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Optical Fiber Sensor for Measurement of Wear in Metallic Cylinder

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ABSTRACT: Optical fiber sensor based test module has been designed, developed and experimented for wear measurement in metallic cylinder. The developed module is based on extrinsic, reflective intensity modulated fiber optic displacement sensor. Multimode PMMA (polymethyl methacrylate) optical fibers, a semiconductor Laser source and Photo detectors have been used for implementation of the optical fiber sensor. A sensitivity of 1.44 µW/mm has been obtained. The sensor performance is repeatable and the set up can measure wear up to an accuracy of less than 1 µm.

Keywords: Optical fiber sensor, intensity modulated, displacement sensor, wear measurement.

I. INTRODUCTION

Measurement of wear in the inner diameter of metallic cylinders is very useful in automotive, engines and mechanical industries [1-2]. A typical wear measurement example for field applications in Army is boroscopic inspection [3] to examine the wear in a gun barrel. However, this method tends to be bulky, lacks high accuracy and is not capable of measuring wear over the whole length of the cylinder or the barrel.

Hence to enable very accurate wear measurement over the entire length of a cylinder, we have taken up the study to use optical fiber based intensity modulated displacement sensor. To the best of our knowledge there is no existing sensor or reported literature on this type of non-contact and optical fiber based measurement. The test module is based on fiber optic displacement sensor. The output of the displacement sensor provides a measure of the wear over the entire length of the metallic cylinder. The analysis of these data can be vital for assessing the fatigue life or wear of the cylinders and can be very successfully applied to typically study wear measurement in gun barrels.

II. EXTRINSIC REFLECTIVE FIBER OPTIC DISPLACEMENT SENSOR

The schematic of a typical Intensity Modulated Extrinsic Reflective Fiber Optic Displacement Sensor is as shown in Fig.1. R.O. Cook *et. al* have presented a detailed study on this type of sensor [4]. Also, fiber optic displacement sensors for different applications have been studied and experimented in the author's laboratory [5-7]. The experience gained from these works has been used here to design and develop the test set up for the wear measurement in metallic cylinder.

The basic principle employed in Fiber Optic Displacement Sensor is the use of an adjacent pair of optical fibers, one to carry light from a remote source to a reflecting surface (here the inner surface of the cylinder) or target whose displacement or motion is to be measured and the other to receive the light reflected from the object and carry it back to a remote photo sensitive detector. The basic operating principle is shown in Fig. 2.

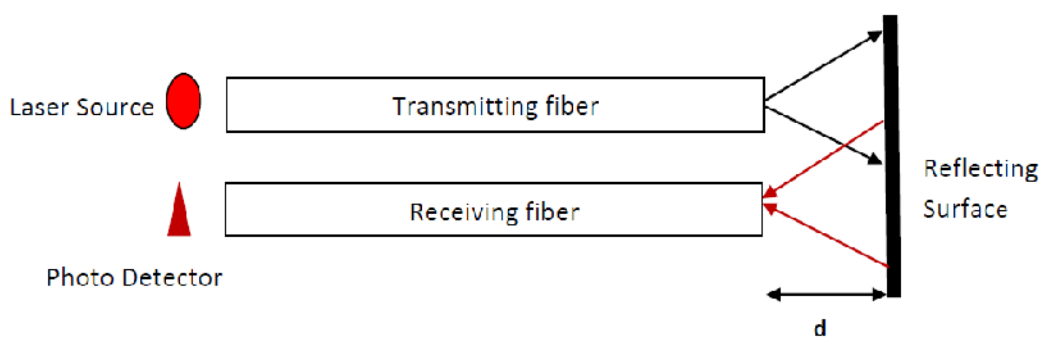

Fig. 1. Schematic of Extrinsic Reflective Fiber Optic Displacement Sensor.

