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Development of innovative sensors for oil and gas sensing based on optical fibers

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Abstract— This research tries to establish how optical fiber sensors can be improved to detect anomalies in the oil and gas transmission. Different improvements have been used to ensure there is incorporation of technology in measuring different physical parameters associated with oil and gas. Though various improvements have been pointed out, pressure has been the parameter that has been considered under this study. Results obtained from the different researches indicate that some of the optical fiber sensor systems are incomplete, while others are complete. Therefore, there is need to ensure that technology is incorporated something that has been clearly pointed in this study. Through the researches that have been undertaken, there are advantages that are associated with optical fiber sensors hence an indication of an encouraging future. A strong conclusion has been obtained in the study in regard to measurement of pressure in relation to oil and gas.

Index Terms— Pressure sensor, Fabry-Perot, volatility, monitoring systems, reflection spectrum, temperature crosstalk and optical fiber sensors

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1 Introduction

There has been researched related to optical fiber sensors for a while now. Different approaches have been used by researchers while incorporating technology in measuring different physical parameters moreso on the oil and gas industry. However, regardless of the various studies, there are other optical fiber sensors that have been commercial of interest due to the fact that they have a played a great role in ensuring safety related oil and gas transmission is maintained. Results obtained from the different researches indicate that some of the optical fiber sensor systems are incomplete, while others are complete. An example is those that include both the detecting and signal processing electronics while others have either one of them. Both approaches have been applied in ensuring that oil and gas safety is ensured through minimizing the anomalies and ensuring everything is kept within the required limit. Through the researches that have been undertaken, there are advantages that are associated with optical fiber sensors hence an indication of an encouraging future. Some of the benefits include; high sensitivity, compactness, minimum weight, large bandwidth, immunity to ionizing radiation (γ-ray, X-ray etc.), and immunity to electromagnetic interference. With these benefits, the optical fiber sensors become one of the photonic devices in the oil and gas where detections and evaluation of different conditions i.e. temperature levels are done in case of both regulation and accidental circumstances. The development of optical fiber sensors have been done in a way that it measures, pressure, temperature, strain, chemical contaminant, current, gas, rotation, displacement, vibration, acceleration, voltage, bending, biomolecules, and torsion.

There has been great interest in relation to chemical optical fiber sensors that are used in the detection of contaminators in the soil, air, and water. They are normally used in the medical application. The interest is due to the fact that they have a close relation to human life. Due to the fact that there are key environmental monitoring systems associated with them, there have been thorough investigations that have been undertaken. Therefore, there association with contamination detection with factors related to human life, they have been very important and they have been given importance in the medical advancement. In the oil and gas industry the future development of sensors looks into ensuring that anomalies can be detected and contained at the same time. This research looks at how pressure is being measured using the optical fiber sensors have been developed in an innovative manner to ensure that the gas and oil anomalies can be detected.

2 Design of fiber optic F-P cavity pressure sensor

2.1 The sensor working principle

Fabry-Perot (F-P) interferometer is the basis under which the fiber-optic F-P cavity pressure sensor operates. This mainly contains the incident fiber, the quartz capillary, and the reflec tive fiber, hence in it has three parts in total. There will be a reflection of incident beams that will be reflected a number of times on the two parallel fiber ends which comes by intensity I0 and wavelength λ of a bunch of monochromatic light that passes through the fiber F-P cavity where the incident passes. Both the structure and spectral information are shown in fig 1& 2 below.

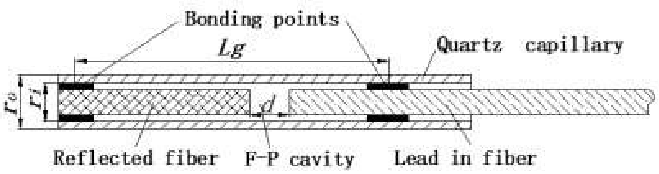

Fig 1. Structure diagram of optical fiber F-P cavity.

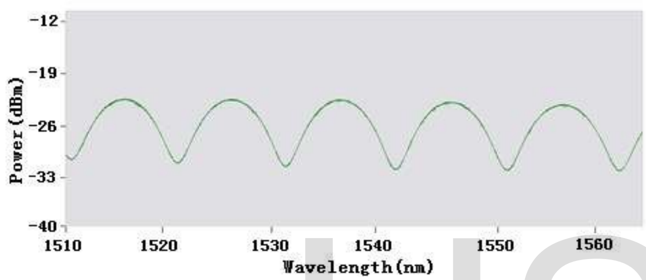

Fig 2. Light spectrum of the optical fiber F-P cavity.

