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Application of Arrayed Magnetic Sensor Module in Real-Time Monitoring the Leakage of Subsea Pipeline

Yung-Hsu Chen [1], Yan-Kuei Wu [2], Chun-Yen Lee [3], Sheng-Chin Shen [4*]

ABSTRACT

This paper designed a creative method which used YF-S201 hall sensors to build up a monitor system to detect the leakage in subsea pipeline. The research used the hall sensors implemented in the pipeline to monitor a part of flowrate in the pipeline per second to find if there's any leakage in it. Through this system, the location and size of leakage in pipeline can be calculated through Arduino Uno, then will be shown on LabVIEW interface. The theory of this paper is based on the conservation of mass, the experiment result proved that the flowrate of each hall sensor will be in only 10% difference due to error in measurement when there is no leakage in the pipeline. On the contrary, the flowrate will decline obviously when there is leakage in the pipeline. The flowrate will decline 23% and 53% when there is 1.98 cm2 and 5.28 cm2 leakage respectively. Through the change of flowrate, the system can use trend line and water velocity to calculate the size and location of leakage. Furthermore, there's a LabVIEW interface that can present flowrate of each hall sensor and the size and location of leakage clearly. The advantages of this method are economic and accurate. Most importantly, this method, better than ultrasonic guided wave and optical fiber, can be used in different materials and shapes. With this system, the leakage of subsea pipeline will be found and fixed in time. The quality of deep-sea water will also be improved.

Keywords: Hall sensor, Deep-Sea water, Subsea pipeline, Real-Time monitoring

1. INTRODUCTION

This paper used several hall sensors to build up a monitor system to detect the leakage in subsea pipeline. Earthquakes and pipeline corrosion usually cause pipeline to crack, leading to the loss in marine ecosystem and economy (Bolotina et al., 2018). American scientific institution said that lots of leakage detection systems only have 20% efficiency (Aloqaily, 2018). Therefore, designing a system that can detect leakage accurately is an issue worth discussing. There are some techniques used in detecting leakage nowadays, such as ultrasonic guided wave and optical fiber. The common disadvantages of those techniques are high-cost in product making and accuracy being influenced by the shape and material of pipelines (Ho et al., 2020).

To avoid the disadvantages mentioned above, Hydraulic leak detection method, which used flow distribution to tell whether there is a leakage in the pipeline or not, is already raised in 1960 (Wang et al., 2001). Among lots of Hydraulic leak detection methods, using hydraulic pressure to detect the leakage has been mentioned. However, this method is more suitable for finding bigger leakage in the pipeline compared to the smaller one. (Hough, J. E.,1988). Therefore, this research aims to use YF-S201 hall sensors to detect the flowrate and find the leakage at different parts in the pipeline. With YF-S201 hall sensor, the accuracy of the system is mainly based on YF-S201 itself. In other words, the accuracy of the system won't be disturbed by other reasons, such as the shapes and materials of the pipeline (Adegboye, Fung & Karnik, 2019). There is a hall IC on the gear in YF-S201 hall sensor. When the water flows through the sensor, the gear will rotate, which leads to IC output signal, and the computer can use this signal to calculate the flowrate. Hall sensor is widely used in detecting flowrate (Sood, Kaur & Lenka, 2013) and water flow monitoring system nowadays (Gosavi, Gawde & Gosavi, 2017) due to their low cost. In addition, the sensor based on gear has high accuracy. According to the statistics, this kind of sensor is one of the most accurate flow sensors (Kolhare & Thorat, 2013). As a result, this research hopes to use magnetic module based on YF-S201 hall sensors to accurately detect the leakage in subsea pipeline and improve the quality of deep-sea water.

2. EXPERIMENTS

The research used an acrylic tube filled with water to simulate the subsea pipeline, as Fig. 1 shows. There are several YF-S201 hall sensors in the acrylic tube to detect the flowrate in the pipeline. When water flows through the hall sensor, the hall IC on gear rotates and outputs PWM signal. The software can use PWM signal to calculate the flowrate. The research designed a

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[1] Student, Department of Systems and Naval Mechatronic Engineering, National Cheng Kung University, Taiwan R.O.C.

