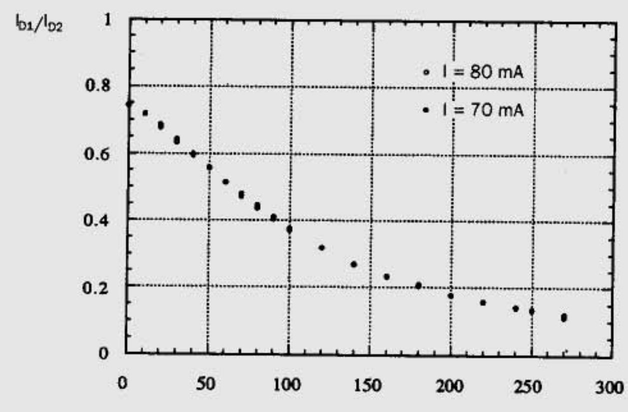

FIGURE 3. Plot of the ratio I_{D1}/I_{D2} versus the distance between the fiber endface and the reflection surface for the LED operating with currents of 70 mA and 80 mA.

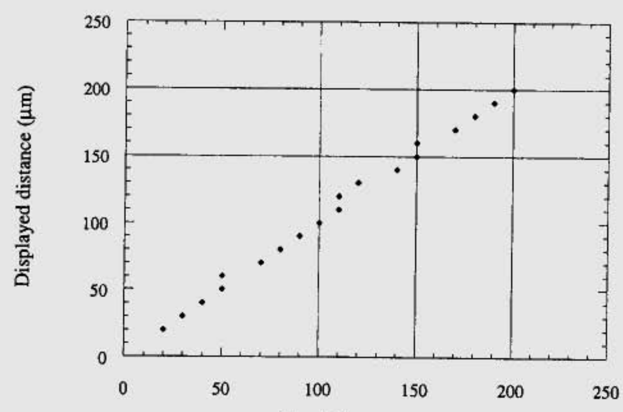

FIGURE 4. Plot of the distance estimated and displayed by the system versus the real distance.

a large flexibility. Therefore, functions such as comparison, arithmetic operations, convolution, or even more heavy processing can be introduced in the system. The only requirement is to change the controlling program of the system for a specific experiment. It is common to find a compiler using a high level language, so vast experience in computer programming is not necessary to achieve good results in programming the microprocessor system.

In conclusion, it was demonstrated a simple interface between an optical system and a digital data processing unit. The concept was applied to a displacement intensity based sensor, but has general validity.

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An Economical Piezoelectric Phase Modulator for Fiber Optic Sensors

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Abstract
A homemade piezoelectric phase modulator for interferometric fiber optic sensors was fabricated using piezoelectric buzzers as strain elements. Six piezoelectric elements were embedded between the two halves of a bakelite cylinder split along its axis and secured tightly together again to form a cylinder. Single-mode optical fiber was then wound around the cylinder to complete the unit. Up to a frequency of 500 Hz, the phase shift produced by the modulator is linearly proportional to the amplitude of the applied voltage. The sensitivity of the phase modulator is about 3.6 rad/V and has a dynamic range of 1,000 rad, which is sufficient for most phase modulation purposes.

Introduction

Phase modulators are widely used in fiber optic sensors to either stabilize against various environmental perturbations or to heterodyne for the sensitive and linear detection of optical phase shift.[1] The most popular form of fiber phase modulator is a piezoelectric cylinder with several turns of fiber wrapped around it under a small tension.[2,3] However, these cylinders are not common components readily obtainable. In some places (like Hong Kong), special orders have to be made from abroad. This results in undue delay and additional cost to the relatively expensive components. In this work, we describe the fabrication and performance of a homemade piezoelectric phase modulator using piezoelectric buzzers as the strain elements. These elements can be obtained off-the-shelf from any shop which provides electronic components. The cost is about 2 HK$ (about a U.S. quarter) each in Hong Kong. The modulator constructed is especially useful in negative feedback loop to eliminate ambient thermal drift and low frequency noises.

Design and fabrication

The body of the modulator is made up of the two halves of a bakelite cylinder of diameter 50 mm and height 90 mm split along its axis. Six piezoelectric elements grouped into three units are embedded between the two halves. Each unit is sandwiched between two rectangular copper plates of dimensions 80 × 40 mm. The plates provide electrical connection for the elements. To prevent a short circuit from

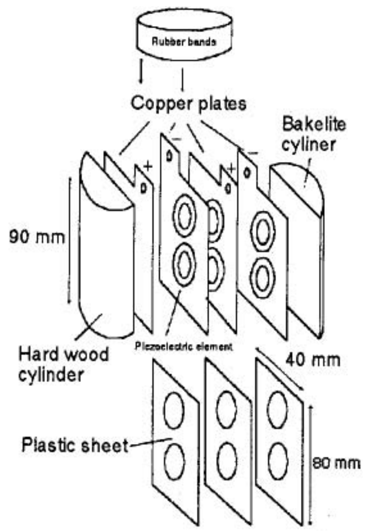

FIGURE 1. The design of the homemade phase modulator.

