HIGH PERFORMANCE LIQUID-LEVEL SENSOR BASED ON mPOFBG FOR AIRCRAFT APPLICATIONS

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Abstract: A high performance liquid-level sensor based on microstructured polymer optical fiber Bragg grating (mPOFBG) array sensors is reported in detail. The sensor sensitivity is found to be 98pm/cm of liquid, enhanced by more than a factor of 9 compared to a reported silica fiber-based sensor.

Introduction

Fuel level monitoring has always been a technical challenge. Generally, in aircraft fuel systems [1] the most frequently used level sensors are the capacitive and ultrasonic level sensors, however they suffer from intrinsic safety concerns in explosive environments combined with issues relating to reliability and maintainability. In recent years, optical fiber liquid level sensors have been reported to be safe and reliable and present many advantages for aircraft fuel measurement [2]. Different optical fiber liquid level sensors have been developed, such as the pressure type, float type, optical radar type, TIR type and side-leaking type. Amongst these, many types of liquid level sensors based on fiber gratings have been demonstrated [3-6]. However, these sensors have not been commercialized because they exhibit some drawbacks, such as low sensitivity, limited range, long-term instability, limited resolution, or high cost. In this paper, a liquid level sensor based on mPOFBG array sensors showing high performance is investigated. The new approach is based on five mPOFBGs inscribed in the same fiber in the 850 nm spectral region. Compared with our previous work [7], the novelty of this approach will be to avoid several connections between silica and POF fibers, reducing the complexity of the liquid level system, and presenting a real device to integrate in an aircraft fuel tank. Furthermore, this new approach exhibits a factor of 9 improvement in sensitivity (compared to the best sensitivity published with silica fiber [6]), a highly linear response, high resolution, good repeatability and fast time response.

Design of sensors and configurations

Five identical mPOFBGs were inscribed in a doped mPOF fabricated from PMMA – details of the fabrication in [8]. With this series configuration, one optical coupler is needed to interrogate the five FBGs inscribed in the same mPOF. Using a single 75 cm long fiber, the multiplexed mPOFBGs are inscribed spatially separated by 15 cm. To obtain five different wavelength gratings, we used two different phase masks (pitches of 557.5 and 580 nm) and utilised the thermal annealing process to change their wavelengths [9]. Thereafter, each mPOFBG is embedded in silicone rubber diaphragms producing highly sensitive sensors. The obtained diaphragms had thicknesses of 1.080 ± 0.005 mm. More details of the diaphragm fabrication can be found in [7]. The sensor configuration shown in Fig. 1(a) represents a departure from the idea of determining liquid level by measuring the pressure at the bottom of the liquid container and has several critical advantages. Sensors above the liquid surface will all read the same ambient pressure, and sensors below will read pressures that increase linearly with depth. The position of the liquid surface can therefore be approximately identified as lying between the first sensor to read an above-ambient pressure and the preceding sensor. However, a much more accurate determination of the liquid level can be made by using linear regression to the wavelength shifts experienced by the sensors submerged at different depths. There are several advantages to this approach: first, temperature induced wavelength shift in the individual sensors as well as temperature induced changes in the sensor pressure sensitivity are automatically compensated; second, the operation of the system is not affected by changes in the liquid density and finally, it provides the possibility to detect/compensate for malfunctioning sensors.

Experimental results and discussion

The design of the prototype consists of a square acrylic tube (800 mm length, with 3.2 mm wall thickness and 38.1 mm outside dimension), with windows drilled at equidistant positions (15 cm) along it as shown in Fig. 1(a). The mPOFBG array sensor system was installed in a liquid container of 80 cm height with an

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inner diameter of 94 mm. The experimental setup consists of a super-luminescent diode centered at 830 nm, a silica single-mode 850 nm coupler, and an OSA. The sensor performance was tested within a liquid level range of 0 to 75 cm and with a liquid level increment step of 2.5 cm. Three cyclic tests were performed to investigate both increasing and decreasing levels of the liquid. Fig. 1(b) shows the first cycle of the sensors 1 and sensor 3. The wavelength shift was extracted and the sensitivity of each sensor was calculated, showing a sensitivity of 98.6 ± 0.3 pm/cm (sensor 1), 98.1 ± 0.2 pm/cm (sensor 2), 98.4 ± 0.6 pm/cm (sensor 3), 97.6 ± 0.8 pm/cm (sensor 4), and 86.1 ± 2.6 pm/cm (sensor 5), respectively. One can see that there is a slight discrepancy coming from sensor 5 in terms of sensitivity variation – this is due mainly to the fiber thermal annealing process used in the sensors 1, 2, 3 and 4 and not in the sensor 5 [10].

