A simple design of vibration sensor using fiber optic displacement sensor

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A simple design of vibration sensor is proposed and demonstrated using fiber optic displacement sensor based on intensity modulation technique. The maximum sensor output voltage obtained is 1.65 mV for a distance of 1.2 mm between the reflective surface and the fiber optic probe. The sensitivity of the sensor is found to be 0.0029 mV/μm over 325 to 650 μm range and -0.0005 mV/μm over 1300 μm to 3500 μm range. The sensor is capable of measuring vibration amplitude ranging from 0.22 mm to 0.44 mm within a frequency range of 200 to 350 Hz. The simplicity of the design, high degree of sensitivity, dynamic range and the low cost of the fabrication make it suitable for real field applications.

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1. Introduction

Vibration sensors is a very important topic which have many applications and thus a large number of measuring techniques encompassing mechanical, electrical and optical devices have been proposed in the literature [1], [2]. For instance, the compact and cheap MEMS-based accelerometers are very popular for vibration measurement but this technique requires the probe to be in contact with the moving object. Many optical methods have been proposed in the literatures since they provide excellent technologies to develop non-contact sensors. In interferometric methods, a laser signal beam is directed onto a moving target and back-reflected light is recombined with part of the incident light, using different schemes such as Michelson or Mach-Zendher schemes [2]. Interferometers are characterized by a very high performance but are also very expensive and impose stringent mechanical requirements because the alignment is critical. Laser vibrometers exploit the Doppler effect [3] to measure the amplitude of the vibration. This method is not accurate enough for the precise measurement of very small displacements as well as quite expensive.

Plastic optical fibers (POFs) are in a great demand for the transmission and processing of optical signals in optical fiber communication system compatible with the Internet. POFs also have potential application in WDM systems, power splitters and couplers, amplifiers, sensors, scramblers, integrated optical devices, frequency up-conversion, etc. [4-6]. In this paper, a rugged, low cost and very efficient bundled fiber optic sensor is proposed for the measurement of amplitude and frequency of vibration of load speaker. The proposed sensor makes use of the principle of fiber optic displacement sensor which the measurement is based on the intensity modulation technique using a bundled POF probe.

2. Experimental setup

The schematic representation of the experimental set-up for the fiber optic vibration sensor for the measurement of amplitude of vibration is shown in Fig. 1. The device consists of a fiber optic transmitter, bundled POF probe, load speaker, audio amplifier and a silicon detector. The fiber optic probe consists of two POFs of length 2 m, which consists of one transmitting fiber with diameter of 1.0 mm and 16 receiving fibers with diameter of 0.25 mm. All the fibers have a numerical aperture of 0.5. The fiber optic probe used is intensity modulated extrinsic sensor and therefore provides many advantages such as small size, light weight, geometrical versatility, EMI immunity and ease of multiplexing and demultiplexing. The bending losses are minimized by putting both fibers in close contact, thus forming an equal radius of curvature [7].

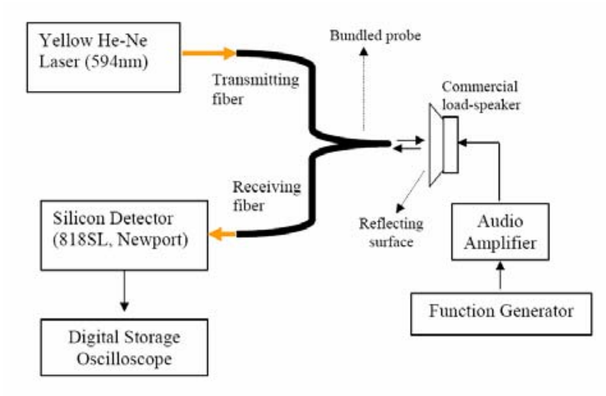


Fig. 1. Schematic diagram of the vibration sensor using fiber optic displacement sensor.

