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Leak detection in a pipe using Fibre Bragg Grating sensor

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Abstract. Being the main and safest oil and gas transportation method globally, the integrity and condition of pipeline system is very crucial. The offline existing maintenance method might have consumed more time and risky as it does not detect the flaws immediately after it is formed. This paper focused on the detection of the leak detection in pipes using the Fiber Bragg Grating pressure transducer. Two different sizes of artificial leak were introduced on the pipe in order to measure the applicability of the FBG sensor in detecting the leak in a pipe. The FBG signals were acquired on a galvanized steel pipe in lab scale size equipped with 5 pairs of valve. During the experimental work execution, the FBG sensor was attached on the pressure transducer that is linked to the pipeline. Findings showed that bigger leak size contributed to higher voltage drop in the pipe which was 0.0075 V compared to 0.0017 V. This study shows that FBG is a reliable method to be utilised in leak detection because it is very sensitive towards pressure changes in pipe. The results also showed that FBG exhibits good uniformity.

1. Introduction

Pipeline assessment or monitoring is critical in order to ensure the pipelines safety. In order to prevent even more leakage of oil and gas pipelines, the area is seeking a more reliable and efficient way to monitor the pipelines. A lot of researches have been performed including utilising the vibration sensor [1], acoustic sensor , piezoelectrical A few researches have been conducted in order to verify whether FBG can be used in pipe leak detection system [2], [4]. Some of the factors that affecting pipelines' health was justified by Kim [5]. The changes of pipe diameter and material, valves usage, orifices of different diamteres, leakages, blockages, joints, junctions, complex boundary conditions, and other non-pipe elements commonly found in pipeline systems contributed to unique unsteady behavioural characteristics during periods of rapid or sudden pressure or flow changes. Besides the detailed knowledge on the pressure wave attenuation, an excellent sensor is necessary too.

In the recent years, Fibre Bragg Grating (FBG) sensor is getting attention in the area of Structural Health Monitoring (SHM) for its versatility. It has been utilised to detect various types of failures in the structures and its capability is comparable to the piezoelectric sensors. A number of studies show that FBG is a reliable sensor to be applied in SHM [6–9]. Its tiny dimension enables it to be embedded inside the composite layers. The Bragg wavelength will shift to forward and positively when the FBG expands and negatively or backward when it is compressed [10]. This study focused on detecting the leak in piping system using the Fibre Bragg Grating sensor.

2. Methodology

2.1. Test rig

The pipeline used in this experiment is made from galvanized steel. The platform was mainly composed of a section of pipeline and an air compressor. A 120 cm long with 11.43 cm diameter pipeline was used in laboratory to test the leak generation at different operational conditions. The internal pressure level is maintained at 500 kPa. There are five valves on each one side of the pipeline with a distance of 20 cm each. These valves represent the artificial leaks. The FBG dynamic pressure transducer was glued on the pipeline's output. The test rig set up is shown in Figure 1.
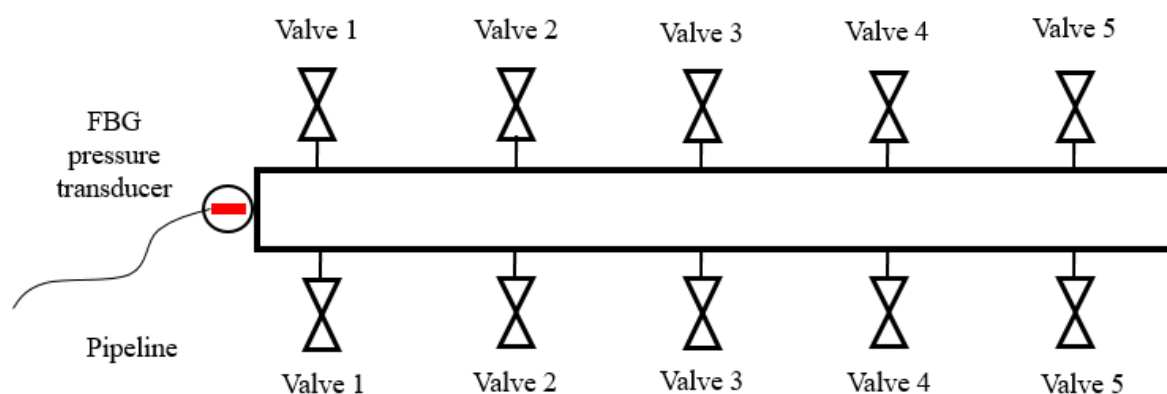
2.2. Experimental work