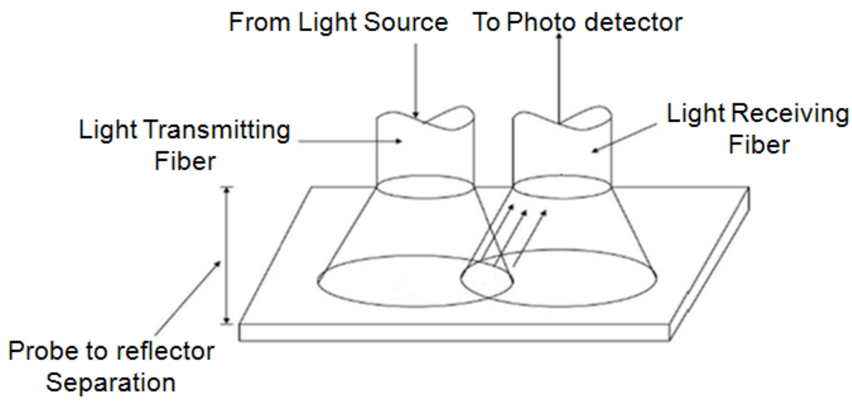

Fig. 2. Operating Principle of a Fiber Optic Displacement Sensor (Cook & Hamm).

At zero gap between the fiber and the target, the light from the transmitting fiber would be reflected directly back into itself and very little or no light would be coupled to the receiving fiber. As the gap increases, some of the reflected light is captured by the receive fiber and carried to the photo-sensitive detector. As the gap increases, a distance will be reached at which the maximum amount of reflected light is transferred to the receiving fiber. Further increases in the gap results in a decrease in the light at the receiving fiber and hence a corresponding drop in the output signal from the photo detector [4]. A typical displacement response is given in Fig. 3.

The detected output intensity within the linear region of the front or back slope provides a measure of the gap between the reflecting surface and the probe and hence the displacement. Thus, for the implementation of a fiber optic displacement sensor, it is required to measure the output intensity of the receiving fiber and then the calibration curve slope or sensitivity is used to find out the corresponding displacement.

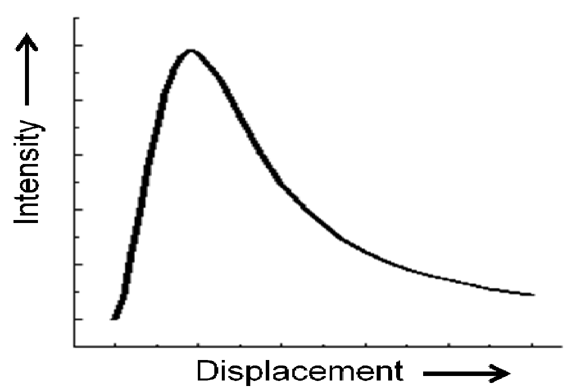

Fig. 3. Typical Fiber Optic Displacement Sensor Response Curve (Cook & Hamm).

III. CONCEPT AND DESIGN OF SENSOR TEST MODULE

The basic aim of the design is to analyze wear in the metallic cylinders along its entire length and circumference. Hence the concept is to provide a test module that provides stability to the sensor system and allow every portion of the cylinder to be examined. An important aspect to remember is that this test module is being designed to analyze the wear in the metallic cylinders. Such a system would thus be required to be small enough to fit into the cylinder and be light weight.

The test module has been designed typically for inspection and wear measurement for a 125 mm metallic cylinder. The idea of choosing this dimension is to evaluate the applicability of this test setup for wear measurement in typical 125 mm gun barrels. The design details are shown in Fig. 4.

The test module is supported on a base plate (mild steel) with two 'V' blocks to hold the cylinder of 125 mm inner diameter. The specific reason behind selecting this dimension is to assess the possibility of using this sensor for typical gun barrel wear measurement. Here, we have made steps inside the metallic cylinder to simulate wear conditions.

