Fiber Optic Vibration Sensor based on Multimode Interference Effects

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Abstract: A fiber optic vibration sensor based on Multimode Interference (MMI) effects is demonstrated. The proposed sensor is tested by characterizing its bending response, impulse response, and its response to fixed external frequencies. Induced vibration is measured in the range from 0 Hz to 2.5 kHz; the main frequency component overcomes on the first and second harmonics with a difference of 32.4 dB and 37.2 dB, respectively.
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1. Introduction

As the mechanical structures deteriorate and the high power electric machines begin to damage, the natural frequencies and the operation frequencies tend to change. Therefore, continuous monitoring of vibration frequency becomes of great importance because it makes possible to detect, anticipate, and even predict changes and damages in the structures. Several techniques to measure vibration have been developed but, compared to traditional vibration sensors, such as magneto-electric, piezoelectric, and current sensors, fiber optic sensors have the advantage of electromagnetic interference immunity and safe operation under hazardous and explosive environments, as well as remote sensing and multiplexing, *in situ* measurement, and high precision. In terms of fiber optic sensors, the most widely studied are interferometric and grating-based techniques, nevertheless most of them perform vibration measurements through an inertial mass [1]. Sensors performing direct vibration measurements are limited to detect low-frequency vibrations and alternative techniques to improve the sensitivity are required [2-3]. In this work a cantilever fiber optic sensor based on Multimode Interference (MMI) effects for direct vibration measurements is demonstrated. The proposed sensor is capable to measure frequencies in the range from 0 Hz to 2.5 kHz with self discrimination between the natural frequency and its harmonics with a difference of more than 30 dB.

2. Principle of Operation and Experimental Setup

A schematic of the MMI vibration sensor is shown in Fig. 1(a). The key element consists of a segment of 105/125 multimode fiber (MMF) spliced to a segment of single-mode fiber (SMF). To perform direct vibration measurements, the MMF section plays the role of the sensing head and thus a reflection configuration is required so a gold layer is deposited on the MMF facet to improve the intensity of the reflected optical signal. The experimental setup to test the response of the sensor is shown in Fig. 1(b), which consists of a super luminescent diode (SLD), a 1x2 splitter (3 dB splitting ratio), and an optical spectrum analyzer (OSA).

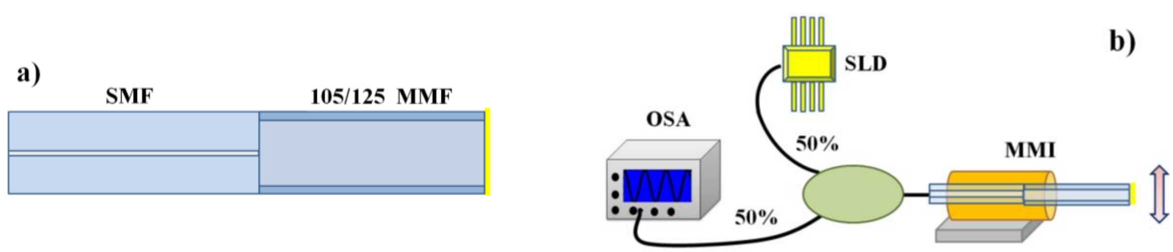

Fig. 1. (a) Schematic of the MMF-MMI Vibration sensor. (b) Experimental setup for direct vibration measurements.

When light is coupled to the MMF through the SMF, self-images of the input field will be formed along the MMF due to MMI effects. Since the peak wavelength depends on the MMF length, it is possible to select the operating wavelength at which vibration is measured by simply cleaving the MMF at a specific length [4]. This allows us to easily provide multiplexed operation.

3. Experiments and Results

Three different experimental measurements were performed to determine the capability of the sensor for vibration sensing: the first one explores the sensor response when the MMF cantilever is bent, the second one measures the impulse response of the sensor, and the third one measures the sensor response when an external vibration is applied to the MMF cantilever.

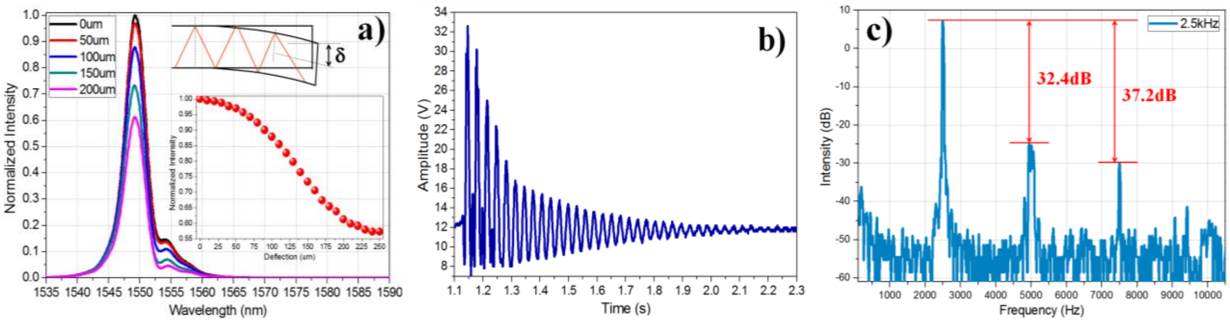

Fig. 2. (a) Sensor response to deflection, (b) Impulse response, and (c) sensor response to a sinusoidal force of 2.5kHz.

The MMI sensor response for several deflections of the cantilever is shown in Fig. 2(a). We can observe that the peak intensity decreases while the peak wavelength remains unaltered. This is due to the fact that during bending, higher order modes exhibit higher losses as the bending is increased. Since the self-image results from the interference of all the propagating modes, the intensity of the self-image also decreases. The insets in Fig. 2(a) show the normalized intensity as the cantilever is deflected, which is also in good agreement with a MMI curvature sensor previously reported [5]. The impulse response of the cantilever is measured by deflecting the cantilever a particular distance, and releasing it to freely oscillate. This is measured using a photo-detector and an oscilloscope instead of the OSA, and its response is shown in Fig. 2(b). At this point, it is clear that due to the sensor bending and impulse responses, the MMI sensor is suitable to perform vibration measurements. Vibration was tested in the range from 0 Hz to 2.5 kHz, as shown in Fig. 2(c). Due to the cantilever configuration several vibration modes are generated in addition to the applied frequency, so not only the induced vibration frequency is detected but also its corresponding harmonics. Nevertheless, the tone of the main frequency overcomes the first and second harmonics with a difference of 32.4 dB and 37.2 dB, respectively, which allows clear identification of the induced vibration frequency.

4. Conclusions

A MMI fiber optic vibration sensor in cantilever configuration has been demonstrated. Several characterizations were performed on the sensor to demonstrate its capability to achieve precise vibration measurements: bending response, impulse response, and sensor response to fixed external frequencies. Induced vibration was tested in the range from 0 Hz to 2.5 kHz and although harmonics were generated because of the free vibrating structure of the cantilever, the component of the induced frequency overcomes the first and second harmonics with a difference of 32.4 dB and 37.2 dB, respectively. The proposed sensor is suitable to perform precise vibration measurements allowing clear identification of the induced vibration frequency.

5. References

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