Firstly, the air compressor was connected to the input of the pipeline and turned on. All of the valves in the pipeline were assured as closed before compressing the air inside of it. The valve on the compressor was turned on and the pressure of the compressor was then adjusted until the value on the pressure gauge showed the value of 5 bar. The pressure gauge on the pipeline was monitored until the value of 5 bar was also shown. After that, the pressure inside the pipeline was let in order to ensure it to be stabilised before turning any valves on. When the pressure gauge on the pipeline showed a constant value of 5 bar, the test was ready to start.

The next step was the setup for NI-DAQ. Then, the output valve was turned on in order to check the signal obtained. After checking whether the graph obtained is correct, the file was saved. For the DASYLab setup, the NI-DAQ was first synchronised with MAX configuration in order to read the output signal in DASYLab. The appropriate module was selected to design the circuit on the worksheet for signal analysis.

For first experiment with 1 mm leak size, the 'start' icon on the DASYLab was pressed before turning on valve 1. Valve 1 was the valve that was the closest to the output and vice versa. Figure 1 shows the schematic arrangement of the valves on the pipe with FBG pressure transducer attached on it. Valve 1 was let to be remained open until the voltage value in the DASYLab return to value 0 V. After that, the valve was turned off. When valve 1 was turned off, the reading on the pressure gauge was checked to make sure that the pressure inside the pipeline has reached a constant value of 5 bar before turning on valve 2. The process of turning on and off the valve was repeated for valve 2, valve 3, valve 4 and valve 5. These steps were also repeated for 2 mm leak test.

Another important parameter to be noted is that since the NI-DAQ has a limited measurement of 5 V, the SNR is set to 20dB in order to get a stable output.

**Figure 1.** Test rig set up

3. Result and discussion

From the experimental works, the voltage drop was monitored using the FBG sensor where it was attached on the pipe wall as explained in section 2. Figure 2 shows the original time domain signal at neutral condition where no loads were applied. The pressure waves in pipe was in steady state condition.
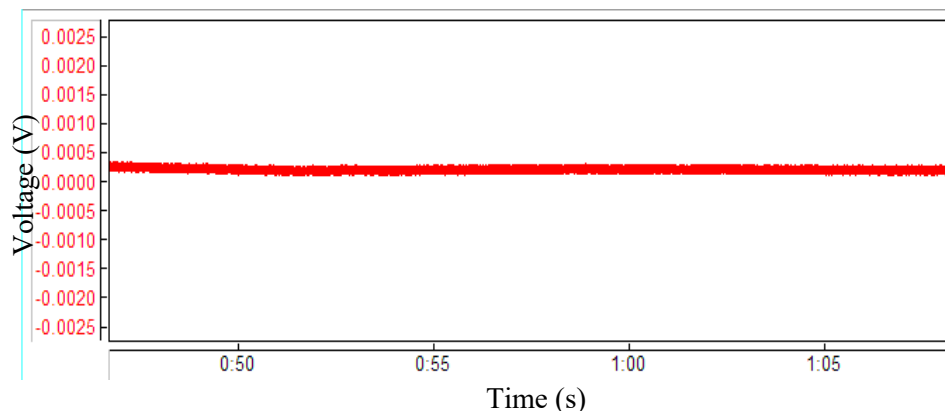
**Figure 2.** Signal at original condition of pipe before any loads were applied on the pipe

After the valve was immediately changed to open position, the spectrum changed as in Figure 3. It can be seen that the voltage dropped at 0.1 s from a steady state at 0 s until certain level and risen up again. This might happen because of the pressure waves changes in the pipes when its original condition was disturbed or changed. It might also have triggered the leak or any flaws in the pipe. Any changes that happen whenever loads were given to the pipe will be sensed by the FBG sensor. However, towards reaching the end of the time windows, the voltage increased and finally became stable as the pressure of the fluid in the pipe was back at steady state again at 0.3 s.

