A micro-displacement stage for scanning white-light interferometry

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Abstract. A one-dimension micro-displacement stage used in Scanning White-light Interferometry (SWLI) profilometer is presented. The stage is a set of two-grade displacement mechanisms that has a hologram diffraction grating fixed on it to form a closed-loop displacement measuring & control system. The stage's vertical scanning range is up to 6mm, the vertical resolution 1nm. Finite element analysis has been used to study the behavior of the flexural hinge guided motion nano-positioning stage. The experimental results of surface profiles of standards sample are also presented.

1. Introduction

Scanning White-light Interferometry (SWLI) has been widely used for measuring surfaces that have discontinuities of larger than the wavelength of the light sources such as rough surfaces, thickness, step heights, and semiconductor line width.¹ ² In SWLI, the surface of the sample is mechanically scanned in the Z-direction while correlogram produced by interfering of the light reflected from the object and the reference surface is recorded with a CCD camera for further processing by a computer. Because the surface profile is directly or indirectly evaluated from the movement of the scanning actuator, the performance of the SWLI is greatly affected by the scanning actuator. Almost all SWLI systems employ the piezoelectric transducer (PZT) as the scanning actuator because of the high resolution and fast frequency response. However, the PZT has some undesirable properties, including hysteresis and nonlinear motion, especially in the large movement range, therefore measures must be taken to ensure the accuracy of scanning motion.

Presented in this paper is a micro-displacement stage for SWLI. The stage is a set of two-grade micro-feed mechanisms. A hologram diffraction grating is fixed to the stage to measure the real displacements of the stage so the accuracy of scanning motion can be ensured. The stage's vertical scanning range is up to 6mm, the vertical resolution 1nm. In the last part of paper, the experimental results of the standard sample’s surface profile are also presented.

2. The setup of the stage

Figure 1 is the schematic diagram of the micro-displacement stage and the SWLI profile system. The stage is a two-grade micro-feed mechanism.
The large range scanning movement is achieved by the coarse grade mechanism. This grade mainly involves a displacement decreasing wedge mechanism driven by a stepping motor through a lead screw. Mounted on the upper wedge is the flexural hinge guided fine positioning stage driven by a piezoelectric actuator. The four symmetrical folded flexural hinges are machined using wire EDM (electric discharge machining). A reflecting hologram diffraction grating is fixed to the fine positioning stage in order to measure the real time displacements of the stage. The output signal of the grating sensor is fed to the computer and compared with the target displacement in order to monitor the operation of the stepping motor and/or the PZT actuator. This closed-loop system in combination with a 16 bit digital-to-analogue converter and precision grating sensor enable the stage’s movements with both high resolution and large dynamic range.

3. Finite element simulation of the flexural hinge guide stage

Simulations of the force, frequency and stresses with various flexural hinge length \( l \) and hinge width \( d \) were performed by the ANSYS version 8.0 finite element code. Both static analysis and modal analysis were performed.

3.1. Static analysis

Figure 2 is the deflection diagram when the force \( P \) is applied by the piezoelectric actuator to the stage. The displacement of the flexural hinge guided stage is given by

\[
\delta = \frac{Pl^3}{2Ehd^3}
\]  

(1)

Where \( E \) is the Young’s modulus, \( l, h, d \) are the hinge length, width and depth respectively. Figure 3 plots the simulation results of the force \( P \) versus hinge length \( l \) for different hinge widths \( d \). A range of 40 \( \mu \)m was used as an input in the simulations. It shows that as the hinge length increases, the driving force decreases. Also, as the hinge width increases, the driving force increases. This behavior is consistent with general beam theory for a cantilever beam.
Figure 4 plots the maximum range of motion under the condition of allowable maximum stress. The allowable maximum tensile stress is defined as 0.1 times the effective yield stress in the analysis\(^4\). The motion range increases with an increase in the hinge length and a decrease in the hinge width.

![Figure 3. Force applied by PZT versus hinge for different hinge width](image)

![Figure 4. Maximum range of motion for different hinge lengths and widths](image)

3.2. Modal analysis

Three modal frequencies of the flexural hinge guided stage were calculated. The results are shown in Figure 5. The first in-plane mode is in the direction of motion and the second in-plane mode is orthogonal to the direction of motion. The third mode is out of plane. The natural frequency of a free vibration beam is given by\(^4\)

\[
f = \frac{\omega}{2\pi} = \frac{1}{2\pi} \sqrt{\frac{k}{m}}
\]  

(2)

Where \(k\) is the stiffness and \(m\) is the mass. For a particular hinge and a given mass, as the hinge length \(l\) increases, the stiffness decreases and hence the natural frequency decreases. Figure 5 also shows the calculation results by equation (2) and by the ANSYS simulations. They are consistent with each other.

4. Experiment results and conclusions

![Figure 5. Natural frequency versus hinge length for different hinge length and width](image)
Experiments were carried out with the self-design system. A domestic Linnik interference microscope, Model 6JA, is used. A $40\times$ magnification objective (NA=0.65) and an unfiltered tungsten bulb were used. Correlograms were detected by a CCD video camera. Figure 6 and Figure 7 show one of the standard sample’s experiment results. The standard has graduation lines on it and the certified height is $1.72\ \mu m$. The measuring height value by our system is $1.73\ \mu m$.

A one-dimensional micro-displacement stage is presented and used in the surface profile measuring system based on the Scanning White-light Interferometry (SWLI). The stage has the characteristic of both large range of motion and nano-positioning precision. Experimental results prove that the stage is able to satisfy the requirement of a SWLI profilometer.

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