ALTERNATIVE METHOD TO MEASURE PRESSURE USING OPTICAL FIBER

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Abstract: A number of different measurement principles are used in pressure measuring instruments. Some principles use fundamental methods and others can use some property of the material, like a mechanical deformation of a sensing element to determine a quantity. Following this possibly of measuring pressure through a physical property, it was created a new kind of pressure sensor that uses guided light in an optical fiber as measurement principle. This new technology has been used in pressure sensors mainly for the petroleum industries by measuring the variations of the wavelength associated with pressure values. Compared with pressure sensors that use traditional technologies of measurement, optical sensors have shown a growing acceptance because they have a good behaviour in harsh and hostile work conditions. This paper describes a calibration system established to evaluate the metrological features of this pressure optical sensors showing up the calibrations results.

Keywords: **pressure sensor, optical fiber, Bragg grating.**

1. INTRODUCTION

Since the industrial revolution is possible to observe an increase in energy demand worldwide. The industry needs have allowed the pressure quantity increase its participation around the world. Typically, the industries use traditional technologies to measure pressure with capacitive techniques, strain gauges techniques, piezo-electric techniques etc. However, in some situations the traditional technologies using pressure sensors have limitations. Traditional technologies when used in harsh and hostile environments may have inconsistencies in their instrumentation decreasing the metrological reliability of the measurement results.

In case of performing measurements where it is desired to achieve better results in terms of a particular type of environment, the use of optical pressure sensors could be a good choice because the signal from the measurand is related with a light property, improving the measurement results. Taking advantage of this new optical technology that was developed a whole theory regarding fiber Bragg grating (FBG). The fiber Bragg grating is an intrinsic element inscribed into the core of an optical fiber and it is be able to measure a wide range of spectrum with a decreasing price. The fiber Bragg grating acts as a sensor element in the optical fiber associating the pressure values with the wavelength displacements. Due to its characteristics, the pressure sensors made with FBG has been increasing their application, especially in the petroleum industry, but still not enough accepted if compared with traditional technologies of pressure measurement.

2. THEORY

A fiber Bragg grating (FBG) is a periodic perturbation of the refractive index along the fiber length which is formed by exposure of the core to an intense optical interference pattern.

This modulation in the fiber core affects the spectrum response of an incident light. The FBGs are located in the range of the infrared spectrum within 1510 nm and 1590 nm. The principle beyond of this technique uses a broadband source that injects light in a single-mode fiber. The light propagating in the fiber core realizes a refractive index variation in the core and reflects a portion of this light that is associated with a wavelength, called wavelength of Bragg (λ_b). The FBG is positioned on diaphragm in a pressure sensor and correlates the deformations in the elastic element with the wavelength displacements (λ_b), according with equation (1).

$$\lambda_b = 2. \, n_{eff}. \Lambda \qquad\qquad (1)$$

where:

n_{eff} = effective refractive index of the optical fiber to the fundamental mode;

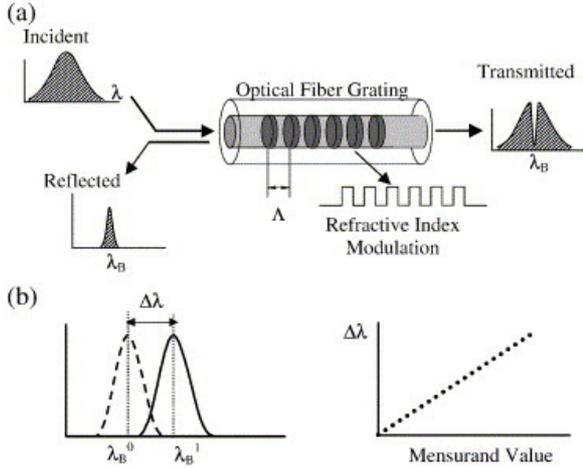Λ = spatial period modulation of the index (induced disturbance in the fiber).

Fig. 1 - Spectrum of wave transmitted and reflected at FBG.

The pressure measurements with FBG use a relation of cause and effect between the pressure variations (deformations) in the core of the optical fibers and the changes behind or forward in the light spectrum. This changing impact directly in the Bragg wavelength. Such relative displacement of the Bragg wavelength, related to strain or temperature variations can be calculated according with equation (2)

$$\Delta\lambda_b/\lambda_b = C_d\varepsilon + C_T\Delta T \qquad\qquad (2)$$

where:

C_d = coefficient of deformation;

C_T = coefficient of temperature;

ΔT = temperature variations in °C;

ε = deflection in m/m.

