INTENSITY MODULATED FIBER OPTIC THREE DIMENSIONAL VIBRATION SENSING SYSTEM

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Abstract- A novel method is demonstrated for the design of three-dimensional non-contact fiber optic vibration sensor based on simple principle of reflected light intensity modulation. A bunch of optical fiber fibers have been arranged to detect vibration in axial, vertical and horizontal directions. The rational output technique implemented to discriminate the acquired signals from each other for their respective direction of vibrations. A LabVIEW program was used to simplify the analysis and to monitor the three dimensional vibration in real time applications. The experiments carried out to study the displacement response of the sensor to calibrate, and also tested the sensor response for vibration in different directions. It is found that the system can measure the three dimensional vibration at a point without any contact to it.

Keywords- Fiber Optic, Intensity Modulated, Three Dimensional, Vibration Sensing.

I. INTRODUCTION

Many engineering systems are becoming more complex in design, function, and maintenance due to advances in technology. Usually they are mechatronic in nature, and their parts are less reliable due to aging effects and are creating greatest risk in operations especially in critical systems like turbojets for power generation, nuclear power generation, space and aircrafts, and monitoring of complex civil and mechanical engineering parts. One of the methods of risk minimization for such type of critical systems is permanent installation of condition monitoring subsystems in order to ascertain the integrity and other operational characteristics of structural parts. Moreover, three dimensional vibration monitoring is a good carrier of many structural measurement systems to study the symptoms and health condition of the engineering tools.

Very few techniques were proposed in the literature to characterize the three dimensional vibration of the engineering structures. Yoshio et al. demonstrated a technique based on magnetostrictive effect, which utilizes the reverse transduction and equipped with three magnetostrictive rods whose output patterns are examined to identify the direction of arbitrary vibration. Shunsuke Ohashi proposed three laser displacement sensors to measure the three dimensional vibration of rotor surface. Shan-Liang Chen et al. designed a three- dimensional vibration sensor with corner cubes and quadrant detectors. Li Zhen et al. presented a detailed design of biometric three-dimensional piezoresistive vibration sensor based on prototype of insect cilia and MEMS technology. However, in the fast growing world, the requirement of the three dimensional vibration sensors is increasing rapidly in various fields such as spacecraft, military, navy and security applications.

Now a days, the rapid development of the fiber optic sensor technology in all respects of the above fields is replacing the conventional sensors. In this chapter an attempt is made to design and demonstrate a simple and compact three dimensional vibration measurement system based on fiber optic reflected light intensity modulated technique. The designed three dimensional sensing system is a combination of dual plastic optical fiber and 1x2 fiber optic fused coupler vibration sensors which are discussed earlier in chapter 2 and chapter 3 respectively.

II. EXPERIMENTAL SETUP

The schematic of the proposed experimental setup for three dimensional vibration measurement is illustrated in figure 1. The sensor probe is configured with a bundle of five fibers having diameters of 1.5mm and length 50cm each , and are arranged in the form of plus (+) symbol. Among the five, the center fiber (CF) is used to monitor axial vibration, the two fibers that are positioned left and right to the CF are used for the measurement of horizontal vibration while the remaining two fibers that are positioned up and down to the CF and are employed for the measurement of vertical vibration. The front view of the sensor probe is shown in figure 4.1. The CF is coupled to the port1 of the 1x2 fused coupler, the port2 is connected to the LED source (IFE-96) having peak wavelength at 650nm and the port3 is connected to the photo-detector IFD-93 (PD5-C) to detect the reflected modulated light.

Therefore, a single CF itself is used for both transmitting and receiving the modulated light from the vibrator. The dimensions of the reflector are designed in such a way that the light intensity variation is observed only in one pair of the adjacent fibers for an offset in horizontal and vertical

directions. The photograph of the experimental setup is shown in figure 2. The sensor probe is calibrated for the vibration measurement using a computer controlled XYZ- translation stage by arranging three actuator controlled micrometers having a resolution of 29nmeach, perpendicular to each other (Thorlabs - Z825B) as shown in figure 3.

