Thesis Topic

Designing and implementation of a intensity based fiber optic vibration sensor

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Declaration

We hereby declared that our project is fully done by ourselves. We did not submit this paper for any kind of publications. This is a researched work based project.

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Acknowledgement

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Abstract

This paper describes the design of an intensity based fiber optic displacement sensor, which can measure the amplitude and frequency of the vibration. The proposed device consists of a fiber optic transmitter, photodiode detector, fiber optic proves, digital oscilloscope, POF fiber, an elastic cantilever & power source. Light from the fiber optic transmitter is coupled into the transmitting fiber. Then the signal will be reflected from the cantilever, coupled to the receiving fiber and is detected by the photo detector. Then the signal is converted to voltage and is measured by the digital oscilloscope. This sensor should be capable of measuring vibration having amplitude ranging from 0.008 to 0.74mm and frequency ranging from 75 to 275 Hz. This fiber optic vibration sensor can be used vastly in high power electric plants and also to detect earthquakes, different problems in aircraft and in robotics.

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1. Objectives

The goal of our project is to design an intensity based fiber optic vibration sensor, which can measure the frequency and amplitude of the vibration. The sensor is implemented by using fiber optic transmitter, Photodiode detector, POF optical fiber, digital oscilloscope, elastic cantilever & power source. The project will describe comparing the distorted signal during vibration according to the original signal and constructing the calibration curve including amplitude of vibration Vs. light intensity.

2. Theory

The light emitted by a LED, which has almost 600μW power, is guided by the F1 multimode optical fiber (fig.1). The optical vibration sensor, joined to the body, oscillates sinusoidally along the axis. Consequently, the free end of the cantilever also oscillates with respect to the sensor body. So that light will be scattered by the cantilever and will be collected by the F2 fiber and finally detected by the PIN photodetector. The behavior of the detected current represents a nearly linear range, whose width depends on the optical properties and the geometric arrangement. The best result was obtained using the arrangement shown on fig.1 with L= 2.5mm and θ= 13° and using silica plastic fibers having core diameter of 200μm. Furthermore, it is not advisable to work close to the cantilever resonance frequency, because gain factor is very high at resonance frequency. The exact resonance frequency can be determined by loading free end of the of the cantilever with a small weight.

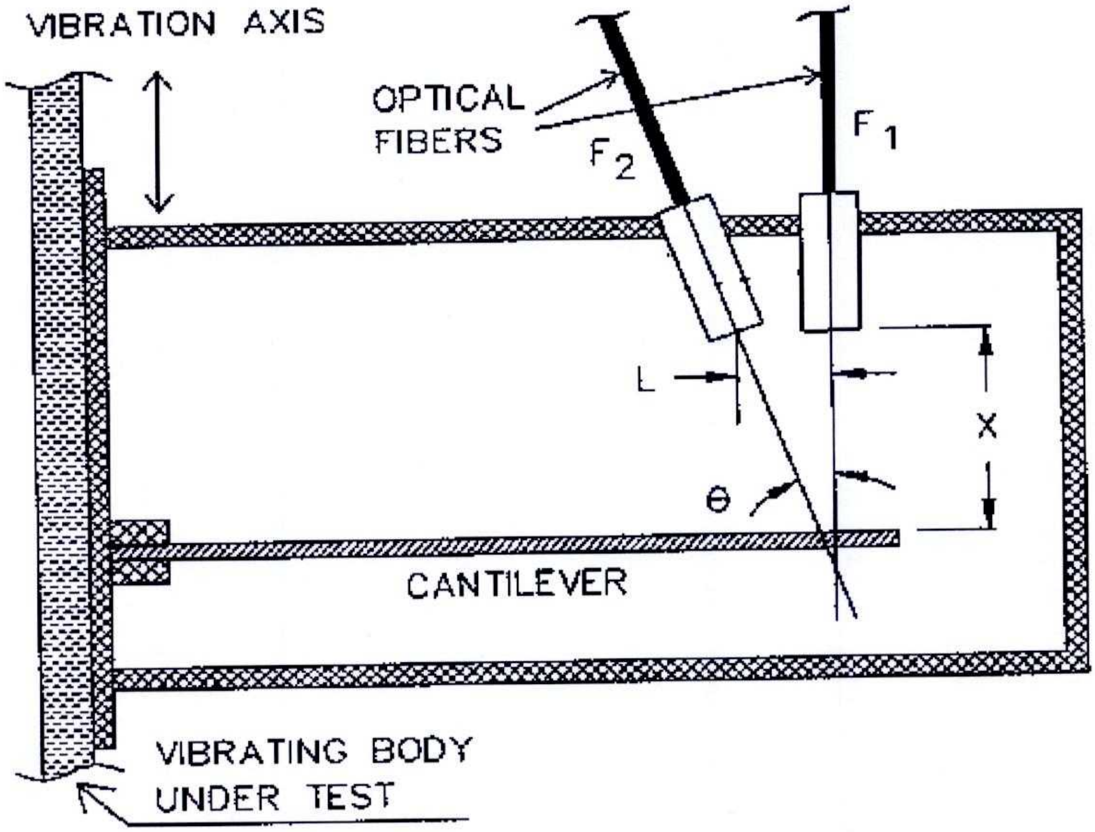

Fig. 1. Sketch of the vibration sensor probe.