A reflective surface is pasted on a load speaker and the probe is held in position perpendicularly to the reflective surface. The static displacement of the fiber optic probe is achieved by mounting it on a piezoelectric displacement meter, which is rigidly attached to a vibration free table. Yellow light from He-Ne laser at peak wavelength of 594 nm is coupled into the transmitting fiber and the signal from receiving fiber is measured by moving the probe away from the zero point, where the reflective surface and the probe are in close contact. In the case, at zero vibration condition, the probe is placed in away such that the detector output corresponds to the center of the linear region of the characteristic curve. The signal from the detector is converted to voltage and is measured by a digital multimeter. The investigation consists of recording the output voltage from the detector at probe distances ranging from 0 to 6 mm in a step of 12 μm. The experiments are repeated for different frequencies of vibration ranging from 200 to 350 Hz and the vibration amplitudes are measured for different driving voltages.

3. Results and discussion

Fig. 2 shows the variation of the output voltage with the displacement of the fiber optic probe from the reflecting target. As shown in the figure, the curve exhibits a maximum with a steep front slope and back slope which follows an almost inverse square law relationship. The signal intensity is minima (near to zero) at zero distance because the light cone does not reach the receiving fiber. When the displacement is increased, the size of the reflected cone of light at the plane of fibers increases and starts overlapping with the core of the receiving fiber leading to a small output. Further increase in the displacement leads to large overlapping which results in increase in output. The output after reaching the maximum starts decreasing for larger displacements due to large increase in the size of the light cone and the power density decreases with increase in the size of the light cone. The maximum sensor output voltage obtained is 1.65 mV for a distance of 1.2 mm between the reflective surface and the fiber optic probe. The sensitivity of the sensor on either side can be obtained from the slope of the curve. Thus a sensitivity of 0.0029 mV/μm can be achieved within a range from 325 to 650 μm for the front slope and a sensitivity of 0.0005 mV/μm can be obtained over a range from 1300 to 3500 μm for the back slope.

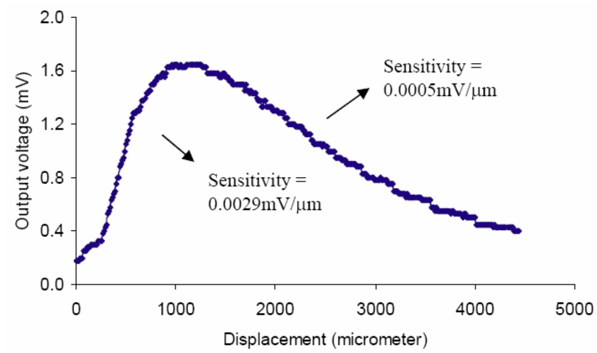


Fig. 2. Variation of the output voltage with the axial displacement of the load speaker from bundled probe.

Fig. 3 shows the vibration amplitude against driving voltage at different frequency of vibration. The sensor is capable of measuring vibration amplitude ranging from 0.22 mm to 0.44 mm within a frequency range of 200 to 350 Hz. As shown in Fig. 3, the variation of the vibration amplitude with driving voltage is higher at lower frequencies of vibration compared to the higher ones. Fig. 4 compares input and output signal of the vibration fiber optic sensor at the frequency setting of 250 Hz. The input signal is detected after the audio amplifier while the output signal comes out from the receiving fiber. As shown in the figure, both waveforms have the same frequency of 250 Hz with the output signal shows a higher noise.

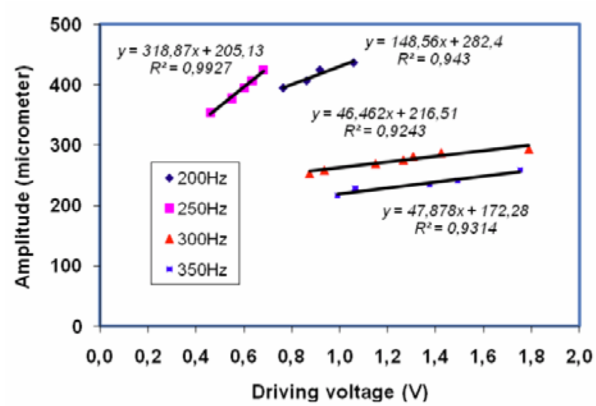


Fig. 3. Output voltage as function of driving voltage of the fiber optic vibration sensor.

