Leak Detection in Water Pipe using FSR (Force Sensitive Resistor) Sensor

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***Abstract*— Monitoring of water distribution pipeline infrastructure has a very important role for water companies. In South Sumatra, there are at least three distribution pipe leaks during 2017. Pendopo, Prabumulih, and Pali are districts that are claimed to be prone to pipe leakage. Many techniques have been applied to monitor water distribution networks. This study presents a modification of the FSR sensor and testing for leak detection in water pipes based on changes in pressure on the pipe. The sensor is specially installed without damaging or piercing the test pipe. The test results show that the FSR sensor successfully detects pressure changes due to leakage. This condition is applied to detect water pipe leaks properly.**

***Keywords*— FSR Sensors, Leaking Pipes, Non-Invasive**

I. INTRODUCTION

Pipe leaks are a major problem that is often encountered in the pipeline distribution industry. Many factors are causes such as infrastructure damage, pipe erosion, cracks, inner or outer side corrosion, lack of maintenance, and theft. South Sumatra, for example, has at least three times leaked distribution pipes in 2017. Pendopo, Prabumulih, and Pali are several regencies which are claimed to be prone to leakage caused by two factors, namely corrosion and theft with sawing or tapping [1] [2].

The water pipe network is one of the most important structures for flowing water remotely either from the top of a hill, canal or city to the city [3]. The clean water distribution pipeline network in South Sumatra can reach hundreds of kilometers. This distant transportation distance is of particular concern to be monitored against security threats, pollution problems, environmental impacts and leaks [4]. Pipelines that have been installed at this time often experience leaks due to several factors mentioned earlier. However, the method of knowing and managing it is still fairly manual and ineffective. This is due to the absence of a monitoring system carried out in real time. So that leaky events can be known based on reports from outside parties and prevention takes a long time.

Many researchers have analyzed the above events in various ways, including making a monitoring system with different methods. For example, the use of robots as a leak detection device from the pipe [5] [6]. The results obtained indicate that the system can detect its corruption well, but this system is done by tracing the pipeline from upstream to downstream using a robot so that it requires considerable cost and time. Another example is the use of water flow sensors [7], FSR sensors [8], membrane sensors [9] and others. Just like what is done on a robot, this sensor system is carried out from inside the pipe, making it difficult to use in pipes that have been installed for long.

This research presents a leak detection system without discussing its corruption position. The detection system from the outside of the pipe uses a new innovation sensor from the development of sensors that have been carried out so far. So that this sensor can find out the pipe leak without having to damage the pipe that has been installed for a long time. This template, modified in MS Word 2007 and saved as a “Word 97-2003 Document” for the PC, provides authors with most of the formatting specifications needed for preparing electronic versions of their papers. All standard paper components have been specified for three reasons: (1) ease of use when formatting individual papers, (2) automatic compliance to electronic requirements that facilitate the concurrent or later production of electronic products, and (3) conformity of style throughout a conference proceedings. Margins, column widths, line spacing, and type styles are built-in; examples of the type styles are provided throughout this document and are identified in italic type, within parentheses, following the example. Some components, such as multi-leveled equations, graphics, and tables are not prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

II. RELATED WORK

A. Monitoring Based on Sensors in the pipeline

Monitoring techniques that use these sensors are usually influenced by many factors such as pressure in the pipe, fluid velocity, and also vibration waves when leaking occurs [8]. This technique is usually used on the inside of a pipe where sensors are installed at each inspection station. Some studies that adopt sensors on the inside of the pipe include the flow meter sensor carried out by Gopalakrishnan et al, where this study detects leaks based on flow meter sensor signals. This sensor serves to detect the flow velocity in the pipe so that the sensor is placed inside the upstream and downstream of the pipe [7] [10]. When the sensor detects a difference in speed, the system will get a threshold value where the difference is greater than the threshold, the solenoid valve is inactive and the alarm sounds. When the value is smaller then the pipe is said not to leak. The results of this study indicate that sensors can provide different signals between leaking and not leaking. And the system can save logging data into the cloud via GPRS. The disadvantage of this system is the installation of sensors only at the inspection station so that this system cannot be used for leaking pipes at other stations.

