

Photoelastic Fiber-Optic Accelerometers

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Abstract

This paper introduces a completely new class of fiber-optic accelerometers based on the principles of photoelasticity. The accelerometers rely on a unique photoelastic fiber-optic transducer originally developed as the sensing element for a photoelastic fiber-optic strain gage. The transducer is modified and incorporated into designs developed for two different types of accelerometers. Experimental tests conducted using prototypes built from these designs demonstrate that the units are both cost effective and efficient, making them competitive and comparable to their electrical counterparts.

Introduction

Many fiber-optic accelerometers have been developed to measure the acceleration of a moving object. In general, these units are very sensitive, weigh less than their electrical counterparts, and have a relatively high signal-to-noise ratio. The optical fibers also have the advantage that they are inert and immune to electromagnetic fields. The majority of the work performed in this area, however, has either focused on a specific application or been directed toward validation of a basic operating principle. Thus, fiber-optic accelerometers lack the sophistication, reliability and cost effectiveness enjoyed by their electrical counterparts. These obstacles currently limit the commercial production of fiber-optic accelerometers and the widespread use of a potentially superior technology. The solution to this problem lies in the development of cost effective and reliable units designed to meet a variety of different engineering applications.

Transducer Design

The shape and arrangement of the parts contained within an accelerometer may be complicated, however, it is often possible to model the essential components by a relatively simple single-degree-of-freedom system consisting of a mass, a spring and a damper. The acceleration is determined by

either measuring the displacement of the mass relative to the base of the accelerometer or by measuring the resultant force, F_r , in the spring. When the dimensionless frequency ratio is less than 0.2 and the dimensionless damping factor is zero,

$$F_r = -m a_0 \sin \omega t \quad (1)$$

where

$$a_0 = -\omega^2 X_0 \quad (2)$$

In Eqns. (1) and (2), m is the mass, ω is the frequency and X_0 is the amplitude of vibration of the base. The equations show that the force is directly proportional to the acceleration; F_r can be measured using a photoelastic fiber-optic force transducer.

Photoelastic Fiber-Optic Force Transducer

Figure 1 shows a schematic diagram of a photoelastic fiber-optic force transducer recently reported by Su et al [1]. It consists of a photoelastic cube, two crossed polarizers and two optical fibers. A stress concentration is produced by the applied load and the quadrature condition is achieved by preloading the transducer. Figure 2 shows the fringe pattern produced when a load P is applied to the sensing element. The stress optic law and the theory of elasticity can be combined to show that for points located directly beneath the load,

$$\frac{\Delta I / I_0}{\Delta P} = \frac{2}{f_\sigma R} \quad (3)$$

where ΔI is the light intensity modulation for a given load increment ΔP , f_σ is the material fringe value and R is the radial distance measured from the free surface to the point in question.

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Figure 3 shows the force transducer incorporated into an accelerometer. The unit is sealed in an aluminum case having outside dimensions of 41 mm x 35 mm x 20 mm. Optical access to the transducer is provided through two, 200 μ m-diameter multimode optical fibers. Fiber-optic ferrules, used to hold the fibers in place, simplify the alignment procedure. A 0.5 pitch GRIN lens is used to collimate the light and increase the optical coupling efficiency.

A prototype was tested using the setup shown in Fig. 4. The accelerometer has a sensitivity of 2 V/g over a frequency range extending from 0 to 600 Hz and a linear amplitude range of 0 to 5-g's. Since the noise level is approximately 5 mV, the resolution is 2.5 mg. The transverse sensitivity is less than 1%; the accelerometer is basically lead in/out insensitive provided that the fibers are not subjected to extremely large vibration amplitudes. An average value for the temperature sensitivity is 0.0224 $g/^{\circ}$ C. The noise level is approximately 5 mV, making the resolution 2.5 mg.

An alternate design was tested which utilizes a GRIN lens as the sensing element. This unit has a natural frequency of 22.3 kHz and linear amplitude range of ± 2000 g's; the accelerometer can accurately measure a shock pulse with a duration greater than 0.224 ms. The unit is housed in a stainless steel case having outside dimensions of 35 mm x 15 mm x 14 mm. The force transducer employs a 1.0 mm-diameter, 0.25 pitch GRIN lens as its sensing element; the lens also acts as a coupler for the optical fibers. The element is placed between two crossed linear polarizers and loaded using a 2 gram seismic mass. The accelerometer employs the same light source, fibers, signal conditioner and display devices shown in Fig. 4.

Reference

1. Su, W., Gilbert, J.A., Katsinis, C., "A photoelastic fiber optical strain gage," *J. Experimental Mechanics*, 35(1): 71-76 (1995).

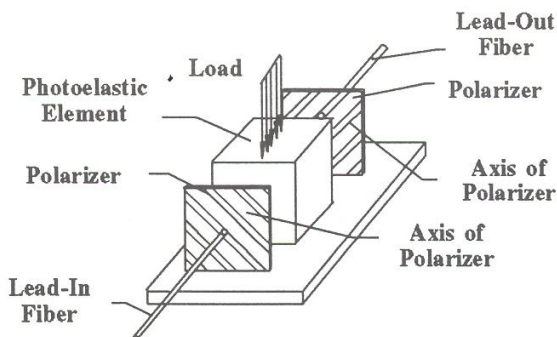


Figure 1. A photoelastic fiber-optic force transducer.

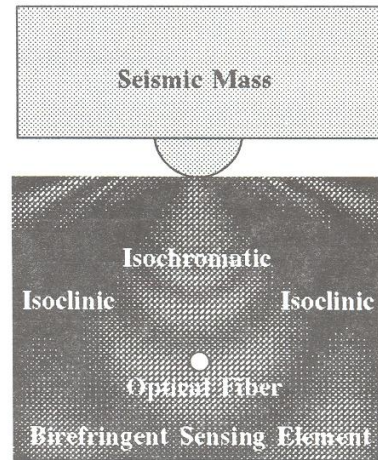


Figure 2. Fringe pattern in the birefringent sensing element.

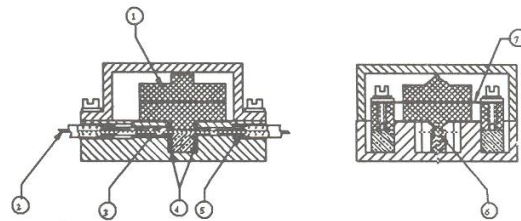


Figure 3. General purpose photoelastic fiber-optic accelerometer; 1. seismic mass, 2. optical fiber, 3. GRIN lens, 4. linear polarizer, 5. fiber-optic ferrule, 6. photoelastic sensing element, and 7. support element.

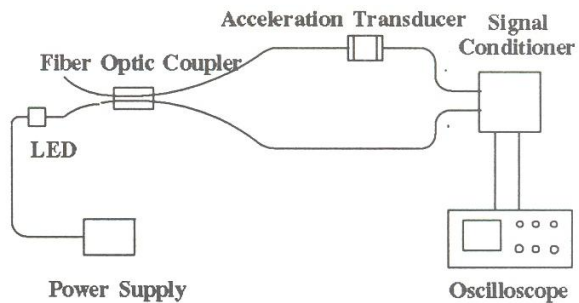


Figure 4. The complete acceleration measurement system.