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Detecting the vibration state of objects based on photorefractive materials

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ABSTRACT

Vibration State of objects was detected based on photorefractive crystal, which photorefractive properties can be changed due to the vibration of crystal along its optical axis. To explain this, a mathematical model was proposed to simulate this process, and the vibration state (frequency and amplitude) are measured by the experiment and numerical calculation. The simulation and experiments show a good agreement. Our work imply that the photorefractive materials have good application prospects in motion detection.

1. Introduction

Non-contact, high accuracy, and high sensitivity motion signal detection technology is the basic requirement of modern engineering technology development [1–10], especially in aerospace engineering and mechanical design. In motion detection technology, Laser Doppler (LD) technology [1,2,8] and Micro-Electro-Mechanical System (MEMS) technology [5–7,9,10] have attracted much attention and have played important roles. LD technology has many characteristics such as non-contact, quick response, and high accuracy. However, LD technology is not easy to find its way into production. MEMS technology has several advantages, such as batch processing, and it has a wide range of applications, but there are also some defects. For example, MEMS sensors have [9,10] poor electromagnetic ability, distortion, and so on. In fact, the development of motion detection technology is based on the actual application. Researchers have also studied photorefractive materials in order to meet different measurement requirements. However, vibration sensors based on photorefractive materials were widely used for the determination of the vibration [11,12]. Ref. [11] described an optical photorefractive frequency-domain method,which approach to measure phase modulation of light scattered from continuously vibrating surfaces.The displacement range that can be detected on the scattering surface is $5 \sim 40nm$. Ref. [12] present a first characterization of a new holographic vibration sensor, the photorefractive velocimeter.This sensor measures linearly the instantaneous velocity of high-amplitude (several μm), low-frequency ($0 \sim 1kHz$) vibrations on scattering surfaces. They were successfully used for the vibration detection, but their light paths are too complex because they are based on coherent detection schemes. How to simplify the optical paths was a problem that needs to be solved in order to industrialise. In this paper, we propose a simple vibration detector for a light path that is based on the influence mechanism of vibration on crystals, rather than based on the coherent detection scheme.

2. Experiment

In our experiments we used a congruently melting Strontium barium niobate (SBN) crystal with a concentration of 0.1 wt. % CeO2

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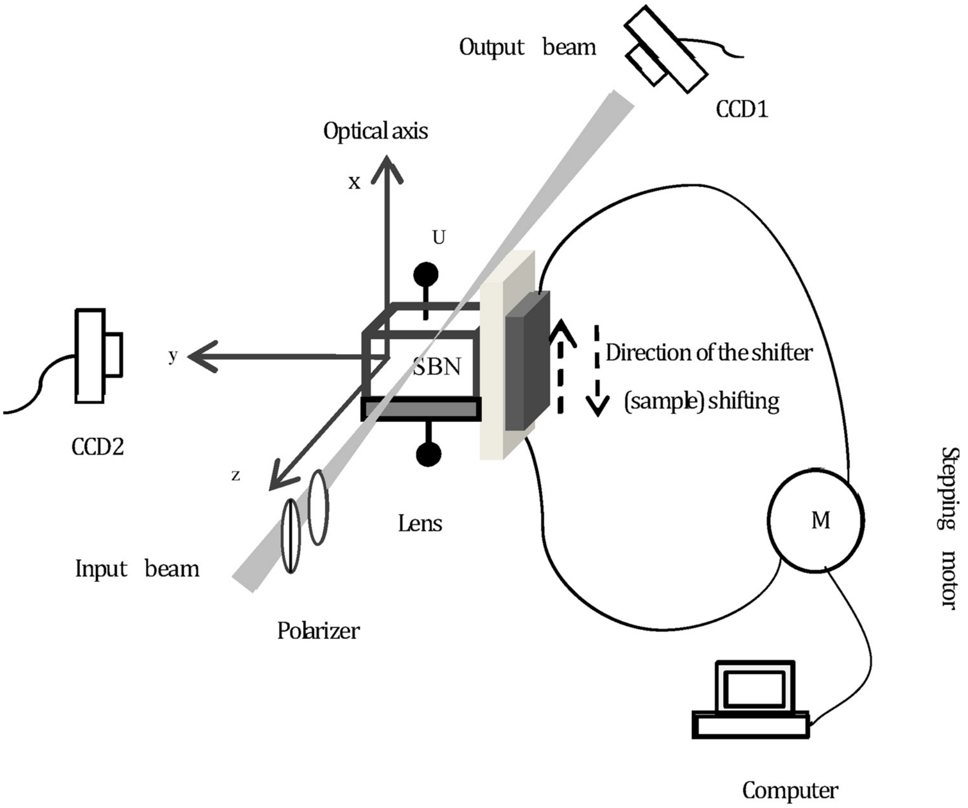