A T-Cube USB Controller Hub (Thorlabs, TCH002) with three T-Cube DC Servo Motor Controllers (Thorlabs, TDC001) has been used to control these actuators, and all these single-channel drivers (T-Cubes) are operated with single window software, APT (Advanced Positioning Technology). The thin square shaped reflector measures 4.5mm square is attached to the square is attached to the translation stage for characterizing the displacement response of the sensor in three directions.

The rational output (RO) method discussed earlier has been implemented to simplify the process of analysis and to measure the Horizontal RO (HRO) which corresponds to left (PD2-L) and right (PD3-R) fibers, as well as to measure the Vertical RO (VRO) corresponding to up (PD4-U) and down (PD5-D) fibers with respect to vibration applied in horizontal and vertical directions respectively.

All these signals are fed to the data acquisition system and are analyzed by using a simple LabVIEW program. The HRO and VRO are calculated in real time with simple mathematical formula using simple mathematical tools available in the LabVIEW software.

The independent TDS signals are shown in front panel of the LabVIEW program which consists five charts to measure the horizontal, vertical and axial vibration of the vibrating object, where in up and down fibers are shown in one chart, left and right fibers are shown in other chart, and only CF is shown in one chart while the HRO and VRO are shown individually in two charts.

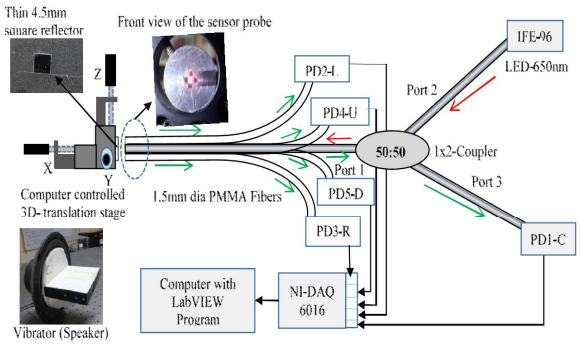


Figure 1. Schematic experimental setup for the three dimensional vibration measurement.

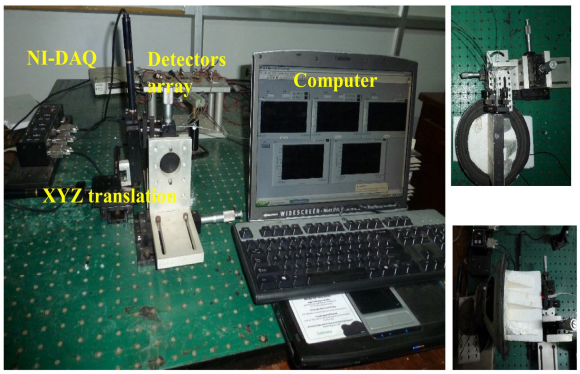


Fig. 2. Photograph of the experimental setup.

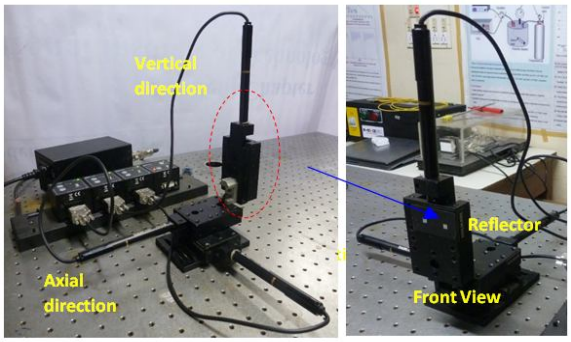


Fig. 3. Computer controlled three dimensional translation stage.

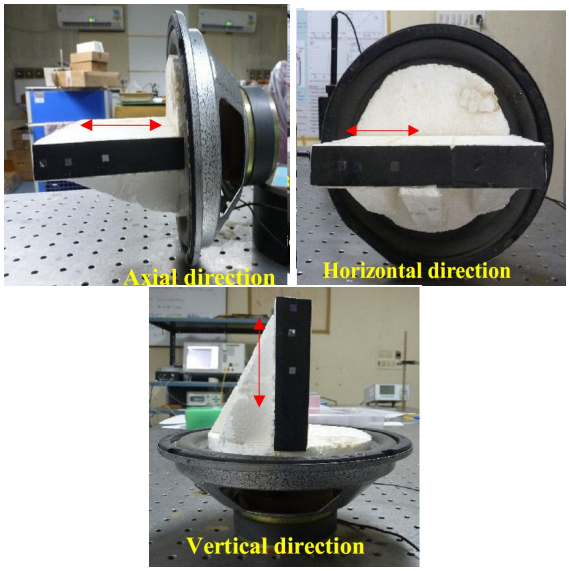


Fig. 4. The designed Vibrator in three directions.