It implies that the FBG sensor can detect and measure any changes, flaws or leakage in the pipe as it is very sensitive to strain changes. One of the factor that representing the dynamic flow behaviour through pipe is the kinetic pressure difference represented by the instantaneous flow acceleration and deceleration [5]. After a fluid flow passing an orifice, the velocity increased abruptly and pressure dropped very rapidly. Pipe leakage may start with small cavitation before it spreads and form a hole that cause leakage. Cavitation is caused by noise, vibration or erosion in the pipelines system. This sudden pressure drop during valve opening explained why the resulting strain of FBG is negative. Less force was exerted on the diaphragm and its deformation resulted to negative FBG strain. This decrement led to the reduction of the output voltage value.
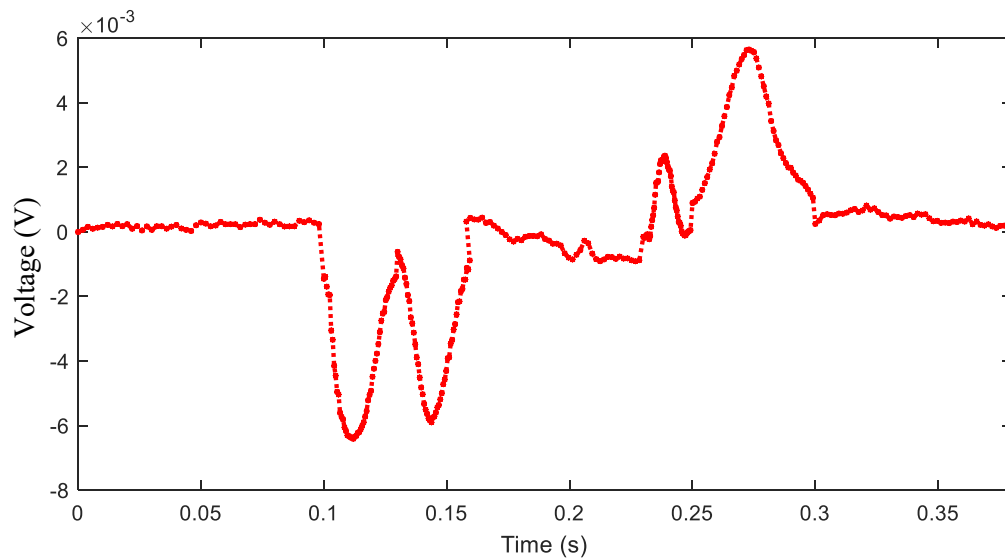
Figure 3. The signal sensed by FBG immediately after sudden valve opening

