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Design and Development of Fiber Optic Sensor System for Rotational Speed Measurement

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Abstract: In this paper, a fiber optic sensor system (FOSS) is proposed for the measurement of the rotational speed of a DC motor. It offers non-contact measurements. FOSS is designed using a fiber optic displacement sensor (FODS). FODS is an intensity modulation based extrinsic type sensor.

In FOSS, the distance between the sensor probe and the rotating shaft of a DC motor is optimized based on the response of FODS. The speed of a DC motor varied from 200 to 3000 rotations per minute (RPM) using a chopper motor controller. The output of FOSS was validated with a digital tachometer from Systems.

Keywords: Fiber optic sensor; Intensity modulation; Plastic optical fiber; Revolutions per minute.

I. INTRODUCTION

The rotational speed is a crucial parameter in the industry because it gives information about the health of rotating devices [1,2]. The accurate, continuous, and quick measurements of rotational speed are necessary for various industrial plants [3-5]. Researchers have been reporting different contact types and non-contact types of sensors. In contact-type sensors, the loading effect causes measurement errors. The problems of wear, slippage, and low measurement accuracy limit its use. Therefore, non-contact sensors based on optical, electromagnetic, imaging, and electrostatic techniques are reported to overcome these issues.

The existing non-contact type sensors have several disadvantages. The performance of the giant magnetoresistance sensor depends on its type, magnetic source, and evaluation unit [6]. In laser Doppler velocimetry, measuring the angle of incidence is the main drawback [7]. In a self-mixing speckle interference sensor, the size of the sensor probe is large [8]. A small change in the distance between the magnet and the sensor disturbs the output of the Hall sensor [9].

The properties of the rotor and the environmental parameters decide the performance of an electrostatic sensor [10-12]. Imaging-based systems are complex in structure and costly [13,14]. Parameter tuning and complex software are required to implement sensors based on current signals [15]. Axisymmetric eddy current sensors require temperature compensation [16]. The noise of the external environment, the motor vibrations, and the distance between the microsphere and the rotating motor affect the performance of the Fabry-Perot interferometer [17].

In this paper, a fiber optic sensor system (FOSS) is proposed for the measurement of the rotational speed of a DC motor. FOSS is designed using a fiber optic displacement sensor (FODS). FODS is small, immune to electromagnetic interference, and corrosion-resistant [18]. It offers high sensitivity, non-contact measurement, non-destructive measurement, remote sensing, and measurement in a hostile environment.

II. DESIGN OF FODS

The geometrical structure of FODS is shown in Fig. 1. The sensor configuration consists of a light source, fiber optic probe, reflective target, and photodetector. The fiber optic probe consists of two plastic polymethyl methacrylate optical fibers. These optical fibers have a core diameter/outer diameter of 0.5mm/1mm and a numerical aperture of 0.5. The fiber optic probe is held perpendicular to the reflective target.

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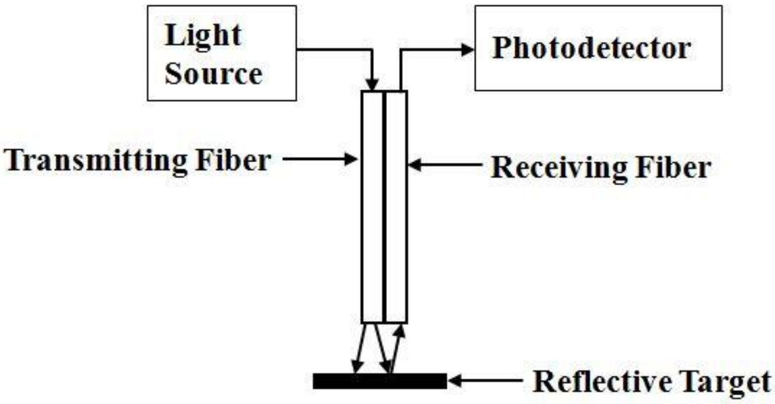

Fig. 1 Geometrical structure of FODS

A light-emitting diode based light source is coupled to the transmitting fiber. The light is launched on a reflective target using transmitting fiber. When the light falls on the reflective target, then the part of the light reflects. The receiving fiber collects this reflected light. The phototransistor is coupled to receiving fiber. The phototransistor converts optical signals into electrical signals. The photodetector circuit based on a phototransistor is designed to get sensor output in voltage signal form.

FODS is an intensity-modulation based extrinsic type sensor. The optical fibers are used for both sensing purposes and the transportation of sensing signals. The light reflected from the reflective target is collected by receiving fiber. The sensor output is a function of the distance between the fiber optic probe and the reflective target.