3. Mathematical Explanation

According to fig.1, the free end of the cantilever oscillates with respect to the sensor body and the oscillation amplitude of the vibration can be expressed as,

$$X_1 = G(f)\, Z \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Here,

X_1 = oscillation amplitude

$G(f)$ = gain factor (depends on frequency)

Z= amplitude of the sinusoidal vibration

The light, scattered by the cantilever, is detected by the PIN photodetector. The detected current is given by,

$$i = h\,(Ax + B) \ldots\ldots\ldots\ldots\ldots (2)$$

Where,

A & B are the parameters of the linear expansion.

h is a gain co-efficient.

The distance of the cantilever from the fiber is x and is denoted by,

$$x = X_0 + X_1 \sin(2\pi f t) \ldots\ldots (3)$$

Here, X_0 = distance when the cantilever is at rest

X_1 = distance when the cantilever is vibrating.

By combining equation (2) & (3), we can get,

$i = hAx + hB$

$= hA\,[x_0 + x_1 \sin(2\pi ft)] + hB$

$= hAx_0 + hAx_1 \sin(2\pi ft) + hB$

$= h\,(Ax_0 + B) + hAx_1 \sin(2\pi ft)$ .... (4)

Now, $I_0 = hA\,(x_0 + B)$

$I_1 = hAx_1 = hAG\,(f)z$

So, $i = I_0 + I_1 \sin(2\pi ft)$ .... (5)

Putting the value of X_1 from equation (4) to equation (1),

$Z = X_1 / G\,(f)$

$= [\; i - h(AX_0 + B) / hA\sin(2\pi ft) \;] / G(f)$

$= [\; I_0 + I_1 \sin(2\pi ft) - I_0 / hA\sin(2\pi ft) \;] / G(f)$

$= [\; I_1 \sin(2\pi ft) / hA\sin(2\pi ft) \;] / G(f)$

$= [\; I_1 / hA \;] / G(f)$

$= [\; (I_1 / I_0) \,.\, (I_0 / hA) \;] / G\,(f)$

$= [\; (I_1 / I_0) \,.\, \{h(AX_0 + B) / hA\} \;] / G\,(f)$

$= [\; (I_1 / I_0) \,.\, (AX_0 + B) / A \;] / G(f)$

$= [\; (I_1 / I_0) \,.\, (X_0 + B / A) \;] / G\,(f)$

4. Circuit Diagrams

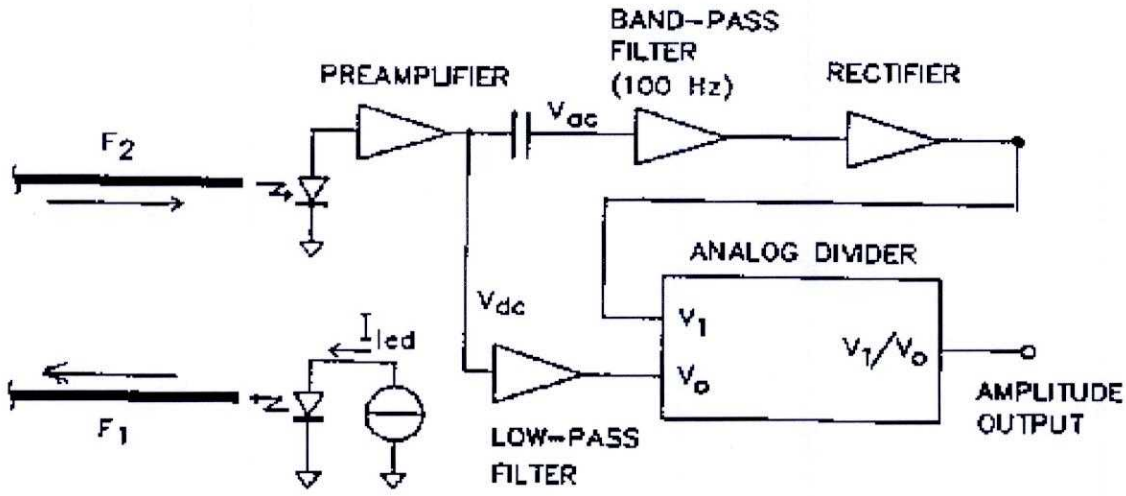

Fig. 2. Block diagram of the electronic circuit

The detected signal is pre-amplified at first and then split into two branches and processed by two different circuits (fig.2). The first circuit amplifies the AC component, which is filtered by a narrowband filter. That filter provides good noise suppression, which increases the SNR. Finally, the signal will be rectified and V_1 voltage will be received. The second circuit amplifies the DC component and gives the V_0 voltage. Here, V_0 and V_1 voltages are proportional to I_0 and I_1 respectively. The signal detected by the photodetector is converted to voltage and is measured by digital oscilloscope. Lastly, the ratio of V_1/V_0 gives the ratio of I_1/I_0, which allows evaluating the vibration amplitude.