Where the structure of the F-P cavity received the exerted static pressure, it results to the crushing of the quartz capillary that results to the production of deformation. When this happens, there are changes that occur to the F-P cavity length. There is a cause of reflection spectrum due to the change of d, and demodulation system signal is the one that measures spectral signal. The change of d is the one that is calculated by the F-P cavity. This can be used to obtain the pressure change of information.

2.2 Pressure sensor design of the fiber optic F-P cavity

Under this study, the sensors have got an oxygen and hydrogen fabrication that bonds under high temperatures of flame thermal. Also, the coefficient of thermal expansion of the materials used is the same as the connection at the point of connection. This enables it to avoid the occurrence of temperature mismatch on the connection point. This leads to solving of the problem that is associated with temperature crosstalk at the point of connection. The innovation that has also been done at this point is the fact that the material used at the point of connection is quartz, this assists to solve the problem associated with high temperature creep that exists in the gelatinized package. Further, this leads to improvement of repeatability, precision and long term stability of the sensor.

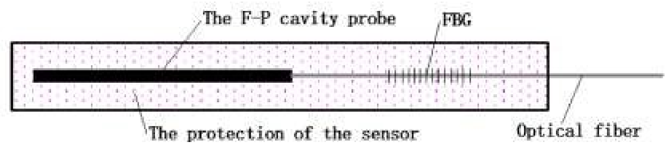

Fig 3. Temperature compensation diagram

The study innovation is such that the fiber grating is connected with fiber F-P cavity in series. This can be indicated in fig 3 above and it's further used in the monitoring of temperature and compensate for the temperature influence and pressure cross sensitivity on the fiber optic F-P cavity pressure sensor. The structure is such that the quartz capillary inner diameter contains the F-P cavity is ri, whereas the outer diameter is ro, and the sensor cavity length changes Δd, that is caused by the application of external pressure P is [9]:

$$\Delta d = \left[\frac{L_g r_0^2}{E\left(r_0^2 - r_i^2\right)} (1 - 2\mu) \right] \cdot P \qquad (1)$$

The formula above is such that, μ presents the Poisson's ratio of quartz glass, E is Young's modulus. The change that occurs in the external pressure can be measured using the cavity length. Further, the formula indicates that the pressure sensor can be adjusted to measure the dynamic range and measurement sensitivity that is within a given range through the adjustment of the capillary diameter ri, outer diameter ro and gauge Lg of the three geometric parameters.

3 Performance Test of the Fiber Optic F-P Cavity Pressure Sensor

The diagram that presents the F-P cavity pressure fiber sensor performance test system that is being discussed in this study is indicated as Fig 4. It comprises pressure pipes, pressure gauges, demodulators, computer, thermostat, and pressure devices. The GE 3100 piston pressure gauge of United States is used in providing a high precision and stable pressure that range between 0 ~ 110MPa and its accuracy is one ten thousandth. Further, the FM841-3 oven of Wu Jiang fei Ma Company is used and its temperature range is room temperature ~ 250 ℃ and the accuracy is ± 2 ℃. Further, a high-pressure pipe of Shanghai Dayton Electrical and Mechanical Technology Co., Ltd is used. The design employed by the pressure device is designed in such a way that it has a maximum pressure is 150MPa and which is used to place the sensors.

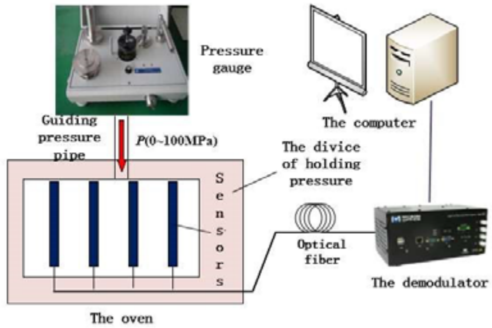

Fig 4. The Schematic diagram of the sensor testing system

3.1 Test of the linearity

For the case of quartz material: E = 74GPa, μ = 0.17, and Lg, ri, and ro the change of this is small and in the process of monitoring it can be said to be constant. Therefore, as indicated from formula 1 the cavity length change Δd is directly proportional to the applied pressure P. Hence, the relationship between the cavity length d and the pressure p through the sensor cavity length that is calibrating.