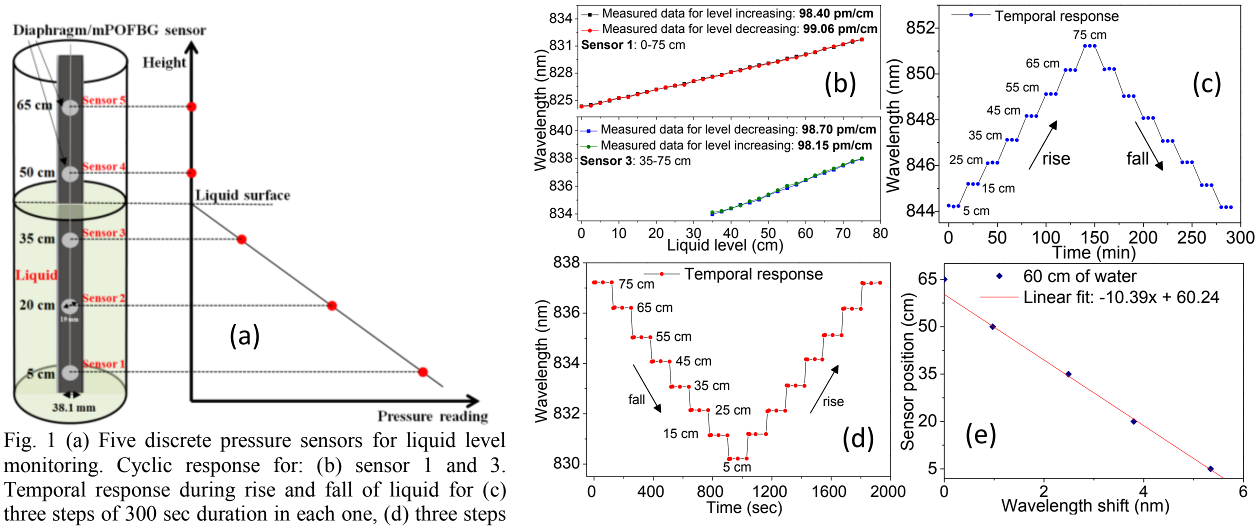

Fig. 1 (a) Five discrete pressure sensors for liquid level monitoring. Cyclic response for: (b) sensor 1 and 3. Temporal response during rise and fall of liquid for (c) three steps of 300 sec duration in each one, (d) three steps with duration of 10, 50 and 120 sec in each one. (e) Liquid level determination using linear regression for a position of the liquid at 60 cm.

At each liquid level three readings were taken separated by 300 seconds. Less than 3 pm shift of the central wavelength was observed (Fig. 1 (c)). The response time of measurement is also an important parameter in fuel monitoring systems. To assess this, the liquid level was changed and then readings were taken at 10, 50 and 120 seconds in each position (see Fig. 1 (d)). Here, the maximum shift of central wavelength in these measurements was around 30 pm in the case of 10 seconds. The results at 10 seconds show a variation larger than those 50 and 120 seconds, as expected, due to the PMMA relaxation time. Fig. 1(e) shows the determination of liquid level using linear regression for a position of the liquid surface at 60 cm. An intercept value of 60.24 ± 0.54 cm was achieved, being a value very close to the real value – 60 cm of liquid level. The resolution of 0.6 cm is more than three times better than our previous result [7].

Conclusion

A high performance liquid-level sensor based on mPOFBG array sensors embedded in SR is investigated. The results show that the proposed system has a high sensitivity to liquid level, great repeatability, a high resolution, a high linear response, and good stabilization time. This new sensor, when compared with a similar sensor based on a silica fiber, exhibits 9 times more sensitivity. A multi-sensor level system is proposed to enable operation insensitive to temperature, liquid density and even effective gravitational force. This new configuration will be a potential tool to integrate in aircraft fuel systems in near future.

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