For versatility and futures perspectives, sensing technology using pressure sensors with fiber Bragg grating needs to be better studied and understood in terms of metrological characteristics.

3. EXPERIMENT

In order to characterize metrologically pressure sensors with fiber Bragg gratings has been developed a measurement system in the Brazilian Pressure Laboratory that has allowed to calibrate these new pressure optical sensors in an environments similar a down-hole well. The sensors were developed and manufactured by the Catholic University of Rio de Janeiro (Puc-RJ) and designed to operate in the range from 0 up to 600 psi (0 up to 4136,85 kPa) and maximum temperature of 120 ºC. The set up was developed with The following features: controlled thermal bath within (25 up to 200) °C, platinum resistance thermometer (Pt 100), optical coupler, digital multimeter with 6 ½ (Fluke), optical spectrum analyzer (Micron Optics), glass liquid thermometer, humidity sensor (Vaisala), dead weight balance (DH-Budenberg) and a computer. Before the beginning of the sensors calibrations, they were submitted an aging process to eliminate residual tensions on theirs structure. The aging process puts the sensors in the maximum operating conditions, that is was 120 ° C and 600 psi (4136,85 kPa) for a period of time when they get a stable behaviour. An optical pressure sensor was placed inside a pressure vessel tightly closed and connected with a deadweight balance that worked as a reference pressure generator. In the center of the pressure vessel was placed a platinum resistance thermometer Pt (100), in order to measure the temperature inside where the reference pressure was being applied on the sensor. This pressure vessel was immersed in a thermostatic bath whose fluid was silicone and could operate until 200 ºC. To equalize differences in temperature between the bottom and the top of the bath, compressed air was injected trying to reduce the thermal gradients on the pressure vessel. The environmental conditions of the Pressure Laboratory in the moment of the measurements remained in (60 ± 10) % and (20 ± 1,0) ºC. The pressure sensor was calibrated in 10 points beginning with 10 % up to 100 % of full scale in a cycle towards increasing and decreasing values.
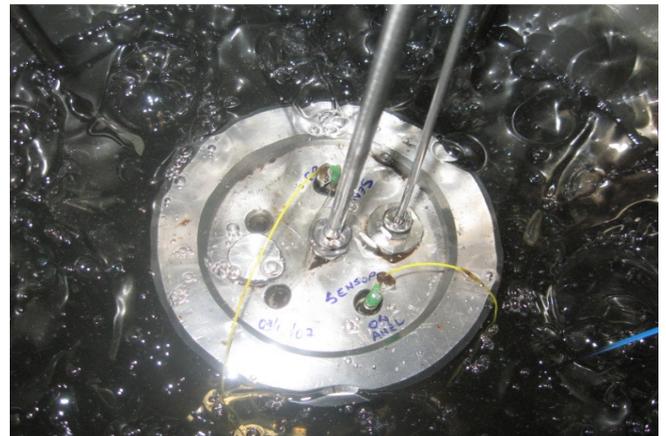

Fig. 2 - Thermal controlled bath with pressure sensor and a reference thermometer Pt 100.

The technique used in the experiment to evaluate the metrological FBG´s sensors behaviour has used an adjustable laser to scanning the optical spectrum. The technique is simple and uses a spectrum analyzer optical (OSA) to read directly the signal of the reflected spectrum.

All the control and data acquisition were carried out automatically by computer, through a program developed in Lab View software.
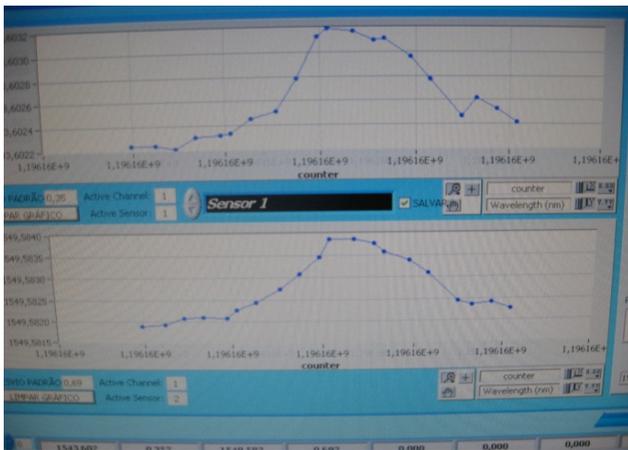

Fig. 3 - Data acquisition system developed in Lab View software.