It was mentioned in section 2 that two holes were introduced on the pipe as artificial leaks of size 1 mm and 2 mm. Figure 4 shows the voltage drop for the size of 1 mm leak for time interval between 0 to 0.35 s. From the results, there were significant difference in voltage drop value between those 2 leak sizes. This can be clearly seen in Figure 4 and Figure 5 that the voltage drop of small and large leak are 0.0017 V and 0.0075 V. It is consistent with the theory that high pressure difference which is in this case was due to leakage will cause deceleration and voltage drop. It also implies that FBG sensor is capable of detecting the pipe leakage according to its level.
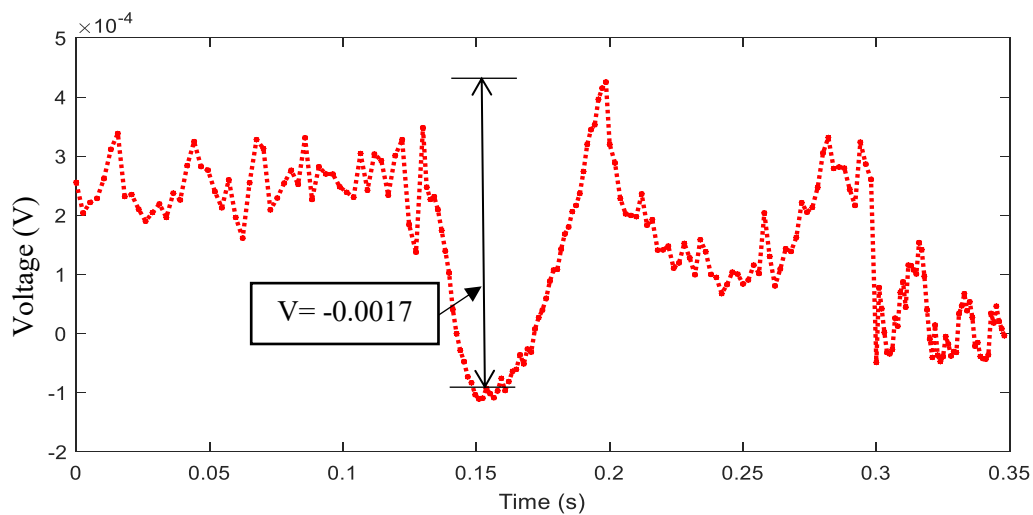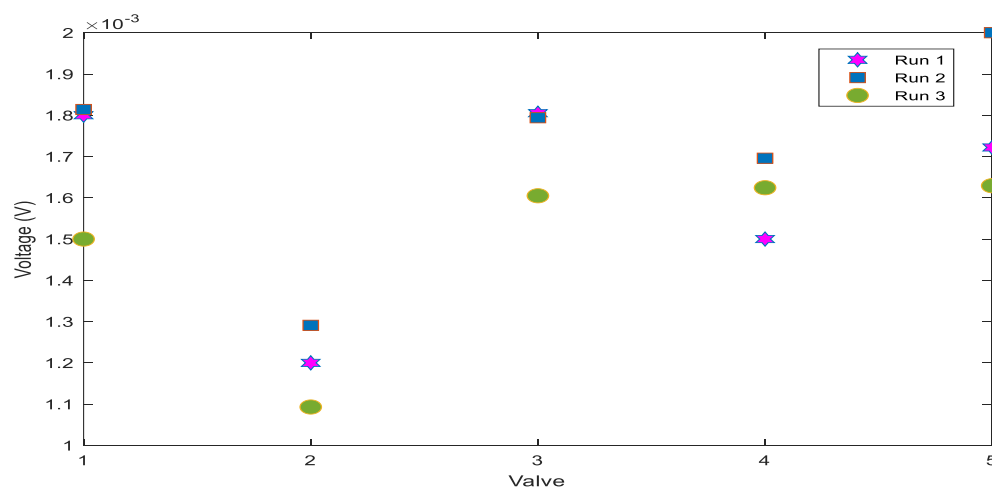

Figure 4. Voltage drop for 1 mm of leak size
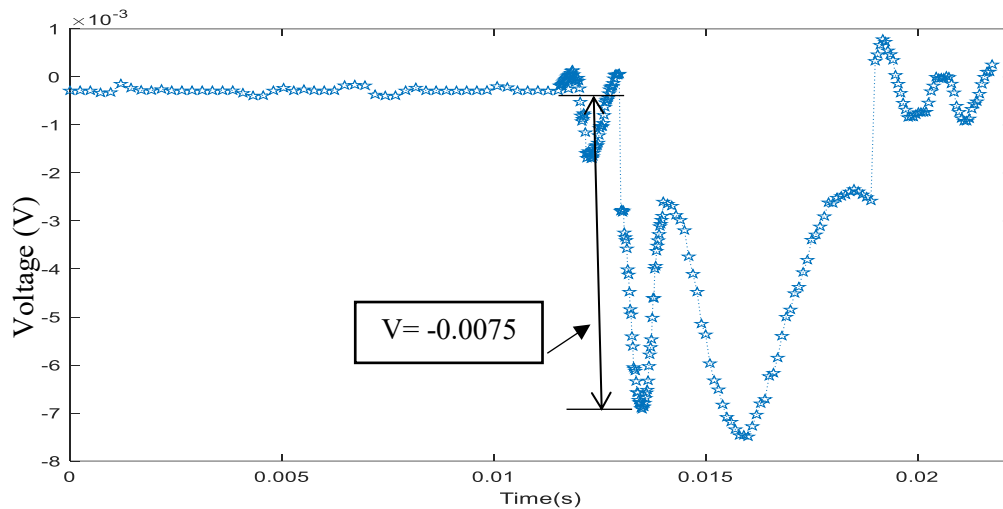
Figure 5. Voltage drop for 2 mm of leak size