adjacent copper plates, a plastic sheet of the same size is inserted between them as an insulator. Two holes of the same size, shape and position of the piezoelectric elements are cut through the plastic sheets. Each element fits into a hole so that both sides are in contact with a copper plate. The arrangement is shown in Figure 1. The components are pressed together to form a cylinder which is secured in form by wrapping rubber bands around its upper and lower circumferences. A length of 6.5 m single-mode optical fiber is then wound around the cylinder. The fiber with a core diameter of 4 μm is optimized for light of wavelength 633 nm. The piezoelectric elements are under slight compression and when a positive voltage is applied across the copper plates, expansion of the elements will push out the two halves of the cylinder and increase the tension of the fiber. Since the optical path length of the fiber is a function of its stress, light transmitted within the fiber will experience a phase change. Voltages in a reverse direction will produce an opposite effect. The device changes the tension of the fiber and hence, the phase of light it carries according to external voltage modulation and can be used as a phase shifter.

Performance

The performance of the fabricated phase modulator is tested with a typical all-fiber Mach-Zehnder interferometer [3] made up with two 3-dB single-mode directional couplers. The modulator under test is coupled to the sensing arm. An electrical modulating signal of sine or triangular waveform is introduced to the modulator and the optical interference output is detected by a PIN diode. The input modulation and the diode output are monitored simultaneously by a dual beam digital storage oscilloscope. Experiments are performed with the amplitude of the voltage applied to the phase modulator kept constant while the frequency of the voltage is varied and vice versa.

The homemade phase modulator has a resonance frequency of about 1.5 kHz. When signals of constant amplitude (21 V peak-to-peak) and of frequency lower than about one third of the resonance frequency are applied to the phase modulator, the number of fringes (12 fringes with a standard deviation 1) observed is quite independent of the frequency, although the best-fit straight line slopes upwards slightly. The radians-to-volts constant is about 3.6 ± 0.3 rad/V. The result is similar to that performed with a commercial PZT cylinder which has similar dimensions as the homemade device and is wrapped with 20 m of the same type of fiber. The radians-to-volts constant for the latter is 2.66 ± 0.06 rad/V. The length of fiber used in the homemade device is substantially shorter than that used in the commercial one to produce a more pronounced fringe shift.

Modulating signals kept at a constant frequency of 100 Hz, 300 Hz and 500 Hz respectively are applied to the phase modulator. Figure 2 shows the relationship between the number of fringes shifted and the peak-to-peak voltage of the signal applied. The result indicates that the phase shift produced by the modulator is linearly proportional to the amplitude of the applied voltage. The slopes of the graph are 0.480, 0.566, and 0.653 respectively, corresponding to radians-to-volts constant of 3.02, 3.56, and 4.10 rad/V. The slight increase with frequency is in agreement with the previous result of constant voltage. Hence the sensitivity of the phase modulator is about 3.6 rad/V. As the piezoelectric buzzer can stand a few hundred volts, the modulator has a dynamic range of at least a thousand radians, which is sufficient for nearly all low frequency modulation purposes.

The homemade device is apparently more sensitive than the commercial one which requires a much longer length of fiber to produce the same effect. However the dynamic frequency range for uniform response is shorter because of its lower resonance frequency. (The commercial cylinder has a resonance frequency ≈3 kHz). This is not a disadvantage when applied in a negative feedback loop to eliminate ambient thermal drift and low frequency noises.

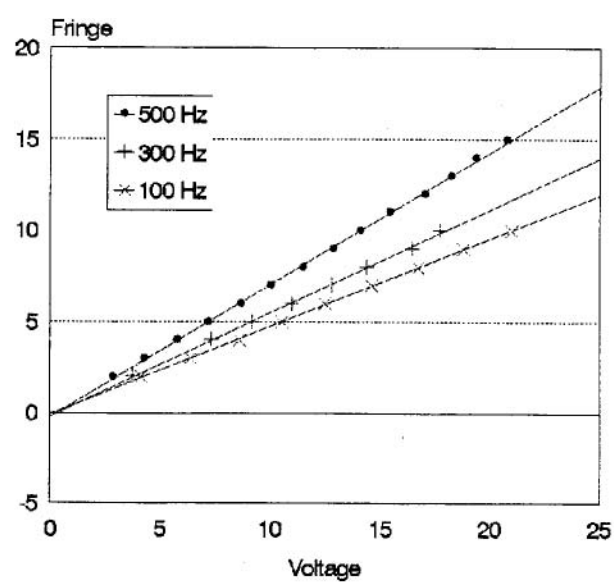

FIGURE 2. Voltage dependence of modulation effect at constant frequencies for the homemade modulator.

The homemade phase modulator can therefore be used as an economical alternative of a cylindrical piezoelectric transducer.

Acknowledgments
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