[2] Masters Student, Department of Systems and Naval Mechatronic Engineering, National Cheng Kung University, Taiwan R.O.C.

[3] Ph.D. Student, Department of Systems and Naval Mechatronic Engineering, National Cheng Kung University, Taiwan R.O.C.

[4*] Professor (corresponding author), Department of Systems and Naval Mechatronic Engineering, National Cheng Kung University, Taiwan. (email: scshen@mail.ncku.edu.tw).

LabVIEW human-machine interface shown in Fig. 2, enabling researchers to see the situation of subsea pipelines. The interface is a real-time monitoring interface that shows the flowrate of each sensor per second. Through calculation by software, it also shows the location and size of leakage in the pipeline. In addition, the red warning light in the interface will light up when there is any leakage. By doing so, the researcher can easily keep track of the situation of subsea pipelines. Fig. 3 shows the experiment setup. In the experiment, there is a 250 cm long acrylic tube filled with water and three YF-S201 hall sensors which are placed in a row. The sensors from the left to right are Sensor A, Sensor B, and Sensor C. The diameter of the tube is 10 cm, and the height of hall sensor is 3.5 cm. The water is poured into the tube from the left side of Sensor A with flowrate about 920 L/hr ,1300L/hr, and 1951L/hr, and the pipeline is inclined slightly to avoid the reflow of water. The research also added some blue ink into the water to make the flow field obvious in experiments. Furthermore, in order to stimulate leakages in the pipeline, the researchers used an electric drill to drill some holes in the tube between Sensor A and Sensor B and observed the flowrate of each hall sensor. With this experiment setup, the research aims to verify the feasibility of the system using hall sensors to detect leakage in subsea pipelines.

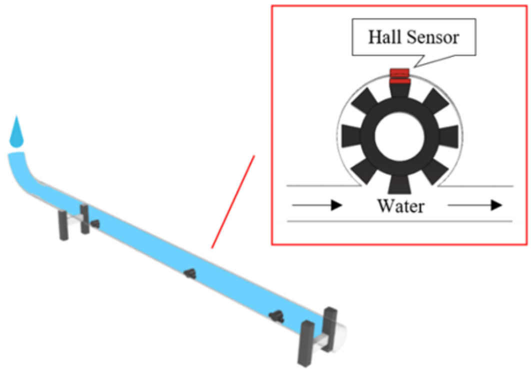

Fig.1 Schematic of hall sensors in the pipeline filled with water

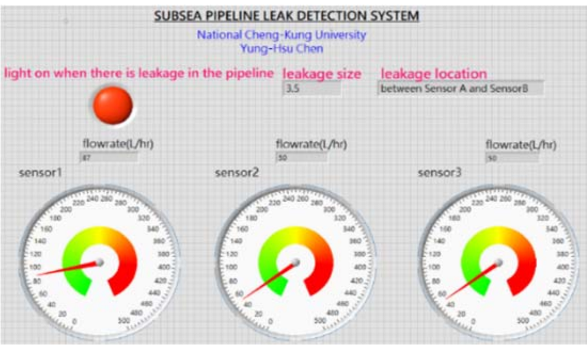

Fig.2 Human-machine interface of subsea pipeline detection system

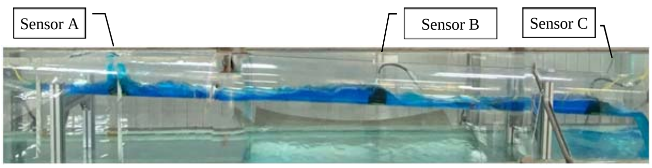

Fig.3 Experimental equipment of miniaturized subsea pipeline with hall sensors

The voltage-related, frequency-related, and flowrate-related are given by the following relations:

The voltage of PWM signal= (making time/total time)* max voltage. (1)

Flowrate of hall sensor(L/hour)= (Gear rotational frequency* 60 / 7.5) (2)

