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Liquid level gauge based in plastic optical fiber

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ABSTRACT

This work reports de development and testing of a low cost plastic optical fiber liquid level sensor for operation within highly flammable or other hazardous environments, such in oil piping or fuel tanks. The sensor consists on a vertical fiber, with engraved grooves, that will be sequentially fulfill when the liquid rises, resulting in an increase of the transmitted optical power. A variation of 2.60% in the transmitted optical power intensity was obtained per measured point. Moreover, the sensor sensitivity and resolution can be tailored accordingly to the application.

1. Introduction

The accurate liquid level measurement in large industrial containers is a difficult task, especially for highly flammable environments, where the use of electronic sensors can be problematical, or even banned by law, due to the risk of electric sparkle.

Nowadays, the petroleum and other petrochemical industries have specific and tight requirements related with the production quantification. Such as the requirement to quantify the production volume, by inferring the liquid level in the container (typically with some meters height). This requirement is not only an individual company requirement, to control the company production efficiency and gains, but also a legal imposition to estimate fiscal taxes [1]. Usually, the liquid level in the container is measured by traditional technologies, such as differential pressure level meters, radar, magnetostrictive, or magnetic float technologies [2,3]. However, some limitation may apply, since such methods are electronic and the sensing system is often exposed to combustible liquids or accumulated flammable vaporous environments. Therefore, the liquid level measurement in the petroleum industry appears as a window of opportunity for the use of optical technology.

Nowadays, the main technological characteristics used for liquid level measurement, are capacitive, ultrasonic or hydrostatic [4,5]. Optical technologies are also gaining position among those sensors, mainly due to the immunity to electromagnetic interference, the inexistence of electrical signal at the sensor head, the possibility of remote sensing and the compactness. Recently, several solutions had being proposed for the measurement of liquid level, such as based on long period gratings [6], fiber Bragg gratins [7,8] or LIDAR systems [9].

Usually, the main disadvantage of all these sensing solutions is the high implementation cost, resulting from the requirement of the interrogation unit. To overcome this disadvantage, polymeric, or plastic optical fibers (POF) are already being used in numerous types of sensors, such as

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physical sensors (elongation, acceleration or pressure) [10,11], chemical [12,13], biosensors [14] or in specific applications, such as to monitor concrete curing process [15]. These sensors can be potentially less expensive than the conventional electronic sensors and more robust than the produced with silica optical fibers [11,16].

Several level sensors based on polymeric optical fiber have been proposed in the last few years. Lomer et al. demonstrate a ‘‘U’’ polished bended POF sensor head to measure the liquid level in a container [17]. A discrete sensor was tested with bended polished POF sensing heads, the sensitivity was quantified through the optical signal attenuation change in each bend, 0.26 dB, per sensing point immersed in water. The resolution can be tailored to each application, by changing the distance between each bend.

Azimi et al. showed an arrangement to measure the optical signal coupled via the evanescent electromagnetic field between two fibers placed close to each other, imposing an intensity modulation on the signal in the acceptance fiber when a liquid is to be found between the fibers [18]. This modulation mechanism was related with the refractive index of the surrounding medium. The sensor was tested as a liquid level sensor for different liquids and a signal contrast of 4.5% was measured when the sensor head was moved from air to water.

Montero and Vázquez demonstrated an intensity based POF sensor for liquid detection in volumetric flasks, normally used in chemistry [19]. In the developed platform, light was launched from a fiber illuminating the volumetric flask and received into a fiber placed at the same longitudinal axes. The system presented diverse sensitivities due to the increasing reflected light from fluid's surface when it rises. An optical power variation of −9.6 dB in the receiver was noticed when the liquid completely blocks the acceptance area of the receiver fiber, and most light is reflected on the liquid surface.

Bottacini et al. proposed a POF sensor for point measurement, working like a retro-reflecting prism [20]. The sensor detects the presence of different liquids by measuring the intensity variation of a green-light signal, back-reflected by special tip-shaped fiber probes with 90° and 60° angled tips. The back-reflected optical signal decreases when the tip is immersed in water (or in other high RI liquids).

In the work here presented we proposed a novel level sensor based on POFs. This allows the combination of the optical technology advantages with the lower cost of the interrogation technique, providing a solution, for harsh or hazard environments. The proposed sensor is based on a periodic indentation on the polymeric fiber core. Each groove disturbs the propagation of optical signal and induces an increase in the optical signal attenuation. The amount of optical radiation loss depends on the external environment surrounding the grooves and on its dimension. Thus, any external disturbance to the surrounding environment produces a measurable effect on the signal optical power at the fiber output. Comparing the proposed solution with other previously reported, such as in references [17–20], although the detection scheme could be similar, the sensor here proposed is simpler and cheaper to manufacture and its assembly in the measuring field easier, because it uses one stretched fiber, without bending or sensing heads. Bended and polished fibers, such in [17] are also more susceptible to failure due to internal stresses in the curvature, furthermore each bending increases a fixed term of attenuation that might considerably decrease the measuring range. A sensing head, such in [18,19], may add alignment complexity to the sensor manufacturing and stability during operation. The sensor referenced in [20] cannot make level measurements with one fiber, and also requires a more complex manufacturing process.

This paper is organized as follows: after an introduction, reporting the relevance of such optical sensors, the developed sensors are introduced in section 2, with the description of the manufacturing process and its working principle. Section 3 deals with the sensors experimental characterization. Finally, the main conclusions are drawn in section 4.

2. Sensor description and manufacturing

As already mentioned, the presence of a groove in the core of an optical fiber disturbs the propagation of the optical signal, resulting in an optical signal leakage to the exterior of the fiber, thereby interacting with the surrounding environment. Considering that the refractive index (RI) of the surrounding medium is equal to the POF core RI, the fiber and the surrounding environment can be considered as continuous medium. Therefore the optical signal leakage is minimum and the transmitted optical power is maximum. If the surrounding medium have an RI that differ the POF one, then the optical power leakage increase and the transmitted signal power decreases. Considering that the liquid refractive index does not change during the measurements and have an intermediate value (~1.33) between the air RI (~1.00) and the POF core RI (~1.46), then, each time a groove is fulfilled, the transmitted optical power increase due to the reduction of the optical power leakage. The amount of radiation lost to the outside depends on the fiber's external environment, the dimensions of the grooves and its depth.

Using the POF fiber with the engraved grooves, placed perpendicularly to the liquid surface, when the liquid rises it will sequentially fulfill each groove, and consequently increase the transmitted optical power. In Fig. 1, is displayed the optical signal leakage through the grooves engraved in a POF.

To produce the grooves in the plastic optical fiber a brass mold was manufactured (Fig. 2a), which allows, in conjugation with a sharp blade, to engraving the groves with a high repeatability and accuracy. This mold was designed to produce grooves with a depth of one quarter or one half of the fiber core diameter, with a minimum groove spacing of 1 cm.

To demonstrate the feasibility of the proposed solution three illustrative sensors were implemented in a large diameter core (1 mm) plastic optical fiber from *Avago Technologies* (HFBR-RUS100Z), with the number of grooves, depth and dimensions outlined in Table 1.

Temperature influence and LED stability have a preponderant effect on the measurements, however, those effects