4. RESULTS

The behaviour and repeatability of the optical pressure sensor could be evaluated by applying pressure to a certain preset point repeatedly from one direction (increasing or decreasing). The largest difference of the sensor output readings can be used to specify the repeatability of the sensor. With a fiber Bragg grating as the sensing element, sixteen measurements were performed for the pressure range from 60 psi to 600 psi (413,69 kPa up to 4136,85 kPa) and the maximum error deviation between the measured pressure values was within the ± 2,5 psi, as shown in the figure 4. The pressure values on the x-axis are from the dead weight balance readouts.

Optical sensors have a reputation of being extremely sensitive by detecting the differential changes in the measurand. The resolution of the sensor system can be interpreted by its standard deviation of series of pressure measurements at a constant pressure value. It is common to use twice the standard deviation as the directly measurement of the resolution.
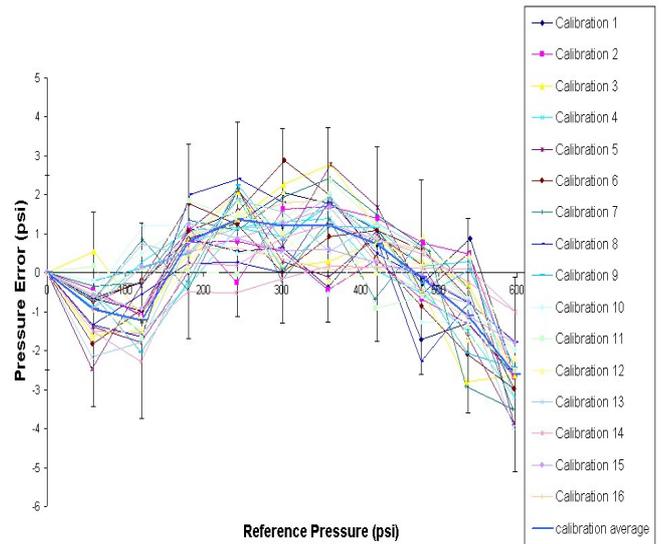

Fig. 4 - Sensor error variation during the time.

The graph on the figure 5, shows results from the sensitivity variations evaluated in the sixteen measurements with the optical pressure sensor. It is possible to notice that the sensitivity deviations are within the twice standard deviation. The average value of the sensitivity was 0,0028 nm/psi that is an interesting result in terms of future applications. The measurement five has a result far from the others probably due an operation mistake.
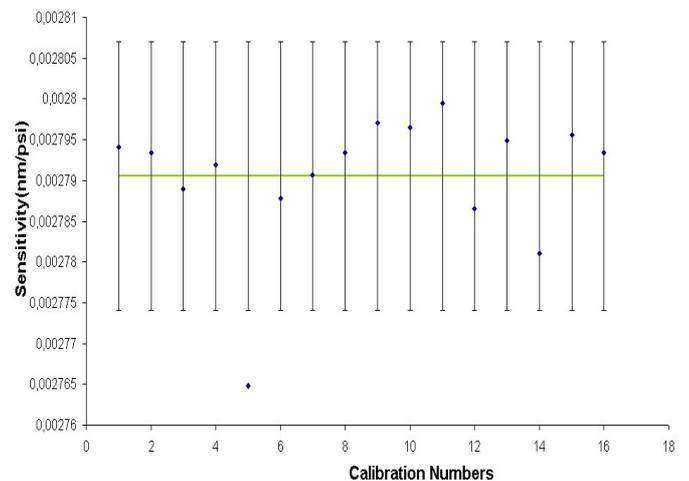

Fig. 5 - Sensor sensitivity variation during the time.

The hysteresis of the pressure sensor was evalueted by cycling the applied pressure between the minimum and maximum of the operating range. The results of hysteresis obtained could be considering negleated for this kind of optical sensor.

5. CONCLUSION

The results obtained in the calibrations performed show the potential of this new optical pressure sensor technology as another alternative measurement of pressure. The experimental system was designed properly, because there were not any significant variations in the data of pressure measurements. It was possible to establish and consolidate a new methodology for the evaluation optical pressure sensors that was not previously applied in Brazil. An optical sensor for pressure measurement has significant advantages such as low hysteresis, immunity of electromagnetic interference, high velocity transmission, etc., that are very suitable in the petroleum industry. The error variations for the sixteen measurements within the ± 2.5 psi with a sensitivity average of 0,0028 nm/psi were very homogeneous within two standard deviations.

6. REFERENCES

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