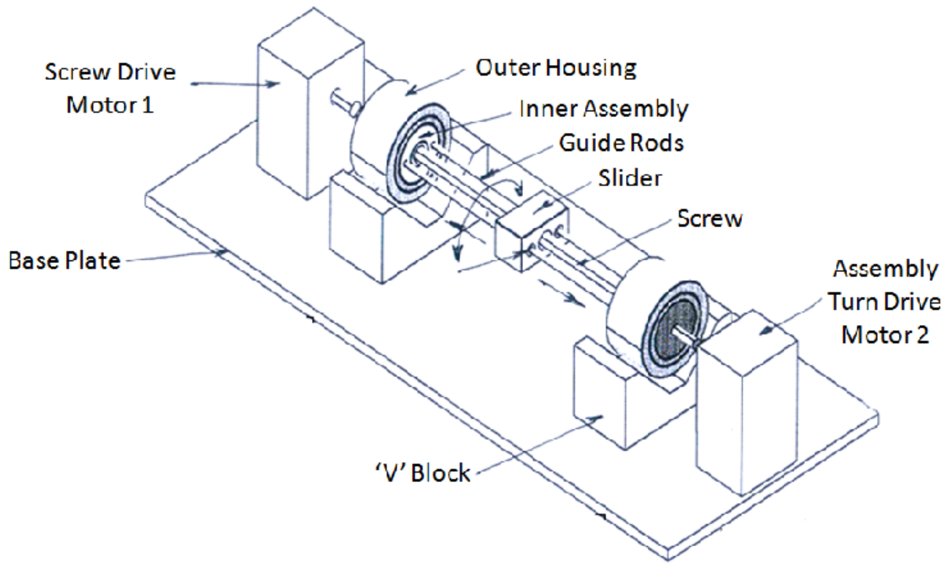

Fig. 4. Design of the Test Module.

The test assembly slides and rotates a pair of optical fibers inside the metallic cylinder for measurement. One of the optical fibers is connected to the Laser source and other to the Photo detector. There are two drive motors for providing the linear and rotational movement to the slider. Hence at any length and at any point on the circumference of the metallic cylinder, a measurement can be taken. Based on the known steps inside the metallic cylinder (made during manufacture) the detected power is measured and the calibration curve is obtained. This is used for analysis of wear.

To ensure a successful implementation of the above design, required components were assembled to develop the sensor test module. A Poly-methyl-metha-crylate (PMMA) multimode optical fiber of 1000 μm diameter, a semiconductor Laser source at 660 nm, Thorlabs make Power meter along with Silicon Photo detector (response in 400 nm to 1100 nm range) and a xyz micromanipulator have been used along with the above mentioned mechanical test module. Photograph of the developed sensor test module is shown in Fig. 5.

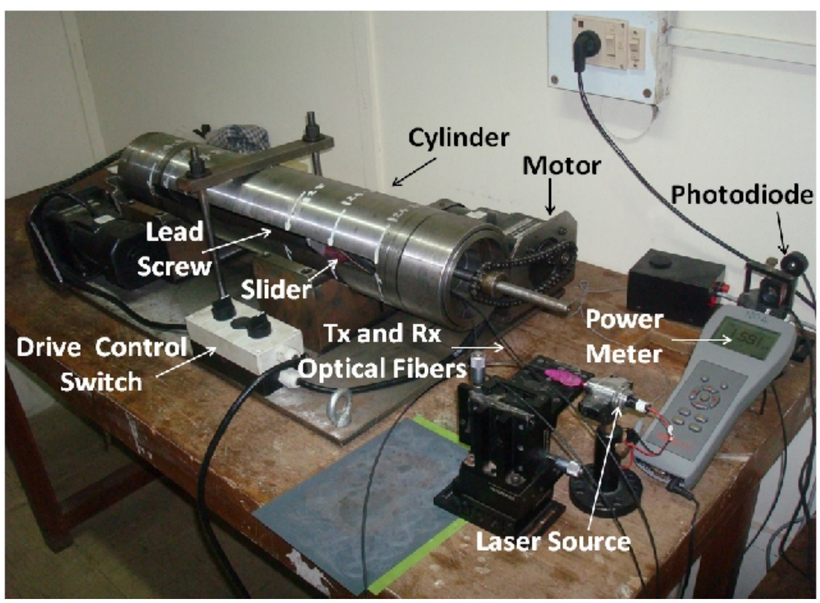

Fig. 5. Photograph of Sensor Test Module.

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The semiconductor Laser output was focused and coupled to the transmitting fiber using the xyz manipulator. The transmitting and receiving fibers were placed side by side and mounted on the slider and kept perpendicular to the cylinder surface and to the base of the slider. The two motors were used to provide linear and rotational movement to the slider. The reflected output power was coupled through the receiving fiber to the photo detector to study the intensity variation with displacement.