Therefore, the research uses PWM signal to calculate the flowrate in the pipeline.
The research takes pipeline as a system, and uses the conservation of law as follows:

$$\frac{D}{Dt}\int_{sys}\rho dV=\frac{\partial}{\partial t}\rho\, dV+\int_{cs}\rho V\cdot\hat{n}\, dA=0 \quad (3)$$

where A is the cross-sectional area of pipeline, ρ is the density of the fluid, V is control volume, V is average velocity of the fluid, Q is flowrate, and $\dot{m}$ is mass flowrate.
Based on Equation (3), when there isn't any leakage in the pipeline, as Fig. 4 shows, the system can use the equation (4) as follows:

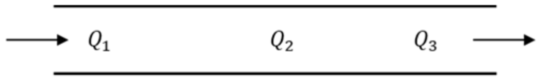

Fig.4 Schematic of pipeline and parameters

$$Q_1= Q_2= Q_3 \quad (4)$$

where Q stands for flowrate in the pipeline.
When there is a leakage in the pipeline, as Fig. 5 shows, the system can use the equation (5) as follows:

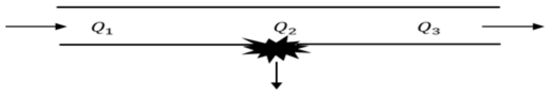

Fig.5 Schematic of broken pipeline and parameters

$$Q_1=Q_2+Q_3 \quad (5)$$

Then put several hall sensors in the pipeline, as Fig. 6 shows. According to many experiments, hall sensors only detect 4.7% flowrate in the pipeline. Therefore, research calculates the flowrate of water through the leakage Q_2^* by the following equation (6):

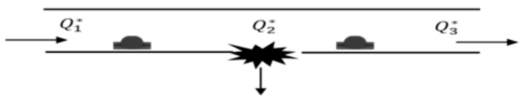

Fig.6 Schematic of broken pipeline with hall sensors and parameters

$$Q_2^*=(Q_3^* -Q_1^*)/0.047 \quad (6)$$

where Q* stands for the flowrate of hall sensors.
And use water velocity V to calculate the size of leakage.

$$A_{leakage}= Q_2^* / V \quad (7)$$

3. RESULTS AND DISCUSSION

This research wants to verify whether the flowrate of hall sensors will be the same when there isn't any leakage in the pipeline. Therefore, we put Sensor A, Sensor B, and Sensor C in the pipeline, and pour water into the tube from the left of Sensor A. The research does every experiment three times; therefore, Fig.7~Fig.9 uses yellow, green, and orange bar charts to show the data in each experiment. The original flowrate in the pipeline is 1300L/hr, Fig.7~Fig.9 shows the flowrate that hall sensors detect under different situations. By doing so, the system can only use the flowrate of hall sensor to tell whether there is any leakage in the pipeline

In Fig. 7, the flowrate of the three hall sensors is 66L/hr in average. In addition, according to the datasheet, YF-S201 hall sensor is specified with an accuracy level of 10% uncertainty. Therefore, the flowrate of the three hall sensors in Figure7 can be seen as the same. With the experiment, we can know there isn't any leakage in the pipeline because the flowrate of hall sensors is approximately the same.

To simulate the leakage in the pipeline, the research uses an electric drill to drill some holes between Sensor A and Sensor B. The holes are approximately 100cm away from the beginning of the pipeline.

According to Fig. 8, when there is 1.98cm2 leakage between Sensor A and Sensor B, the flowrate of Sensor A will be the same as Fig.7; however, the flowrate of Sensor B and Sensor C will decline. The flowrate declines approximately 23% due to the leakage in the pipeline. Thus, through the system, we can tell that there is leakage between Sensor A and Sensor B, and there isn't any leakage between Sensor B and Sensor C, because of the flowrate of Sensor B and Sensor C are approximately the same.

According to Fig. 9, when there is 5.28cm2 leakage between Sensor A and Sensor B, the flowrate of Sensor A will be the same as Fig.7; however, the flowrate of Sensor B and Sensor C will decline even more. The flowrate declines approximately 53% due to the leakage in the pipeline. Thus, through the system, we can tell that there's a bigger leakage between Sensor A and Sensor B, and there isn't any leakage between Sensor B and Sensor C, because the flowrate is approximately in Sensor B and Sensor C.

