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Micro-controller based air pressure monitoring instrumentation system using optical fibers as sensor

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ABSTRACT

This paper describes a micro-controller based instrumentation system to monitor air pressure using optical fiber sensors. The principle of macrobending is used to develop the sensor system. The instrumentation system consists of a laser source, a beam splitter, two multi mode optical fibers, two Light Dependent Resistance (LDR) based timer circuits and a AT89S8252 micro-controller. The beam splitter is used to divide the laser beam into two parts and then these two beams are launched into two multi mode fibers. One of the multi mode fibers is used as the sensor fiber and the other one is used as the reference fiber. The use of the reference fiber is to eliminate the environmental effects while measuring the air pressure magnitude. The laser beams from the sensor and reference fibers are applied to two identical LDR based timer circuits. The LDR based timer circuits are interfaced to a micro-controller through its counter pins. The micro-controller samples the frequencies of the timer circuits using its counter-0 and counter-1 and the counter values are then processed to provide the measure of air pressure magnitude.

1. Introduction

Fiber optic sensor has been a major user of technology associated with opto-electronics and fiber optical communication [1–3]. Many of the components associated with these industries were often developed for fiber optic sensor applications. They are widely used for the detection of temperature [4–8,18,19], pressure/strain [9,10], displacement [11], rotation and angular position [12], liquid level [13], electric and magnetic field measurement, acoustics, vibration [14], acceleration[15], linear, curvature measurement [16] and host of other applications. It is due to the fact that fiber optic sensors offer unique advantages, such as immunity to elector-magnetic interferences, stability, repeatability, durability against harsh environment and fast response.

Being a programmable device, microcontroller offers enormous flexibility and opportunity to researchers to investigate and develop sensor based system according to their convenience and application. An electronic microcontroller-based system for high-pressure measurement using a fiber-optic sensor has been proposed [18]. A digital microcontroller based transducer has been proposed for liquid-level measurement, it uses two optical fibers, from which the cladding was removed in suitably spaced zones at known distances [19]. A multifiber temperature sensor, based on the relationship between temperature and the refractive index using the microcontroller-based hardware has been proposed [20]. A PIC16F877 8-bit microcontroller based displacement measuring system based on one optical emitter (laser diode) has been described [21]. An ATMega163L based instrumentation system has been proposed for the monitoring of environmental parameters using hydrogen sensor and microelectro mechanical system (MEMS) [22]. Two microcontrollers are used to measure turbid water sample using the principle of interaction among the incident, absorbed and scattered light by the turbid water sample. The resultant light produced after the interaction has been collected by plastic optical fiber located at 180° (transmittance measurement technique) and 90° (90° scattering measurement technique) from the incident light [23]. The effect of intensity modulation and the micro-bending technique have been investigated for remote measurement of strain/stress. For this purpose, a microcontroller has been used for processing the single input from a sensor fiber, and display the output over a LCD [24]. A system has been described to evaluate accurate illuminance and luminous emittance, which is equivalent with measurement of luminous power per unit area[25]. AVR Atmega128 microcontroller has been used to implement the scheme, which realizes the majority of the processing functions, including the signal conditioning from the optical sensor.

The paper describes a micro-controller based optical fiber pressure sensor system consisting a He–Ne laser source, a beam splitter, two multi-mode optical fibers, two LDR based timer circuits and micro-controller AT89S8252. The beam splitter is used to divide the laser beam into two parts that are than launched into

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the pressure sensing and reference fibers respectively. The intensity of the laser beam from sensor fiber changes according to the change in air pressure and as well as the change in environmental condition around the sensor system. Whereas, the intensity of the laser beam from reference fiber changes according to the change in environmental condition around it. These two beams are applied to two identical LRD based timer circuits. The outputs of the timer circuits are fed to the $T0$ and $T1$ of AT89S8252 micro-controller (counter pins) to sample the frequencies of the timer circuits for a fixed time and using these sampled data, air pressure magnitude is determined by eliminating the environmental effect associated with the measurement. The advantage of the scheme is that it directly converts the air pressure measurement into a 16 bits digital word using simple interfacing timer circuits.

2. Description of sensor unit

The Fig. 1 shows the sensor unit developed for detecting air pressure magnitude. It consists of two multi mode optical fibers: one is used for detecting the change in pressure and termed as "sensor fiber" and other one is called "reference fiber" which is used for the purpose of rectifying environmental effect from pressure measurement. A thick plastic base plate is used to provide structural support for the different components of the sensor unit. The "sensor fiber" is used to create two loops as shown in Fig. 1. Holes in the plastic base plate are used to provide structural support to these "sensor fiber" loops. These two loops create four curvatures of the sensor fiber. Around these curvatures, cladding of the sensor fiber is partially (slightly) removed to make the sensor more sensitive.