5. Experimental Result

Two optical boards are used for the optical vibration sensor. One is for transmitting & other one is for receiving. Two pieces of POF fiber are connected with these and coupled with each other. A laser diode injects 600μW power into F1 fiber and the photodiode detector in the receiving end will detect the signal. The signal detected by the oscilloscope will be similar to the input signal, (fig. 3) as there is no vibration.

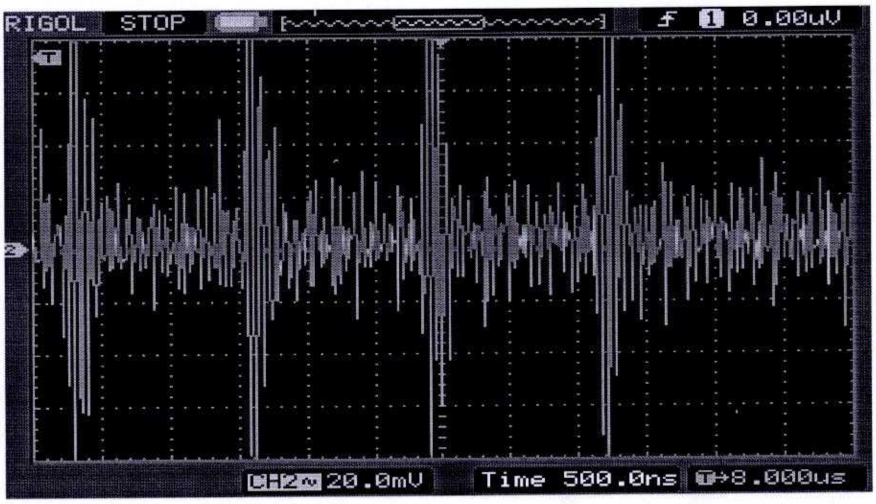

Fig. 3. Output wave shape of fully coupled fiber

But if the two fibers are 60° apart from each, the detected signal will be a little bit distorted and the voltage level of the received signal will be decreased (fig. 4).

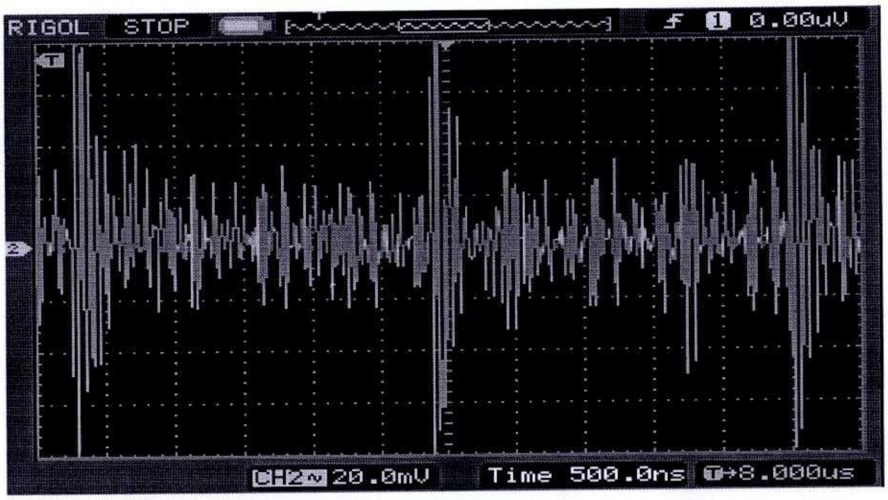

Fig.4. Output waveform when fibers are 60° apart

Similarly, for the different angle and different aperture, the voltage level of the output signal is decreased as far as the intensity of the light is decreased.

6. Goal of the project:

The goal of the project is to measure the voltage level of the output signal at different aperture and angle between two fibers. We also want to evaluate the outputs using reflecting mirror, as well as cantilever. After that, we will determine the amplitude and frequency of the vibration according to the output waveforms and will construct the calibration curve including amplitude of vibration Vs. Light intensity.

7. Advantages

The project is very simple to implement. It consumes very low power and covers wide range of frequencies. This device is relatively more noiseless and stable for long term.

8. Conclusion

An intensity based fiber optic vibration sensor has been proposed for the measurement of amplitude and frequency of vibration.. It can be used not only in high power electric plants, but also in monitoring of commercial machinery, turbines, helicopter gear-boxes and civil structures. Considering its simplicity, accuracy, reliability and various usages, this sensor is a promising alternative to other well-established methods for the measurement of amplitude and frequency of vibration.

9. References

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