There is also a pipeline leak detection using a Robot-based e-nose sensor [10], MQ-2 [11] gas sensor and piezoresistive sensor [5]. This study detected the position of gas pipeline leakage by walking along the path along the experimental pipeline. When a leak occurs, the robot immediately approaches the leak source. The experimental results show that the robot is able to detect leakage position properly. But this system cannot be used on different distribution pipelines because the shape of the robot and the sensor design are only used in certain cases of leakage. This system also cannot detect leaks in pipes that are fluid in nature.

The research conducted by Wu, et al., 2017 has similarities with research as discussed earlier. The difference is not using robots but placing sensor membranes in the test pipe [9]. The sensor initially moves to the right in the direction of the movement of fluid in the pipe. When leaking occurs, the pressure in the pipe is disrupted so that the sensor membrane experiences a pulling force towards the left. As a result of this attraction, the sensor undergoes a change of motion. This change of motion is used as an indicator of leakage. The test results show that a pipe leak of 4 mm can be detected properly where the average leakage is 5.6 L / min from the experimental pipe pressure 1.7 Bar and flowrate 0.4 m / s. the weakness of this system is that the sensor cannot be used for other pipes because the sensor is static in the pipe being tested.

B. Monitoring Based on Sensors Outside the Pipe

The sensor used in this technique is usually determined by factors of temperature, humidity, the nature of the pipe material used and others. In this technique, leaks can be detected using methods such as the use of visualization, InfraRed (IR), Ground Penetrating Radar (GPR) or reflectometry and other sensors. This monitoring system can be used in various pipeline leak situations and is mobile in nature. For example, the use of IR. To detect leaks investigated by Shakmak and Habaibeh, this is done by approaching the effects of changes in soil temperature humidity due to evaporation [12]. This difference in soil moisture is then detected by IR which is combined using a camera. The camera system that is equipped with IR will be mobilized using a car or drone vehicle. The test results show that the IR sensor can detect leaks based on differences in soil temperature even though it is not clearly visible on the ground. However, this system is very expensive and cannot be used in all distribution channels. This is due to the detection system without direct contact with the testing pipeline.

Pipeline leaks monitored from outside the pipe can also be detected using sensors such as pressure [13], acoustic waves, flow sensors, fiber optics and more. The pressure sensor can read the pressure inside the pipe without having to insert the sensor into the pipe. However, to be able to read the pressure inside the sensor pipe requires a hole in the pipe where this is difficult to apply to a pipe that has been installed for a long time. Whereas on the acoustic sensor detection does not have to pierce the pipe because this sensor system records the sound that occurs in the pipe [14]. The sensor will send a signal using the wireless. The results of the sound spectrum will be sent from the station to the observer server for signal analysis. Kadri et al. Explained that the sound of liquid in the pipe before and after leaking has a significant difference. When leaks the sound recorded by the sensor is greater than before [15]. Based on the results of tests that have been done, it shows that the detection system using acoustic sensors is very good to use on pipes that have long been installed. However, the output of this sensor has a large noise caused by the acoustic sensor that has a very large sensitivity to the sound around it. This makes it difficult to analyze between leak signals with false signals.

This research presents a new innovation from research that has been done [13], which is detecting from the outside of the pipe without damaging the distribution pipe.

III. Framework and Experimental Results

A. The design of the leak detection system scenario

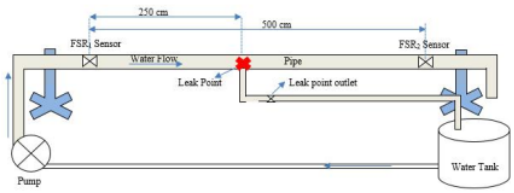

Fig. 1. Design of a pipeline leak installation system [16]; Leak point (**X**) at a position of 250 cm from the side of the upstream pipe, FSR1.2 sensor is installed on the upstream and downstream side of the pipe

This design includes several parts, namely the design of the piping system as a simulation for leakage, the design of the FSR sensor position on the pipe, the design of pipe leak points simulated by the outlet, the design of the pumping device position into the test pipe and shelter design for continuous circulation of pipelines. For more details can be seen in Fig. 1.