A three dimensional vibrator is specially designed for this purpose using a speaker having the diaphragm diameter of 7.5 inch with additional attachments. Weightless thermo coal material is used to fill the diaphragm up to the top of the speaker, and then rectangular shaped thermo coal is attached perpendicular to the diaphragm of the speaker. A black colored paper sheet is attached to the vibrator to minimize the reflection of light surrounding the

reflector, and the calibrated thin weightless reflectors are glued to it in two directions. The photographs of the designed vibrator in different directions are shown in figure 4. Further, the translation stage is replaced with the vibrator (speaker) which is specially designed to apply the vibrations in three directions in front of the sensor probe. The vibrator is vibrated for known frequencies and amplitudes by using a synthesized function generator (HM8130, Scientific).

III. RESULTS AND DISCUSSIONS

The amplitude of vibration is measure form the calibration of the sensor from displacement response and study the vibration response by applying the known vibrations.

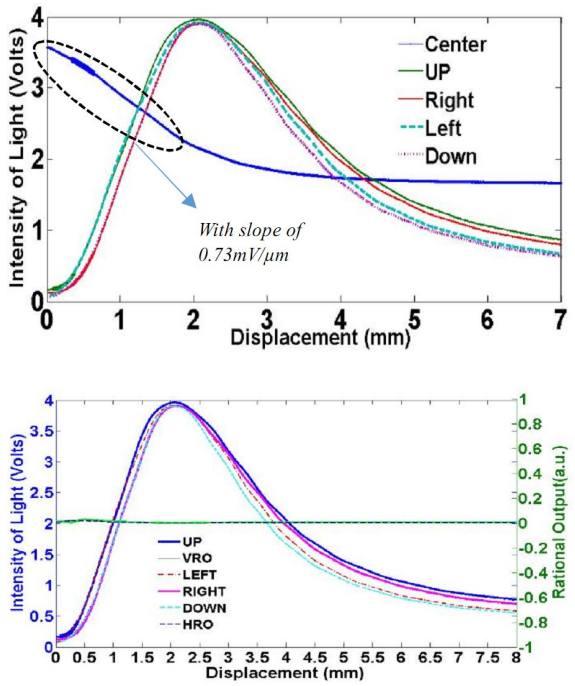


Fig. 5. Displacement response of the sensor for a) axial direction and b) axial direction RO.

A. Displacement Response of the sensor

The displacement response of the sensor is characterized to calibrate the sensor probe for three dimensional vibration measurement. The X-translation stage is driven with the speed of 10μm/sec to determine the displacement response in axial direction. The corresponding data for all the five signals of the sensor probe with the sampling rate of 1kHz are acquired as shown in figures 5(a). Figure 5(b) represents the response of the vertical and horizontal fibers. It can be observed that since the individual signals received from of all these fibers follow the similar displacement response, the RO corresponding to axial displacement exhibit a constant output in contrast to that of the HRO and VRO, thereby showing the insensitivity of the VRO and HRO for axial-direction displacement. The CF exhibits linear region of about 2mm with a sensitivity of 0.73mV/μm, whereas other fibers exhibits linear region of about 1.5mm. Hence, the sensor probe is positioned within the linear region of about 1.5mm for the vibration measurement in horizontal and vertical directions.

