A Fiber Optical Sensor For Non–Contact Vibration Measurements

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This paper describes an optical sensor for non–contact vibration measurement that is based on plastic optical fibers. Issues concerning the sensors usage during vibration tests are highlighted and an innovative calibration procedure based on an accelerometer is described.

1 Introduction

Vibration tests are widely employed in many industrial fields, and in particular in aerospace industry to evaluate the mechanical behavior of parts for aircrafts and satellites. Usually, these tests are carried out with shakers, while inertial accelerometers are used to measure the shaker table acceleration from which the vibration amplitude is computed. Some applications require the measurement of displacements and accelerations directly on the device surface. However, in some cases, as in the testing of printed circuit boards and solar panels, the inertial sensors cannot be fixed on the surface due to lack of space or because their mass perturbs the tests. These limitations can be overcome using the low-cost fiber-based sensor able to perform non-contact displacement and acceleration measurement that is described in the following section.

2 Sensor Working Principle

The proposed sensor exploits the variation in the received power between two plastic optical fibers (POFs) facing the vibrating target at a nominal distance d (Fig. 1). The choice of POFs and of an intensity modulation detection method allows developing a sensitive yet low-cost sensor, with all the advantages typical of optical fibers such as immunity to EMI and simplified positioning of the transducer head.
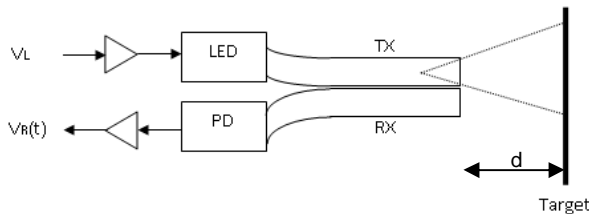

Fig. 1 *The schematic block diagram.*

The transmitting fiber is fed by a LED source driven with a constant current v_L, while the receiving fiber collects the light reflected from the target. The received signal is composed of a DC and an AC terms, the latter being proportional to the vibration amplitude through a constant factor k:

$$v_R^{AC} = k \cdot s(t) \qquad (1)$$

The sensor response depends on several terms: amplifier gains, fiber losses, source efficiency, and target distance and reflectivity. Some of these terms can be calculated through theoretical models [1], but others depend on the target, so they can be evaluated only through an experimental characterization [2].

Frequently, this kind of sensors is calibrated using a reference target and applying known displacements in order to directly obtain the sensor constant k. However, in many applications, the working target can have different characteristics from that used for the calibration. A common case is that of a different target reflectivity requiring a compensation technique, such as the one based on fiber bundles [3]. In other applications, such as the testing of PCBs, the target can be also not flat or have a position-dependent reflectivity and in these cases a more sophisticated calibration technique is required.

3 Proposed Calibration Technique

The proposed calibration procedure takes advantage of the accelerometer already employed to control the shaker. During the calibration step the shaker is driven with a sinusoidal signal having a known frequency w_c and the acceleration A_c is measured using the piezoelectric sensor; thus the corresponding displacement D is obtained as:

$$D = A_c \cdot w_c^2 \qquad (2)$$

The amplitude of the detected signal is measured too and the calibration constant is obtained as the ratio between the received signal and the displacement:

$$k = \frac{V_R}{D} \qquad (3)$$

Using this procedure, the sensor can be calibrated just before its use, while it is lighting the actual device. Moreover, several sensors can be calibrated at the same time independently from the characteristics of the surface they are facing, since the calibration can be carried out at low frequency and, in this condition, the vibration can be considered constant over the whole vibrating table.

4 Experimental Results

To obtain the experimental results is used the setup shown in the Fig. 2. It is composed of a computer-controlled shaker, some optical sensors, a custom made conditioning circuit and a digital acquisition system. The sensors are made using step index plastic optical fibers, with about 1 mm core diameter and 3 m length. The sources are high intensity LEDs emitting at the red wavelength. The device under test (in this case a printed circuit board) is mounted on the vibrating table fixed on the shaker. A piezoelectric accelerometer is mounted on the fixture and employed to measure the table vibrations and to control the shaker so that it forced known accelerations.
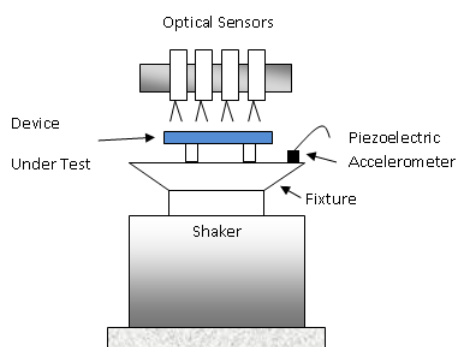

Fig. 2 The schematic experimental setup .

A multiple-head sensor is arranged combining several of the sensors, sketched in Fig. 1, as shown in Fig. 3, and mounted over the printed circuit board in order to monitor several points at the same time.
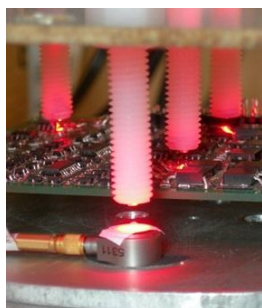

Fig. 3 The multiple-head optical sensors used to measure the vibrations of a printed circuit boards. One sensor is located over the accelerometer to compare the results.

The optical signals are detected using a custom made conditioning circuit having low noise and

about 4 kHz of bandwidth. Then, after being acquired using a digital acquisition board with sampling rate of 10 kHz and acquisition time of 1 s, the signals are analyzed using a Discrete Fourier Transform algorithm. One of sensors is located close to the accelerometer to compare the results. Moreover, the piezoelectric accelerometer is employed for the calibration of the optical sensors. After the calibration, some vibration tests under sinusoidal conditions are performed. To monitor the PCB behavior over time, the tests are carried out at constant frequency. In this way it is possible to map the behavior of the printed circuit board and observe the displacements from the reference position due to vibrations. One of these maps is shown in Fig. 4 as an example.
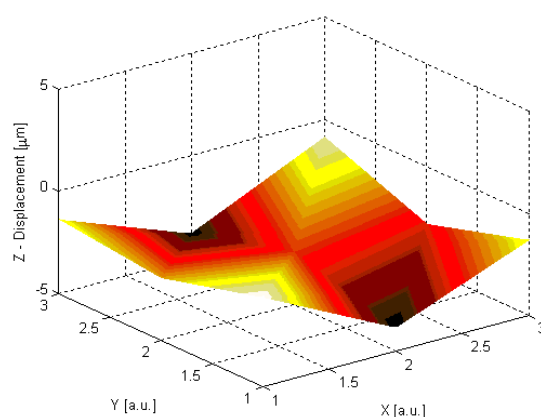

Fig. 4 The PCB deformation under sinusoidal conditions. It is possible to notice the displacement from the reference position (z = 0 μm).

5 Conclusions

The development of an optical sensor for vibration monitoring and an innovative calibration procedure, which works also in the presence of non–uniform targets, have been presented. The sensor allows non–contact measurements to be carried out with sub–micrometric resolution and it takes advantage of plastic optical fibers and amplitude detection systems to maintain low the overall cost.

References

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