The static displacement of the reflective target is achieved by mounting it on a micrometer screw gauge. The micro-level static displacement is carried out to calibrate the fiber optic probe by calibrating the detected voltage. The investigation consists of recording the output voltage from the photodetector at probe distances from 0 to 10 mm in a step of 0.1 mm. Fig. 2 shows the variation of the sensor output with the displacement of the fiber optic probe from the reflective target.

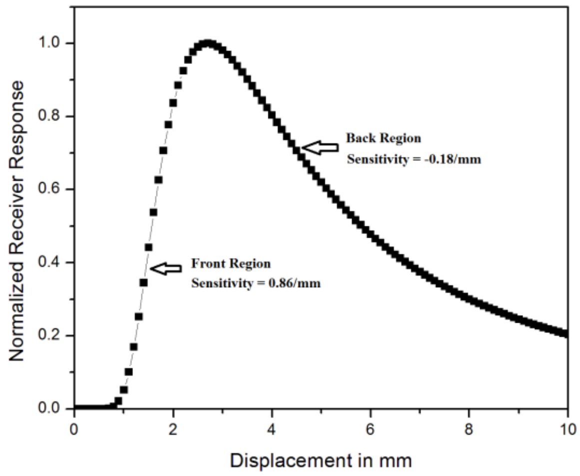

Fig. 2 Variation of the sensor output with the displacement of fiber optic probe from reflective target

The sensor response has two regions: the front and the back region. In the front region of the sensor response, the reflected light does not reach the receiving fiber for a small distance. Because of this, the output of FODS becomes zero. When the distance between the fiber optic probe and the reflective target increased, the reflected light cone increased. Due to the increase in light cone size, the receiving fiber received more light. Therefore, the output of the sensor increases.

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In the back region of the sensor response, the light cone size increases for a further increase in displacement. However, the power density decreases. The effect of the decrease in power density on sensor output is more than the increase in the light cone size. Therefore, sensor output decreases for large displacements.

The performance of FODS is shown in Table I. In the front region, the sensor offers a sensitivity of 0.86 mm^{-1} and a linear displacement range of 0.7 mm. In the back region, the sensor offers a sensitivity of -0.18 mm^{-1} and a linear displacement range of 2.7 mm. The sensor offers maximum sensitivity in the front region as compared to the back region.

TABLE I PERFORMANCE OF FODS

Front Region		**Back Region**	
Sensitivity (mm^{-1})	Linear Displacement Range (mm)	Sensitivity (mm^{-1})	Linear Displacement Range (mm)
0.86	0.7	-0.18	2.7

III. EXPERIMENTAL ARRANGEMENT FOR ROTATIONAL SPEED MEASUREMENT

Fig. 3 shows the experimental arrangement for rotational speed measurement of a DC motor. The experimental set-up consists of a chopper motor controller, DC motor, FOSS, and tachometer. A FOSS consists of a light source, fiber optic probe, reflective target, photodetector, comparator, and microcontroller-based rotations per minute (RPM) meter. A reflective target is pasted on the rotating shaft of a DC motor. The fiber optic probe is held perpendicular to the reflective target. The distance between the fiber optic probe and the reflective target is adjusted by utilizing the front region of the FODS response.