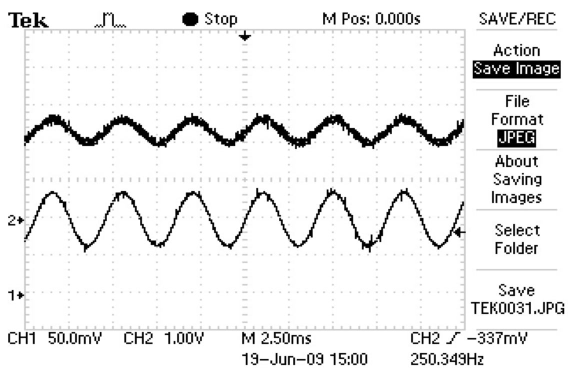
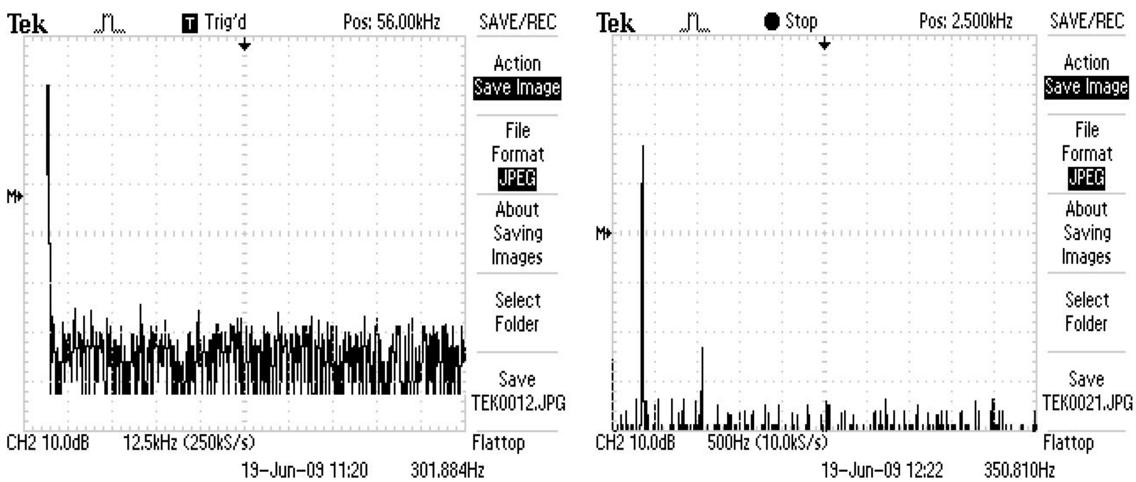


Fig. 4. Original input signal (lower) and the measured output signal (upper) of the vibration sensor.

Figs. 5(a) and (b) represent the fast Fourier transform (FFT) spectra for mechanical vibrations corresponding to 300 Hz and 350 Hz, respectively. The FFT spectral response clearly shows that output from the vibration sensor can be resolved into corresponding characteristic frequencies of vibration. The spectra also show higher harmonics. The possible sources of error in sensor operation can be due to light source fluctuation, stray light and possible mechanical vibrations. To reduce these effects a well-regulated power supply is used for the yellow He-Ne laser and this minimizes the fluctuation of source intensity. The sensor fixture is also designed so that the stray light cannot interfere with the source light and room light does not have any effect on the output voltage. To reduce the mechanical vibrations, the experimental set-up is arranged on a vibration free table. The simplicity of the design, high degree of sensitivity, dynamic range and the low cost of the fabrication make it suitable for real field applications.



a b

Fig. 5. FFT signal from fiber optic vibration sensor (a) 300 Hz and (b) 350 Hz.

4. Conclusions

An extrinsic bundle POF displacement sensor has been proposed for the measurement of amplitude and frequency of vibration. The displacement curve exhibits the maximum output voltage of 1.65 mV at a distance of 1.2 mm between the reflective surface of the speaker and the fiber optic probe. The sensor is capable of measuring vibration amplitude ranging from 0.22 mm to 0.44 mm within a frequency range of 200 to 350 Hz. The sensitivity of the sensor is found to be 0.0029 mV/μm over 325 to 650 μm range and -0.0005 mV/μm over 1300 μm to 3500 μm range. This finding may be quite useful for many real field applications especially in non-destructive testing, damage monitoring, and structural analysis.

References

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