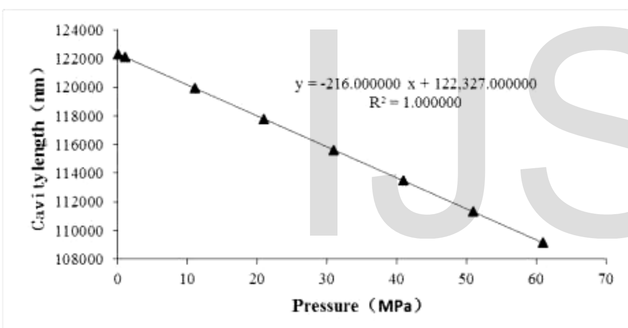

Fig 5. The linearity of the optical fiber sensor based on F-P cavity

On the process of testing, the pressure is inserted into the sensor with a positive stroke that runs from 0 – 63 MPa or reverse stroke that runs from 63 – 0 MPa. From this, the length of the F-P cavity is recorded and linearly fitted. The graph obtained indicates that there is a linear occurrence on the test of the fiber optic F-P cavity pressure sensor, for linearly fitted degree R2> 0.9999991, the cavity and pressure cavity relationship is expressed as y = -216.00000x +122327.00000. From this, the sensitivity index is at 217nm/MPa, and a 0.005MPa resolution is greater than the normal.

3.2 Test of the repeatability

The definition of repeatability is the volatility (inconsistency) that comes as result of characteristics of a curve that is obtained through continuous repeated measurements that are under conditions that are similar to that of operation within the input of a full range of the reverse or forward stroke.

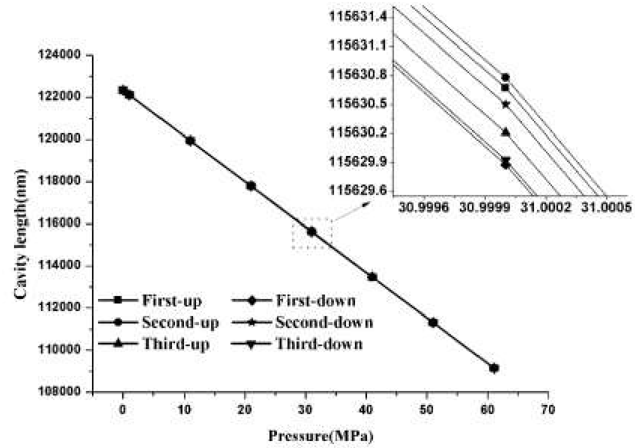

Fig 6. Repeatability of the optical fiber sensor based on F-P cavity

Fig 6 above indicates the fiber optic FP sensor repeatability test results. Where the temperature is maintained on constant while the procedure of testing from the range of 0-63 MPa, it is calibrated three times and the repeatability measure is reversed by the stroke from 63Mpa to 0 MPa. The results indicate that the maximum deviation of F-P cavity length is 1nm and the repeatability is less than 0.01% F.S (Full scale) in three measurements, and the repeatability is okay and within the recommended range.

4 Conclusion

On the fiber FP cavity, the kind of pressure sensor is developed so that it can be able to detect harsh environment like that of high pressure, high temperature, and corrosive of gas and oil wells. Fabrication is done on the sensor using oxygen and hydrogen flame thermal bonding when the temperatures are high technically. The compensation that occurs in the change that happens in the sensor's cavity length happens due to changes that occur in temperature that are influenced using the Bragg grating cascading fiber. The design of the pressure sensor ranges from 0 ~ 70MPa, and it has a resolution that is higher than 0.0051MPa, where the linear fit turns out to be higher than 0.99999, the repeatability is at 0.011% FS, whereas hysteresis is lower than 0.011% FS, the length of the cavity fluctuates within 4.01nm (where the pressure is lower than 0.021MPa). All this is an indication that there is an environment that is 21MPa and 100℃ that is of good stability. When it is being applied, it can be used to measure the pressure accurately that is contained at 2000m deep of a well. The comparison that exists between the monitoring pressure sensor and the mature electronic pressure sensor, is a deviation that is estimated to be about 0.01% and there is 1℃ temperature deviation.

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