During the experiments, an attempt was made to record the readings with the moving slider and compare with the readings taken with static slider at the same position of the cylinder. It was noted that there is no difference in the readings. Thus, it has been established that continuous scanning and recording of data is possible using the testing module, without sacrificing any aspect of measurement.

Experimentation has been carried out with three geometries of the fibers viz. transmitting fiber placed 0.5 mm ahead of the receiving fiber, both fibers placed equidistant from the barrel surface and transmitting fiber placed 0.5 mm behind the receiving fiber. The cylinder has been precision manufactured with known steps in the inner diameter ranging from 125 mm to 124.8 mm. A constant output power was coupled to the transmitting fiber and linear & rotational movements were provided by using the two motors as shown in Fig. 4.

Output was noted from the power meter and was plotted against known displacements (steps) for all the three fiber geometries. It was observed that the response in terms of linearity and consistency was the best in the case with both fibers placed parallel and equidistant from the cylinder surface. Also, it was observed that the average received output power for the same source power was maximum when the two fibers were equidistant. The sensor response for the equidistant case is as shown in Fig. 6.

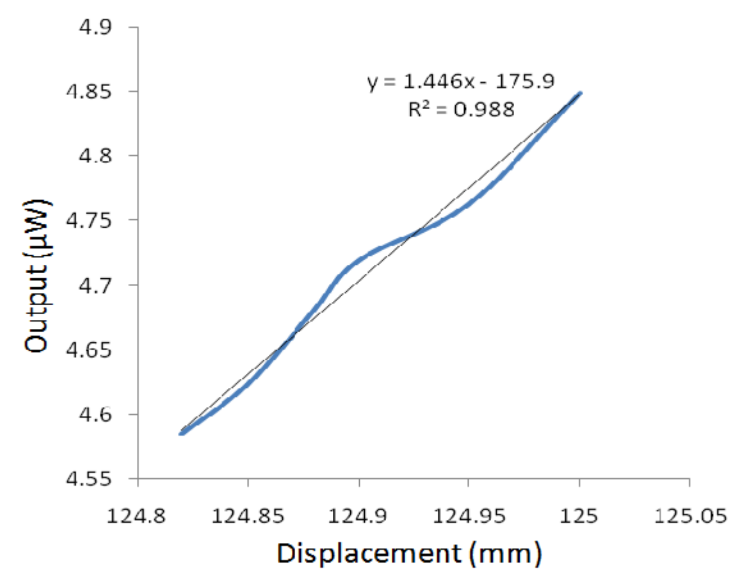

Fig. 6. Response of the Sensor.

It is observed that the variation in the received output varies linearly with displacement (or wear). Consistent and repeatable results are obtained with the set up and the sensitivity obtained from the linear fit is 1.44 µW/mm. This sensor response is to be used for the calibration. Since we are capable of detecting output with a resolution of 1 pW with our detector, any wear of the order of a µm can be very easily measured with the module. So for wear measurement of a cylinder after use for some time, all we need is to use the test module at various locations of the cylinder and compare the received output with the calibrated output obtained from the sensor response. Hence variations in the inner diameter of the cylinder in terms of wear depth (made during manufacture) are measured by the sensor test module. Since there is a linear relationship between the inner diameter (ID) and the power detected, this system can be used to examine and detect wear in the cylinder. In practice, we propose that a new cylinder be used as a reference and ID of an worn out cylinder (after put into use for a specific time) depth as measured by the test module be compared in terms of the change in ID to determine the wear and evaluate the fatigue life or present condition of the cylinder. A typical and efficient use of this type of sensor can be for the wear measurement in gun barrels after certain rounds of firings and hence to decide on further usage or not.

Based on the sensor design aspects and analysis of the response, we would suggest that a stable Laser source be used for the measurements. One small limitation of the developed module is that the sensor has to be calibrated with respect to a Laser source before the measurements are taken to ensure similar response in all cases of wear measurement.

V. CONCLUSION

We have presented the design, development and the experimental aspects of an optical fiber based test module for wear measurement in metallic cylinder. The sensitivity of the sensor is 1.44 µW/mm. It enables wear measurement to an accuracy of 1 µm over the entire length of the cylinder and at any point on the circumference. The sensor response is linear, consistent and repeatable. The sensor module is of light weight, portable and can be fitted into the cylinder easily for the wear measurement.

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