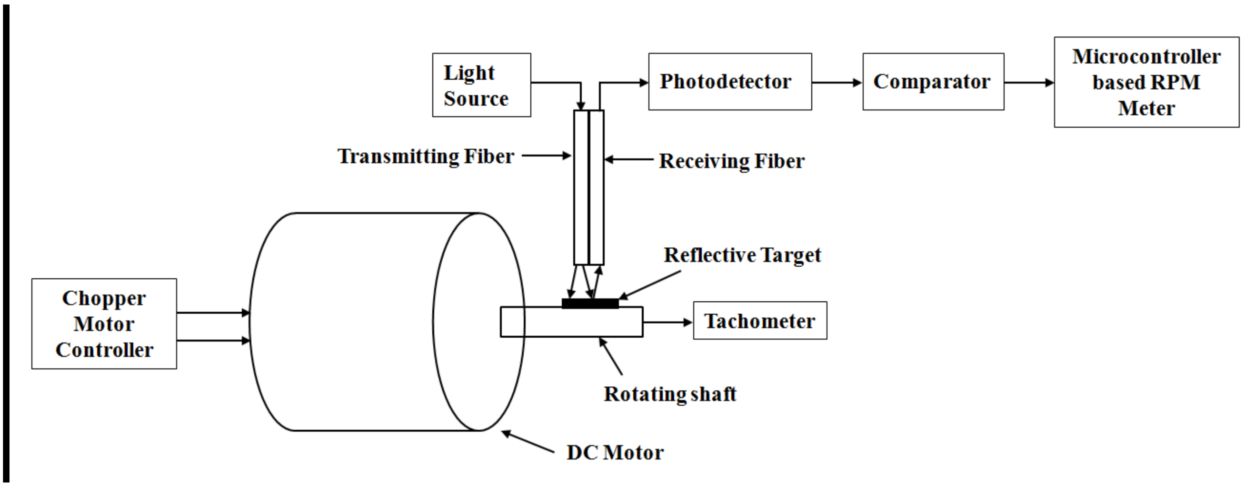

Fig. 3 Experimental arrangement for rotational speed measurement

A light-emitting diode based light source is coupled to the transmitting fiber. The light is launched on the rotating shaft of a DC motor using a transmitting fiber. The light gets reflected when the fiber optic probe faces the reflective target. The light reflected from the reflective target is collected using the receiving fiber.

The reflected light carries information about the rotational speed of the DC motor. The reflected light signal is converted into an electrical voltage signal using a photodetector. The photodetector output becomes high when the reflective surface comes in front of the fiber optic probe. But the output of the photodetector is in analog form.

The operational amplifier-based comparator is designed to convert an analog signal to a digital signal. The reference voltage of the comparator is adjusted with reference to the output of the photodetector circuit. A comparator circuit generates a digital pulse for every rotation of a rotating shaft. The output of the comparator is sent to a microcontroller-based RPM meter for further analysis.

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A microcontroller-based system measures the duration (T) between two digital pulses. The 8-bit ATmega328 AVR microcontroller is used to design RPM meter. The rotational speed (v) in terms of RPM is obtained using the following formula:

$$v = 60/T \quad (1)$$

The speed of a DC motor is controlled using a chopper motor controller. The rotational speed of a DC motor varied from 200 to 3000 RPM.

IV. RESULTS AND DISCUSSION

The experiments were conducted for the measurement of the rotational speed of a DC motor using FOSS and a tachometer. Fig. 4 shows the response of the FOSS and tachometer. The FOSS is tested for RPM ranging from 200 to 3000 RPM. A commercial digital tachometer (Model No. HTM-590) from Systems with an accuracy of ±0.05% +1 digit provides reference measurements.

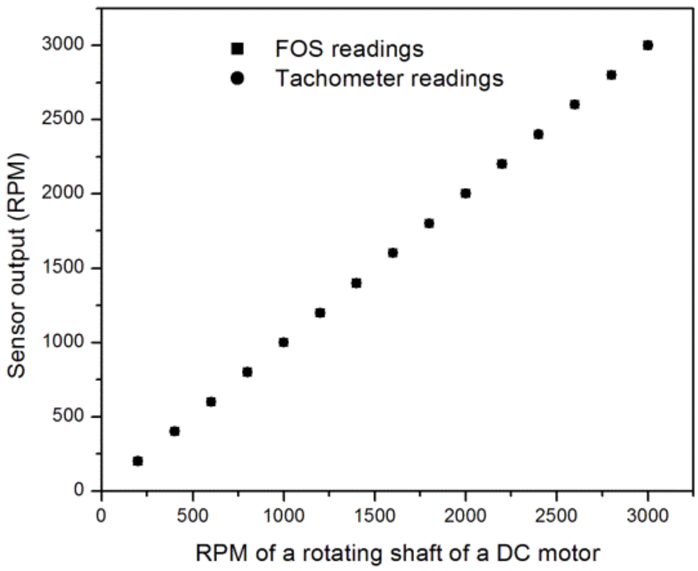

Fig. 4 Experimental arrangement for rotational speed measurement

V. CONCLUSION

The FOSS is reported for the measurement of the rotational speed of a DC motor. The intensity modulation based extrinsic type FODS is used to design FOSS. The rotational speed of a DC motor is measured without touching the rotating shaft.

In FOSS, optical fibers are used for both sensing purposes and the transmission of sensing signals. Therefore, remote monitoring of the rotational speed of the DC motor is also possible. Due to the small size of the sensor, it can also measure the rotational speed of machines that are installed in compact spaces.

FOSS is a promising alternative to other methods by considering its advantages as non-contact, remote sensing, simple structure, ruggedness, and immunity to electromagnetic interference.

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