Fig. 10 shows the variation of flowrate of hall sensors when the size of leakage in the pipeline is different. The experiments poured water with the flowrate about 920L/hr, 1300 L/hr, and 1951 L/hr into the tube. We can see the flowrate decrease as the size of leakage increases. Therefore, the experiment verifies that the system can use flowrate of the hall sensor to tell the size of leakage in the pipeline.

The experiments mentioned above can prove that the location and size of leakage can be told through the flowrate of hall sensors. Through this system the leakage in the subsea pipeline can be found by accurate and low-cost method, which cheaper than ultrasonic guided wave and optical fiber.

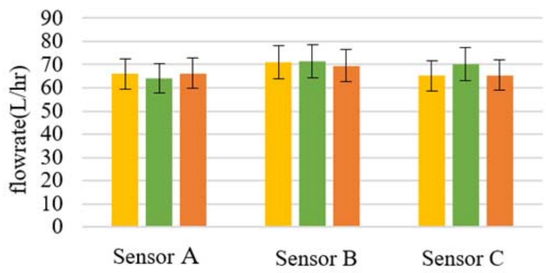

Fig. 7 Flowrate of sensors when there isn't any leakage in the pipeline

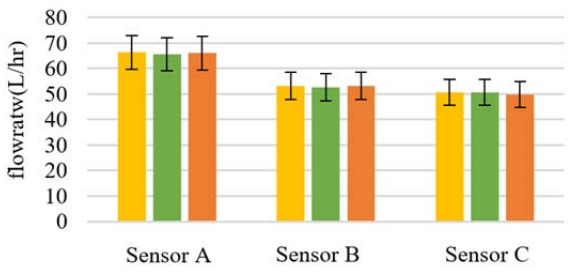

Fig. 8 Flowrate of sensors when there is 1.98 cm2 leakage in the pipeline

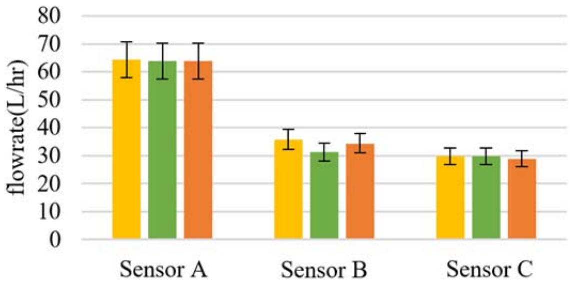

Fig. 9 Flowrate of sensors when there is 5.28 cm2 leakage in the pipeline

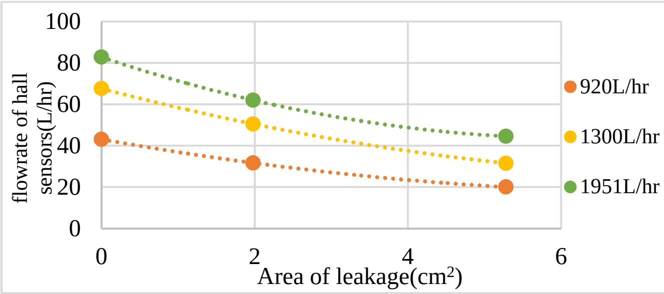

Fig. 10 Variation of flowrate of hall sensors with respect to different size of leakage, for different flowrate in the pipeline

4. CONCLUSION

Through many experiments, the research verifies that the system can use flowrate of hall sensors to tell the location and the size of leakage. When there isn't any leakage in the pipeline, the flowrate of hall sensors will be the same. When there is a leakage in the pipeline, the flowrate of the hall sensor will decline. The bigger the leakage is, the more the flowrate will decline. In addition, through the human-machine interface, researchers can clearly monitor the situation of the pipeline to find the location and the size of leakage as soon as possible. By doing so, the leakage of subsea pipeline will be fixed as soon as possible and the quality of deep-sea water can be improved in the future.

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