Sensitivity is one of the important factors in determining the performance of a leak detection system. However, the comparison between all techniques solely based on sensitivity point of view is hard. Figure 6 and Figure 7 show the voltage variation at 5 different valves for 1 mm and 2 mm leak size, respectively. Referring to table 1, the sensitivity coefficient was 0.0002, 0.0003 and 0.0003 respectively whereas in table 2, the sensitivity coefficient was 0.0008, 0.001 and 0.0008. The sensitivity coefficient was quite consistent for both leak sizes but not very accurate. This results show that FBG sensor has a strong uniformity.

The voltage reading for valve 1 and valve 2 shows a slightly different shapes towards each other. However, starting from valve 3 onwards, the voltage drop is almost linear regardless of distance. The voltage drop for 2 mm leak size is more linear compared to the smaller leak size. This finding shows that distance from the FBG sensor cannot be used as an implication of a good or bad signal readings. It is not reliable to be utilised as a base for the voltage difference calibration for FBG sensor.
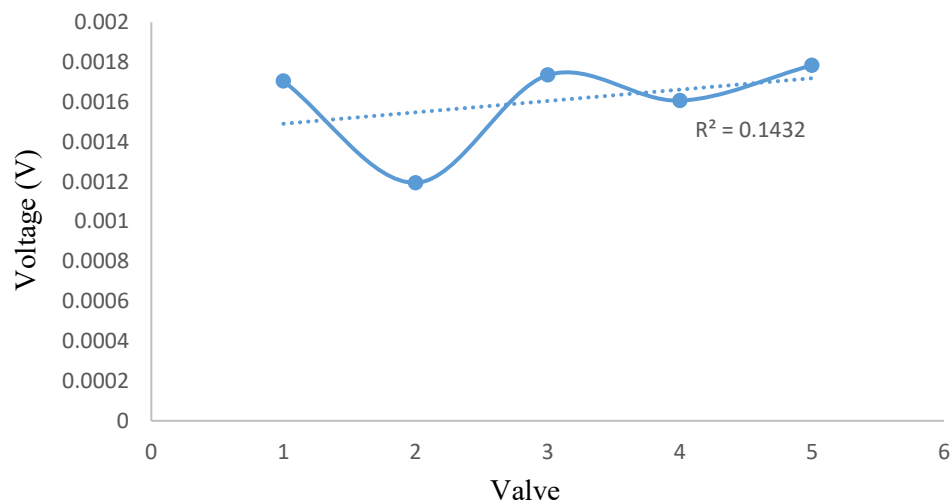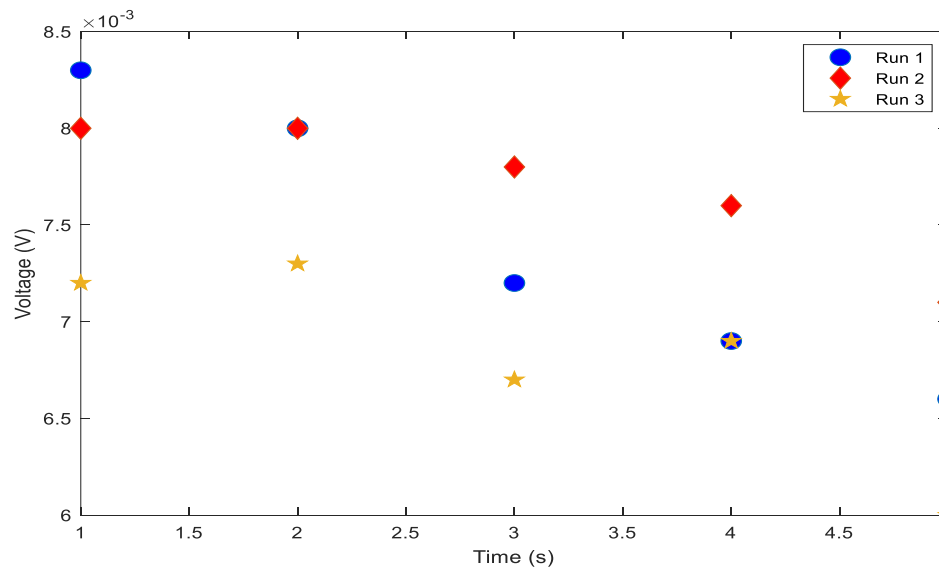