Fig. 1. Experimental setup, in which the motion of the crystal was controlled by a stepping motor.

($\gamma_{33} = 225pm/V$, $n_e = 2.35$; γ_{33} is the linear electro-optic coefficient; n_e is the unperturbed extraordinary index of the refraction)in the melt. The dimensions of the sample were $5.7 \times 5.9 \times 3.6mm^3$. The length of the C axis along the crystal was $d_c = 3.6mm$ and the propagation length was $z = 5.9mm$. The applied external field was about $E_0 = -40kV/m$. The wavelength of the incident beam was $\lambda_0 = 500$, $r = 0.1$ (r is a dimensionless coefficient and r was controlled by a non-coherent background irradiated light in our experiments). The characteristic length of the incident beam was $x_0 = 10\mu m$ [13]. We obtained $\beta = -2.17$, $\gamma = 0.14$, $\alpha = 0$ (There was no photovoltaic field in SBN). In our experiments, we chose $x_d = 0.005mm$, $\tau = 0.03s$ [13] (x_d was the equivalent length of the region in each process in Section 3, τ was the response time). The acquisition interval of the camera was $T_0 = 1ms$.

The experimental setup is shown in Fig. 1. The laser beam was propagated in the crystal along the z-axis with the polarization parallel to the optical axis. The motion of the crystal was controlled by a stepping motor, where the stepping motor was equivalent to a vibrating object and the motion equation of the crystal was $y = A\sin(2\pi\nu t)$ (A is amplitude, ν is frequency). It should be pointed out that the direction of the crystal's vibration was parallel to the optical axis. The images were captured by the CCD1 and CCD2.

After reaching a stable state, the beam in the crystal would have the following important phenomena: **1)** The beam in the crystal was observed to bend up and down with the vibration [14], as shown in Fig. 2(a). When the crystal moves upwards, the beam will bent upwards and vice versa, which resembles the "swinging soliton" recorded in the literatures [15–17]. **2)** Similar to the beam in the crystal, the exit point of the beam moves up and down with the vibration, as shown in Fig. 2(b).The oscillation frequency of "swinging soliton" and the oscillation frequency of exit point is consistent with the vibration frequency of the crystal. **3)** When the vibration frequency is constant, there is a positive correlation between the bending degree of the beam and the crystal amplitude.The maximum bending degree of the beam is limited by the size of the crystal. **4)** When the amplitude is constant, the bending degree of the beam is positively correlated with the vibration frequency.Similarly, the maximum bending degree of the beam is limited by the size of the crystal.

According to phenomenon 2), the vibration frequency of crystal can be obtained by measuring the oscillating frequency of the exit spot.The oscillating frequency of exit spots can be obtained by gray analysis of a certain point, as shown in Fig. 3. Fig. 4 shows the changes in the gray value of a point over time when $\nu = 1Hz$. Obviously, the spot center appears twice in the Fig. 4 in a cycle period. We could observe that the vibration period of the crystal was $T = 1s$ ($\nu = 1Hz$). The minimum period of measurement depended on the minimum acquisition interval of the camera.

The vibration frequency can be obtained by experimental phenomena, but the amplitude can not be obtained. In order to measure amplitude, mathematical model should be established for explain experimental phenomena.