Fig. 1 shows that the system scenario was tested on a laboratory scale. The distribution of water into the pipeline uses a water pump with a closed-loop system. Faucets are installed to simulate leaking points and do not leak. The main pipe as a test material using PVC with a diameter of 20 mm. Figure 2 shows the results of installing a pipeline leak installation trial system [13].

Based on Fig. 2, it is explained that the water distribution system as a simulation uses a water pump as shown in figure (a). The test pipe uses 5m of pipe. The circulation of water flow is used by a reservoir as shown in the figure section (b). In figure (c) shows a leak point simulation using a faucet mounted in the middle. FSR sensors are installed non-invasively in the upstream and downstream pipes as shown in figure (d).

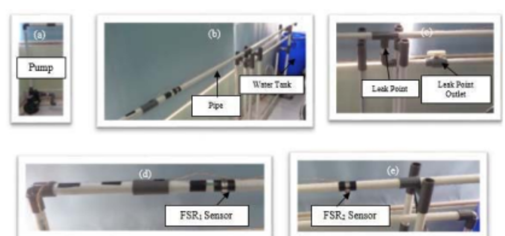

Fig. 2. Results of a Pipe Leakage Experiment Installation System with several main features, namely FSR sensor (d, e), water pump (e), test pipe (b), leakage point (c), reservoir and water media.

B. FSR Sensor Design

This research uses FSR sensors totaling 2 units. The two sensors are used to determine the position of the leak that will be discussed in the next study. For now, only the FSR sensor is able to detect changes in pressure due to leakage both upstream and downstream of the pipeline. Installation of sensors on pipes as shown in Fig. 2. The installation of these sensors is done without damaging or piercing the test (non-invasive) pipe. The design illustration of sensor installation in this pipe can be seen in Fig. 3 below

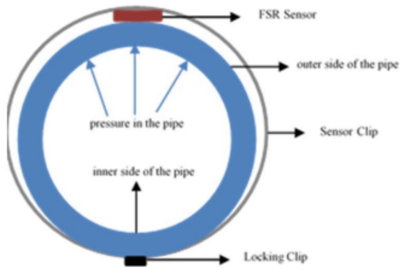

Fig. 3. Installation of the FSR Sensor in the Experiment Pipe

Based on the schematic shown in Fig. 3, the FSR sensor works when there is a change in pressure in the pipe caused by the flow of water being distributed. When the water in a pipe is turbulent, the surface of the pipe is deformed. The deformation in this pipe is a benchmark for FSR sensors to detect changes that occur in the pipe. The FSR sensor is installed on the outside of the pipe with a pipe clip to get a static sensor position. With static conditions, the FSR sensor can properly detect deformation changes from the pipe based on changes in sensor resistance.

Before conducting a direct test of the experimental pipeline. Resistance value The FSR sensor is measured using a multimeter. This test is conducted to determine the level of sensor sensitivity to changes in sensor elements. Testing is done by applying pressure to the sensor element. The results show that the greater the pressure applied, the smaller the resistance value of the sensor. When the sensor is given a very small pressure, the sensor resistance approaches the maximum value of the sensor resistance.

After that, test the sensor output for reading the Arduino ADC. The sensor input pin is connected to a 330ohm resistor as a pull-up voltage. Testing is done to determine the response of the FSR sensor output. The illustration of the sensor circuit can be seen in Fig. 4.

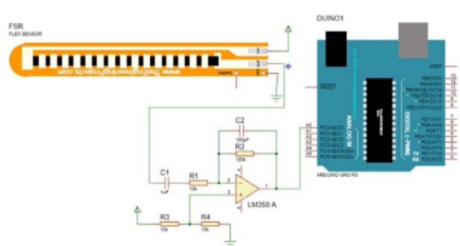

Fig. 4. FSR Sensor circuit with Arduino UNO

The circuit design shown in Figure 4 explains that by using a 330ohm pull-up, the sensor output voltage response is not linear. This is also evidenced in the FSR sensor datasheet shown in Fig. 5.