Figure 6. Voltage at 5 different valves for 1 mm of leak size

Table 1. Distance linearity for 1mm leak

No. of run	Linear equation	Regression
1	y = 0.0002x + 0.0007	0.4014
2	y = 0.0003x + 0.0007	0.6194
3	y = 0.0003x + 0.0006	0.5495

Figure 7 shows the average value of all the repeated measurements for the 5 different valves. The regression value for voltage at 1 mm leak size was 14% while for 2 mm leak size was 93%.
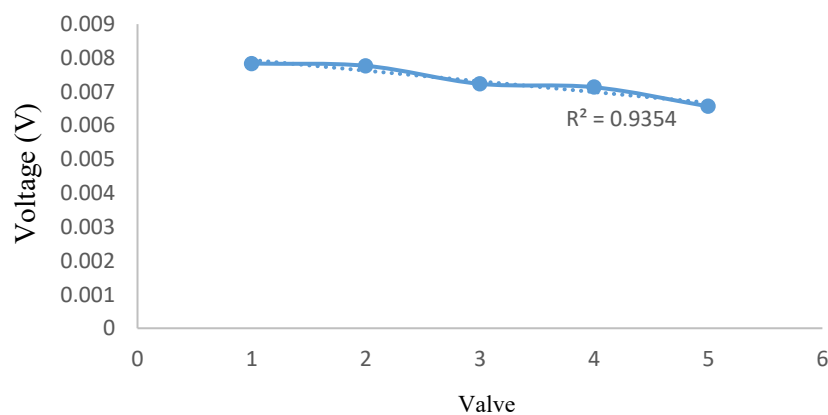

Figure 7. Average value of voltage for 5 different valves

Figure 8. Voltage of 5 different valves for 2 mm of leak size

Table 2. Distance linearity for 2 mm leak

No. of Run	Linear equation	Regression
1	y = 0.0008x + 0.0041	0.2372
2	y = 0.001x + 0.004	0.3324
3	y = 0.0008x + 0.0036	0.2913

Figure 9 Average voltage at 5 different valves

4. Conclusion

From the overall results obtained in this study, it can be concluded the FBG dynamic pressure transducer is applicable and reliable in detecting leak in pipe as it shows significant voltage drop in the event of to leakage variations. The obvious difference in voltage drops could be seen as the bigger leak size contributed to higher voltage drop and vice versa. It is clear that FBG is reliable in detecting the pressure variance in a piping system. Compared to conventional pressure transducer, the signal can be obtained without electromagnetic interference. However, the leak localisation cannot be determined using the

calibration of voltage difference between valves because based on the graph plotted, the voltage drop is almost linear. FBG dynamic pressure transducer is reliable to be utilised as a method to detect and monitor the leak events in the pipelines.

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