Four supporting posts are used to provide support and free movement to a thin bakelite plate having cross sectional area (A) equals to (1.0 cm × 2.0 cm) 2 cm^2. The air pressure is applied to this thin front bakelite plate. Four thin springs are placed around the supporting posts. The function of these springs are to (i) ensure the elasticity, (ii) enhance the pressure measuring capacity or range and (iii) better reflex action of the sensor unit. The "reference fiber" is also given a shape of two loops using two holes in the plastic base plate. This is to ensure that the lengths of "sensor fiber" and "reference fiber" are approximately equal, so that under no pressure condition, the intensities of laser beams from the two fibers remain approximately same.

3. Principle of operation of the sensor unit

The configuration of two loops of the multi mode "sensor fiber" forms four curvatures with a loop height 2.0 cm. These curvatures can be treated as four semicircular arcs having radius R. Therefore,

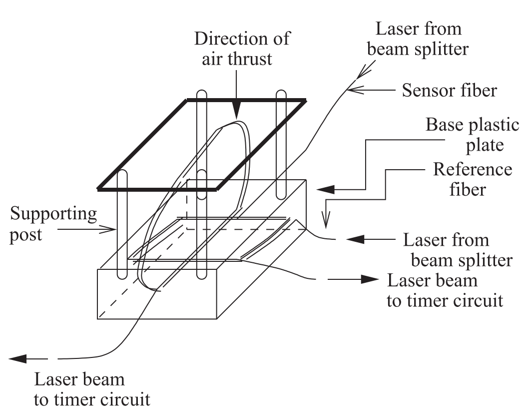

Fig. 1. Sensor unit for detecting air pressure magnitude using optical fiber sensors.

when laser beam is applied to the "sensor fiber", the modes associated with the outer diameter of the semicircular arcs of the fiber have to travel faster than that on the inside of the semicircular arcs of the fiber to maintain a wave front which is perpendicular to the direction of propagation. This results radiation (loss) of energy associated with the modes of outer diameter of the "sensor fiber". The radiation attenuation/absorption coefficient associated with the radius of curvature of a bend multi mode optical fiber is represented as [17, p. 336]:

$$\alpha_B = C\epsilon^{-\frac{R}{R_c}} \tag{1}$$

where C is a constant, R is the bend radius of curvature of the fiber, $R_c = \frac{a}{\sqrt{n_1^2-n_2^2}}$, a is the radius of the fiber, n_1 is the refractive index of the core, and n_2 is the refractive index of the cladding.

R_c is called critical radius of curvature of a multi mode optical fiber [17], i.e., when radius of curvature of a bend optical fiber approaches this value, very large bending loss is taken place.

When air pressure is applied to the thin front baketile plate, the thin springs and two loops formed by the "sensor fiber" offers resistance due to their combine elastic effect. Therefore, the extent of displacement of the thin bakelite plate depends on the magnitude of the air pressure experienced by it. The displacement of the thin baketile plate will induce additional macrobending of the semicircular arcs of the "sensor fiber". This would result in change of radius of curvature (ΔR) of the semicircular arcs. The change in attenuation coefficient due to these change in curvature of the semicircular arcs of the "sensor fiber" can be given as:

$$\Delta\alpha_B = C\epsilon^{-\frac{\Delta R}{R_c}} \tag{2}$$

Therefore, the change in intensity of laser beam from "sensor fiber" having four semicircular arcs will be

$$\Delta I_B = 4\Delta\alpha_B I_{R0} \tag{3}$$

where I_{R0} is the intensity of the laser beam from "sensor fiber" without any air pressure, can be treated as constant. Again, the change in intensity of laser beam from "sensor fiber" is proportional to the magnitude of pressure (P) applied on the bakelite sheet. Therefore,

$$P \propto \Delta I_B \tag{4}$$

Therefore, for Eqs. (3) and (4), we have,

$$P \propto 4\Delta\alpha_B I_{R0} = 4K_p\Delta\alpha_B I_{R0} \tag{5}$$

where K_p is the constant of proportionality. Eq. (5) shows that any variation of air pressure would induce change in radiation attenuation/absorption coefficient associated with the radius of curvature of a bend multi mode optical "sensor fiber". As a result, the intensity of laser beam from "sensor fiber" would change according to the change in air pressure experienced by the sensor unit. This change in intensity would change the resistance of the LDR of the timer circuit.

4. Scheme of the instrumentation system

Fig. 2 shows the scheme adopted for the measurement of air pressure magnitude using two multi mode optical fibers. The scheme consists of a laser source, a sensor unit consisting of two multi mode optical fibers, two LDR based timer circuits and a micro-controller system. A beam splitter is used to divide a laser beam into two parts that are then launched into the "sensor fiber" and "reference fiber" of the sensor unit respectively. The laser beams from the "sensor fiber" and "the reference fiber" are applied to the LDRs of the two identical timer circuits.

$T0$ (the counter pin of counter-0 of micro-controller AT89S8252) is interfaced to the first LDR based timer circuit where beam from the "sensor fiber" is applied and this timer circuit is

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