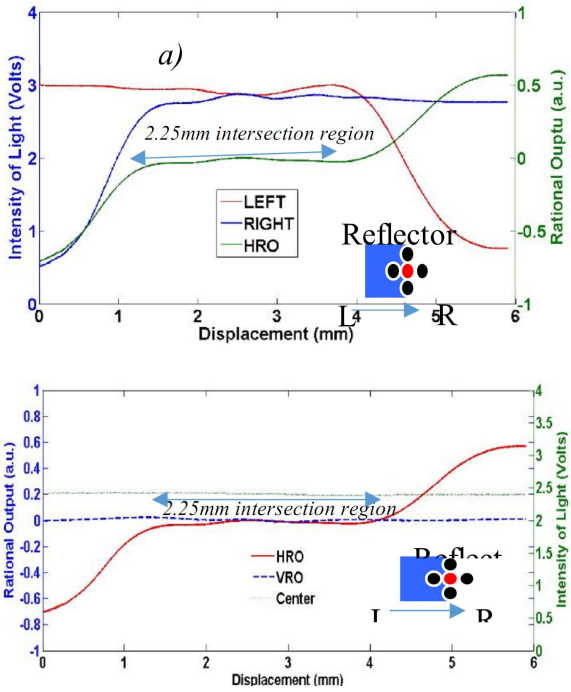


Fig. 6. Displacement response of the sensor for a) vertical direction and b) vertical direction RO.

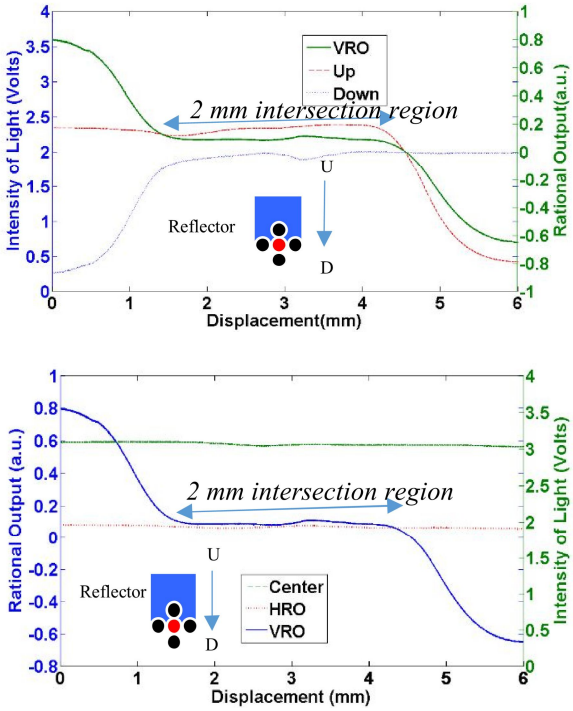


Fig. 7. Displacement response of the sensor for a) horizontal and b) horizontal directions RO.

In the horizontal direction; to reduce the backlog

errors, the Y-translation stage is set to move by a maximum of 2mm offset in left direction to that of the sensor head and then the continuous motion is applied with a velocity of 10µm/sec. The sensing signals are acquired by the DAQ with a sampling rate of 1kHz and are analyzed by using LabVIEW program. Figure 6(a) represents the displacement response of the left and right fibers in horizontal direction and it's HRO about the dynamic range of 6mm. The characteristic displacement curve of the VRO, HRO and CF with respect to horizontal direction shown in figure 6(b), reveals that VRO and CF exhibit constant output, representing insensitivity to horizontal direction.

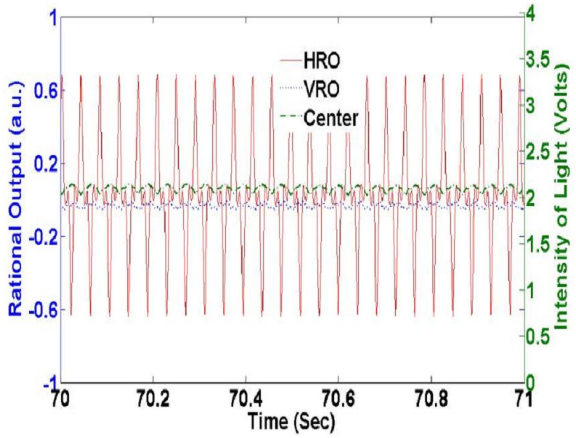


Fig. 9. Response of the sensor for the vibration in horizontal direction.

