Noncontact Detection of Nanoscale Vibrations of Solid Surfaces by Laser Interferometry

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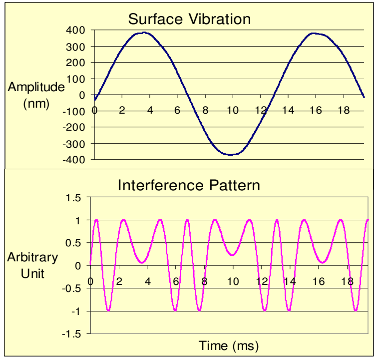
Abstract:

A miniature laser interferometer is used to detect the vibration amplitude of a piezoelectric disk with a resolution of about 10 nm. The vibrations of the disk are induced by an applied potential difference of a few volts. Laser light (He-Ne λ=632.8nm) is directed through an optical fiber onto the vibrating surface. Two reflections are produced, one from the cleaved fiber tip and another from the vibrating surface. When these two reflected beams reenter the fiber, an interference signal results. The vibration amplitude is measured by counting the fringes of the interference signal. Our data show the disk vibrates sinusoidally with a peak located slightly off center and with an amplitude proportional to the applied voltage. The disk serves as a prototype to explore the limits of this technique in detection of very small vibrations of solid surfaces. Our goal is to use the interferometer to profile solid surfaces with nanometer resolution.

Figure 1



Sample interference pattern and corresponding disk waveform. The interference signal has 2.45 fringes which corresponds to an amplitude of 388nm.

$$Y(t) = A\cos[(2\pi\Delta/\lambda_l)+\pi] \qquad \text{Eq. 1}$$

$$Y(t) = A\cos[b\sin(wt+\beta)-\varphi] \qquad \text{Eq. 2}$$

$$\text{where} \quad b = 4\pi a/\lambda_l$$

$$\varphi = \pi + 4\pi d_o/\lambda_l$$

$$a = \frac{\lambda_l}{4}\left(\frac{b}{\pi}\right) \qquad \text{Eq. 3}$$

Theory and Methods:

A miniature laser interferometer[1] previously used to study capillary waves on fluids and to measure surface tension and viscosity was adapted to study the surface vibration of solids.

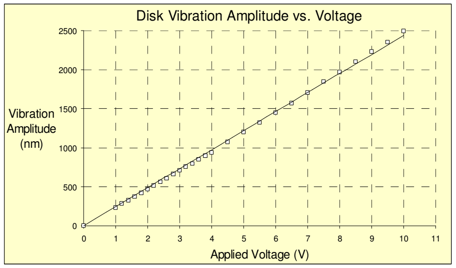
Laser light (He-Ne λ=632.8nm) is directed through an optical fiber onto the vibrating surface. Two reflections are produced, one from the cleaved fiber tip and another from the vibrating surface. When these two reflected beams reenter the fiber, an interference signal results (Fig. 1).

The number of fringes in the interference signal is proportional to the amplitude of the vibrating surface. A higher number of fringes corresponds to a higher amplitude.

A fitting program[2] is used to fit Eq. 2 to the digitized data to obtain the two parameters *b* and φ. Once *b* is determined, Eq. 3 gives the amplitude of vibration.

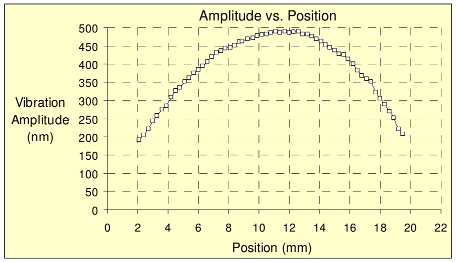
The piezoelectric disk used was a Radio Shack transducer (273-073A) 30Vpp with a diameter of 25.4mm. It was driven by a sine wave and at a range of frequencies from 37 to 1013 Hz and an applied voltage from 0.8 to 20 Vpp.

Figure 2

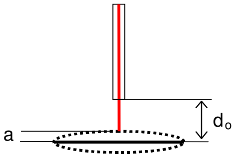


Data at 197Hz show the proportional relationship between the vibration amplitude at the center of the disk and the applied voltage.

Figure 3



Data at 523Hz, 4Vpp, shows the vibration amplitude of the piezoelectric disk surface as a function of position. As expected the maximum amplitude occurs near the center of the disk.



$$\Delta = 2[d_o - a\sin(wt+\beta)]$$

Delta is the path difference between the beam reflected from the vibrating surface and the beam reflected from the fiber tip.

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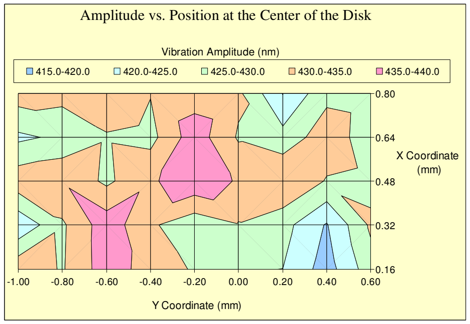
Results:

- The relationship between the applied voltage and the amplitude of vibration (Figure 2) is linear. For the disks used, the vibration amplitude increases by 250 nm per volt.
- As shown in Figure 3 the vibration amplitude is a maximum near the center and diminishes sinusoidally as we approach the disk boundaries.
- The central peak is not in the exact geometric center of the disk, but is instead off center by a minimum of 0.4mm in each perpendicular direction (Figure 4).
- The fringes can be counted to within ±0.05 and the amplitude calculated to within ±10nm.

Figure 4



Contour plot of data at 523Hz, 4Vpp shows an off center peak. The position of the peak is about (0.45 mm,-0.35 mm) away from the geometric center of the disk. The height change shown is only 20nm in the Z-direction.

Discussion:

- The vibration amplitude of the piezoelectric disk is a linear function of the applied voltage as long as the vibration amplitude is below 2.5 μm.
- As shown in Figure 4, the peak amplitude is very near the center of the disk in the Y-direction and off center by about 1mm in the X-direction. This is because the wire attachments supplying voltage to the crystal add some mass to the disk and cause a decrease in the amplitude. Consequently the peak is shifted away from these wires.
- In a new experiment, an optical fiber has been attached to the center of the piezoelectric disk. This geometry allows the fiber to move back and forth across a stationary surface to obtain data on the surface height variations. Currently we can measure changes in the slope of a surface under the probe.

References:

1. F. Behroozi, B. Lambert, and B. Buhrow, “Direct measurement of the attenuation of capillary waves by laser interferometry: Noncontact determination of viscosity,” Appl. Phys. Lett. **78**, 2399-2401 (2001).

2. F. Behroozi and P. Behroozi, “Efficient deconvolution of noisy periodic interference signals,” J. Opt. Soc. Am. **23**, 902-905 (2006).