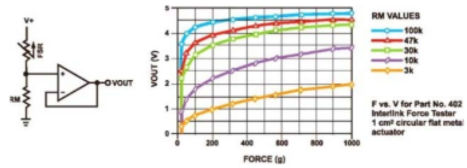

Fig. 5. Sensor Output Response to Force (g); RM values are 100k resistor values; increasing the output voltage results in a greater force value.

To obtain the results of linear sensor output, the FSR sensor of the circuit shown in Fig. 5 added an operational LM 358 amplifier. The RM sensor is used for 100k. Fig. 6 shows a series of LM 358 op-amps.

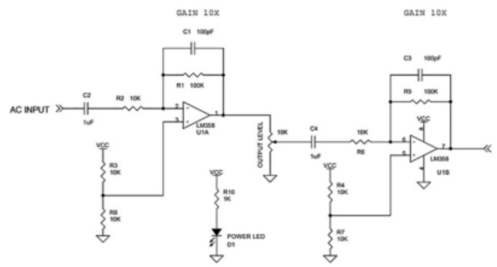

Fig. 6. LM358 Schematic Circuit Module

IV. Leakage Detection

Testing of the FSR sensor includes testing the FSR sensor resistance to pressure, testing the upstream side pressure sensor and the downstream side of the flow not leaking and leaking. The following data are the results of testing of water pipe leaks.

1) FSR Sensor Resistance Test Results

To obtain an accurate sensor output, it is necessary to test the sensor resistance against pressure. Based on the results of the experiment, it was shown that the FSR resistance before getting an external pressure of 6.45 Kohm. When the sensor gets pressure from outside the sensor's resistance turns small. The greater the pressure applied, the sensor resistance value is closer to zero Kohm.

2) FSR Pressure Sensor Test Results

To find out the output voltage generated by the FSR sensor on the change in ADC value on Arduino A.0 port can be obtained by (1)

$$FSR_V = \frac{ADC_{fsr1} \times v_{cc}}{1023} \quad (1)$$

where, FSR_V for the FSR sensor voltage, ADC_{fsr1} is the ADC value generated from each change in both FSR, sensor v_{cc} is the input voltage of ADC and 1023 is the ADC reference value for 10 bits.

The FSR sensor changes in value based on changes in the resistance value of the sensor itself. The resistance of the FSR sensor can be obtained using (2)

$$FSR_R = R\_DIV\left(\frac{V_{cc}}{FSR_V - 1.0}\right) \quad (2)$$

where FSR_R is the sensor resistance and R_ DIV is the resistance of the resistor used in the sensor circuit (3.3Kohm).

Fig. 7 shows the test results for the FSR sensor voltage response of the sensor to the force from the outside shows that the greater the force applied to the sensor, the higher the sensor output voltage. This is in accordance with the sensor datasheet shown in Fig. 7.

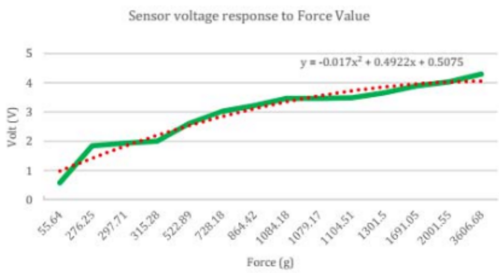

Fig. 7. FSR Sensor Response between Voltage (v) to Force (g); the higher the value of the sensor voltage the higher the resulting force value (line orange), the trendline forms a polynomial with order 2 with the formula y = -0.017x2 + 0.4922x + 0.5075

The FSR sensor output voltage response to the force shown in Fig. 7 shows the similarity of linearity. So it can be easier to convert force into pressure according to the desired output results in this study. The results of this sensor test are divided into several parts, namely testing the sensor against leaks without using amplifiers and testing using an amplifier.