Similarly, the displacement response of the sensor in vertical direction is shown in figure 7. It also reveals that the sensor response shows only in VRO whereas CF and HRO signals remained constant indicating insensitivity to the vertical direction. Suppose, (a) the axial distance from the reflector, the intersection region will be minimized in the response of HRO and VRO. But, in practice, since the sensor head is fixed at a distance of 'a' within the linear region of the displacement curve, as the 'a' increases, the intersection region also increases. Thus, the position of the sensor head in axial direction is selected depending on the requirement of the amplitude of vibration measurement in horizontal and vertical directions. To minimize the intersection region, the sensor should be fixed as much as near to the vibrator as possible. However, the importance of this sensor design is the possibility of measuring the vibrations in three directions simultaneously at a point.

B. Vibration Response of the sensor

From the above acquired results, it is observed that all the three signals; CF (axial), HRO and VRO are independent to each other and they respond only for respective directions of vibration within the limits. To test the sensor response for the three dimensional vibration measurement, the designed vibrator with calibrated reflector is placed in front of the sensor head within the linear region and the vibration is applied in different directions using a synthesized function generator with variable frequencies and amplitudes.

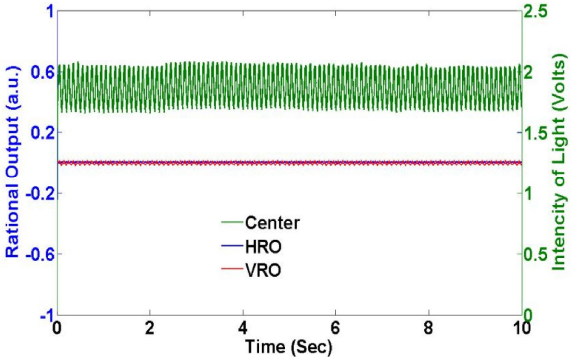


Fig. 8. Axial direction vibration response of the sensor.

Figure 8 shows the response of the sensor for axial vibration at the frequency of 10Hz. It is evident from the figure that only CF signal is responding to the axial vibration whereas HRO and VRO exhibit constant output. Then the vibrator is arranged such that it vibrates in horizontal direction. The sensor response for the frequency of vibration at 24Hz is shown in figure 9. It illustrates that, only HRO is responding to the horizontal vibrations whereas CF and VRO are remaining as constant signals indicating insensitive to the horizontal direction of vibration. Similarly the vibration in vertical direction at the frequency of 16Hz is applied to the vibrator and the corresponding sensor response is represented in figure 10, which illustrates that only VRO is sensitive to vertical vibration whereas other signals will remain constant. The sensor is tested for different frequencies in both vertical and horizontal direction and found that the sensor can measure the vibrations up to 100Hz only.

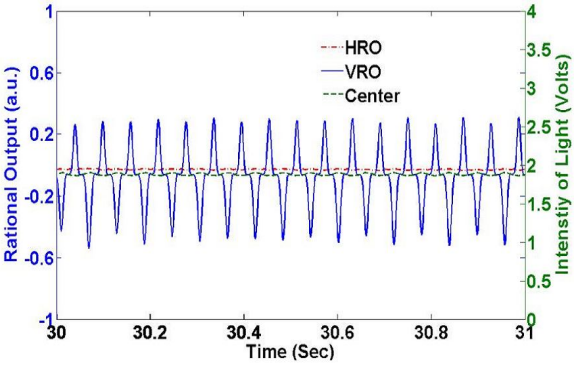


Fig. 10. Sensor response for the vibration in vertical direction.

From the above discussions, it is found that the sensor is capable to measure the vibrations up to 1kHz with resolution of 1µm in axial direction whereas in vertical and horizontal direction up to 100Hz with a resolution of 10µm. It is observed that this sensor is capable of measuring the vibrations up to 100Hz with

the resolution of 10μm. The discrepancy in frequency range and resolution might be due to the difference in sensitivities of the linear regions. The frequency range and resolution of the sensor may not be the important factors in this design because these factors depend only on the diameter of the fiber and can be easily improve the response.

CONCLUSION

A novel method is demonstrated for the design of multidimensional non-contact fiber optic vibration sensor based on the principle of reflected light intensity modulation. The signals acquired from the sensor are analyzed and the rational output technique is successfully implemented to discriminate them from each other in their respective directions of vibration. LabVIEW program is successfully implemented to simplify the analysis and also to monitor three dimensional vibration for real time applications. The flexibility in selection of fiber diameter facilitates the sensor response in the frequency range and also improves the amplitude resolution.

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