP4194A) is applied to obtain the electrical impedance and phase curves, which allows us to identify resonance frequencies of this piezoactuator. Computational simulations by finite element method (FEM) are done to verify bimorph behavior and experimental results.

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Experimental Analysis

The bimorph used in this work is illustrated in figure 2. Each piezoelectric layer and aluminum plate sandwiched have 200 μm thickness and its other dimensions are illustrated in same figure. A quartz mirror with 1 mm thickness and 5 mm diameter with vaporized aluminum on its surface was bonded to bimorph with epoxy resin.

Optical techniques are applied to characterize the bimorph displacement. In this work, measurements are done by using a non-stabilized Michelson-type interferometer (figure 3) based on a phase-shift measurement of one-point displacement [6,7] of the bimorph surface, as illustrated in figure 2, and by a commercial optical system (MTI-2000), which measures the intensity variation of reflected light by surface. The measurements are performed by considering harmonic excitation of bimorph actuator in a frequency range from 10 Hz to 1.2 kHz.

Phase-shift of an optical wave due to the movement of a sample [2,7] changes of 2π to an actuator displacement of λ/2 [7], where λ is the laser wavelength. In this setup a He-Ne laser (λ=632.8 nm) is applied. This measurement technique consists of counting interference fringes due to reflected laser beams from a reference mirror (R) and an analyzed sample (S). Calibration is not necessary, because the distance between each bright fringe (or each dark fringe) is λ/2. As shown in figure 4a there are 4 bright fringes (n=4) between a minimum and a maximum of the input signal corresponding to a displacement of 1265.6 nm (4λ/2).

Figure 4: (a) input and output signal of actuator obtained by a laser interferometer; (b) electrical impedance curves.
Notice from figure 4a a phase difference between input and output signals ($\Delta\Phi$). This is due to a measurement done close to a resonance frequency. Then, it is necessary to stay in a range far from resonance frequency to apply this actuator to stabilize the interferometer.

Impedance analysis is done by HP4194A. Electrical impedance and phase curves are shown in figure 4b, from these results is determined that the impedance range between 100 Hz to 800 Hz has approximately same phase. The ambient noise frequency measured has an average value of 250Hz. Therefore, bimorph piezoactuator response is linear for the input signal in this desired frequency range.

**Finite Element Method (FEM)**

Bimorph piezoactuator is modeled by using finite element method (FEM) through software ANSYS. Two-dimensional finite element models are built based on plane strain assumption due to bimorph rectangular shape since the width is much larger than thickness. The mirror is modeled considering plane stress assumption.

Figure 5a shows first and second resonance modes obtained by modal analysis at frequencies 57.18 Hz and 944.72 Hz of bimorph modeled in 2D. Experimental resonance frequencies obtained by optical techniques and impedance analysis are 72 Hz and 1019 Hz. Three-dimensional model is built only to illustrate the displacement and bending close to the first resonance frequency, as shown in figure 5b due to the high computational cost. These models are built considering electrodes in both surfaces perpendicular to the poling direction and grounded in the thin metal layer. Piezoelectric material used in simulations is PZT-5A and metal is aluminum.

![Figure 5: Bimorph deflection by FEM: (a) 2D simulation with mirror; (b) 3D simulation for illustration.](image)

Figure 6 shows experimental and simulated displacement frequency response between 10 Hz and 1.2 kHz. The bimorph has a large deflection close to first and second resonance frequencies, as shown in figures 5a and 6. Therefore, for laser interferometer control vibration purposes, the bimorph actuators must operate between these frequencies. Notice from figure 6 that computational simulations by FEM are close to reality although difficulties to obtain an accurate model of bimorph piezoactuator. The main difficulty is to model the built-in boundary condition.

![Figure 6: Experimental and simulated results displacement frequency response.](image)
Laser Interferometer Stabilized

A Michelson-type interferometer with a bimorph actuator attached to the reference mirror (R) position is assembled (figure 7a). Bandpass filter operating in a range from 100 Hz to 1 kHz was designed and implemented. This filter is connected to photo-detector and controls the bimorph actuator (figure 7a) by applying low voltages (milivolts) to stabilize the interferometer. This bimorph piezoactuator has a fast displacement response and it is in phase with the input signal in a range from 150 Hz to 800 Hz, as illustrated in figure 6. To stabilize the interferometer, it is necessary a inverter bandpass filter with phase difference $\pi$ in relation to ambient vibration noise signal, as shown in figure 7b. Therefore, bimorph displacement is equal but with opposite sign to the displacement due to the ambient noise.

Ambient noise produces amplitude displacements up to an average of 60 nm measured by photo-detector. Bimorph cantilever actuator has an average deflection of 500 nm/V in a range from 150 Hz to 800 Hz. To stabilize the interferometer in this range it is necessary to drive the bimorph with voltages up to 140 mV. Stabilization is done at frequencies under 1 kHz. For measurements at higher frequencies, such as 10 kHz up to 5 MHz, this system is able to measure in nanometric scale.

Conclusions

Bimorph was successfully implemented to stabilize laser interferometer at low cost. This system is able to measure displacement amplitudes of piezoelectric transducer at frequencies higher than 10 kHz. Laser interferometry and impedance analyzer were applied to characterize bimorph cantilever. These results were compared with computational simulations by FEM showing good agreement with experimental results.

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