Testing the FSR sensor without an amplifier indicates that the FSR sensor can detect changes in pressure when the outlet is opened as a leak sign. This test graph can be seen in Figure 8 (first test) without using an amplifier when there is a leak; the sensor voltage before leaking ranges from 2.15 - 2.16 volts, the voltage after leaking ranges from 2.14 - 2.15 volts, the leaked simulation starts the data to 1100ms.

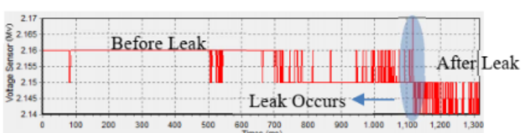

Fig. 8. Graph of FSR sensor output (upstream) without using an amplifier when there is a leak; the sensor voltage before leaking ranged from 2.15 - 2.16 volts, the voltage after leaking ranged from 2.14 - 2.15 volts, the simulation leaked started data to 1100 ms

Based on the graph shown in Fig. 8 proves that the resulting FSR signal can detect changes in pressure caused by inside the pipe. This proves that the FSR sensor can be used to detect pressure in the pipe non-invasively. however, the signal produced is still experiencing fluctuations that are not in accordance with the actual conditions. From several experiments that have been carried out, the results obtained by the FSR sensor have the same pattern, that is, when the pipe leaks the sensor signal will decrease from the state before it leaks. Fig. 9 shows a graph of the test results that have been tested several times.

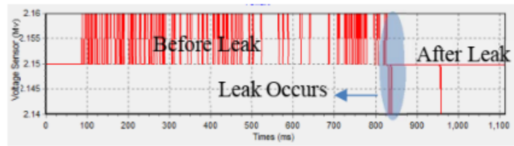

Fig. 9. Graph of FSR (Downstream) sensor output without using an amplifier when there is a leak; the sensor voltage ranges from 2.15 - 2.16 volts (before leaking) and 2.14-2.15 volts (after leaking), leaks occur starting at 830 ms

To overcome the problem of cut off sensor output as shown in Figs. 8 and 9 is to do an additional operational circuit of LM 358 amplifiers which serves to produce a more sensitive sensor signal output. Besides that, it is also a very small sensor voltage signal amplifier so that it can be read properly by the Arduino ADC. The results of tests that have been carried out on the sensor using LM 358 are shown in Fig. 10.

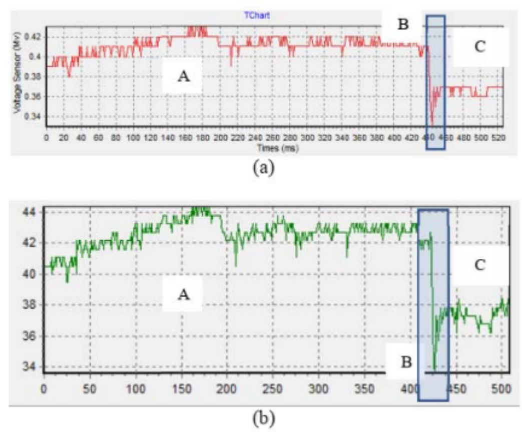

Fig. 10. FSR sensor output signals (a) Upstream and (b) Downstream using Op-Amp LM358; (A) show the phenomenon of pressure fluctuations from the pipe before leaking, (B) are the pressure phenomenon undergoes a significant change which shows as a leaky phenomenon and (C) is an output signal after the leak.

The graph shown in Fig. 10 proves that the FSR sensor can be applied to detect pipeline leaks well. A very significant difference from the output of the FSR sensor to the pressure reading in the pipe is clearly seen between conditions at point A (normal / before leak), B (Leaking) and C (after leaking). However, the signal generated in figure 10 still produces noise in the original signal. A signal filter is needed to get a more accurate and precise sensor signal.

V. Conclusions

The results of the tests conducted in this study prove that the FSR sensor designed using the LM358 operational amplifier can function properly to detect non-invasive water pipe leaks. The installation of sensors in the Upper and Lower parts concludes that more sensitive signal leakage is detected downstream compared to upstream. For further research, the implementation of sensors in the upstream and downstream pipes can be used to predict the position of the leak that occurs using the right method.

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