Using Pressure Sensors towards Pipeline Leakage Detection

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***Abstract*— Pipe leakage is one of the problems became reasonable high cost for the company. Water, Oil, and Gas are natural resources using pipe for media distribution. Leaky pipe occurs caused by many factors such as environment, pipe resistance, illegal tapping and etc. This research aimed to detect leakage of pipes by illegal tapping. Illegal tapping is a theft method to get stabbing or tapping pipeline. Illegal tapping impact of changing in pressure value between the upstream and downstream pipes. Pressure will be changes if sensor detected any irregularly mount on upstream and downstream value in experimental pipe. The result value will processes and analyze using continue wavelet transformation to finding the differences time and frequency. Although the results became measure experiment, that pipeline leaked could be detected.**

***Keywords*— Leaking Pipe, Pressure Sensor, and wavelet transformation**

I. Introduction

Pipeline leakage could causing on many factors, such as environmental, pipe resistance, and theft. The theft, also called illegal tapping, is an act to pierce the pipe. This is serious industrial problems during piped distribution network systems. Along with pipeline distribution network development, many case pipeline leaks does not received a responses from industrial/company to solve this matter. This case is a research concern for human awareness including in terms of utilizing leak state.

Since 2013 many researchers has analyzed with various methods for leakage pipe. Suherman and Wibolo analyzed the leakage of pipes in a approach base on different lengths of pipe specimens state. The results shows that changing in length of the pipe specimen, length of the threaded specimen, and characteristics of the connection became the effect of pipeline leakage [1]. Salman et al in the same year predicted the position of PDAM pipeline leak using Adaptive Splines Threshold Autoregression (ASTAR) method. The results show that the system can only detect in a very small range of 0.001 to 0.6 L / s [2].

Pipeline leakage signals can be detected based on changes value as water flow and pressure inside the pipe. The signal was generated using flowrate and pressure sensors. R. F Rahmat, et al 2016 developed a monitoring system based on sensor flow in real time. The sensor signal is used to determine the location of the leak that occurs[3]. According Hariyanto et al leaks can be detected and analyzed based on the difference in water flow in and out [4]. The research was conducted on small-scale pipes with the ratio of water discharge where the smaller the comparison the further the point of leakage. In addition to the water flow, a pressure in the pipeline became parameter to detect leakage of the pipe. The pressure inside the pipe will remain continuously stable as long as the pipe not leakage. While leakage of water discharge is not only reduced but also the pressure of the pipe decreased significantly [5].

Based on these pressure value changes, this research developed by leaking pipeline detection monitoring system using two pressure sensors in real time. Both of pressure value changes will be analyze using the Wavelet Transform Method. Althougth this system implementation for repair practical, fast processing, accurate and low cost.

II. Theory for Leak Detection

A. Wavelet Transform

Wavelet is defined as a small wave that concern in energy consumption over a limited time [6] and to analyze the changing values occurs over time span. The conversion function using divide function or signal into different frequency components, which in turn became measurement value according to scale transformation. This is called a wavelet transform.

Frequency distribution and time when leakage can be detected and analyzed using continues wavelet transform (CWT). CWT is define as time and frequency domain decomposition method where the convolution process between signal x (t) with a window function. The window function and scale can change at any time. The window function is the mother wavelet which is the basic function of the wavelet. Mother wavelet is the basic function used in wavelet transformation by translation and scaling [7][8]. Mathematically the CWT of a signal x (t) calculated by (1).

$$CWT_x^{\psi}(\tau, s) = \psi_x^{\psi}(\tau, s) = \frac{1}{\sqrt{|s|}} \int_{-\infty}^{\infty} x(t).\psi^*\left(\frac{t-\tau}{s}\right)dt \quad (1)$$

where S show the value of scale is inversely proportional to frequency, τ is a time shift that indicates shifting or translational mother wavelet and $\psi^*\left(\frac{t-\tau}{s}\right)$ shows the mother wavelet.

If ($\tau > 1$) then the wavelet function ψ stretches along the time axis, and if ($\tau < 1$) and is positive then the wavelet function ψ will narrow. when τ is negative then it can cause the wavelet function to turn around in the direction of the time axis. The symbol (*) indicates that the operation of complex conjugate numbers, as well as $\frac{1}{|\sqrt{S}|}$ for the normalization of the τ and S values that have the same energy.

B. *The Pressure*

The fluid flow in a pipe could be measured based on the pressure value changes inside the pipe. Pressure is forcing per unit area of the surrounding fluid. This measurement technique can be done based on Bernoulli's law. The basic principle of Bernoulli's law of continuity as shown in Fig. 1.

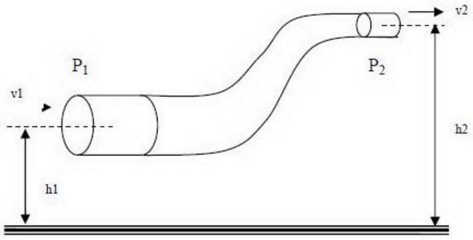

Fig. 1. The Principle of Bernoulli's Law

Based on Fig. 1, can be proved that the relationship between the pressure of the fluid flowing in a pipe is shown in (2),

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho.g.h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho.g.h_2 \qquad (2)$$

where P as the fluid pressure in the pipeline, ρ is the density of the fluid, v is the fluid velocity, g is gravity and h is the height of the fluid from the surface.

C. *Filter Design*

Filter design is used to reduce the fluctuations in pressure sensor signals. This is due to the amount of noise in the pressure sensor signal. The moving average filter (MAV) is one of many filters that can reduce noise from the sensor signal. The MAV filter process is based on the size of the window value. The value of the MAV window will have an impact on the large phase as well. This may impact the change of sensor signal value. To overcome this problem can be done so that the value of the phase back as before. This process is called zero lag. This zero lag value is obtained from the filtering of the pre-made MAV so that zero lag can produce excellent filters.

III. THE EXPERIMENTAL WORK

This study consists of several research methodologies which are designing a pipeline leak detection system, designed the testing pipeline pressure sensors, pressure sensor testing upstream and downstream parts, pressure sensor signal testing, testing methods of wavelet transform in signal processing of leakage.

A. *Designing Detector Pipe Leaks*

The design stage of this section consists of several parts such as the design of the piping system as a simulation system for leakage, the design of the leak point position on the pipe, the design of the pipe point simulated by the faucet, the installation of the pumping equipment into the test pipe and the design of the shelter for flow circulation pipe continuously. For more details see Fig. 2.

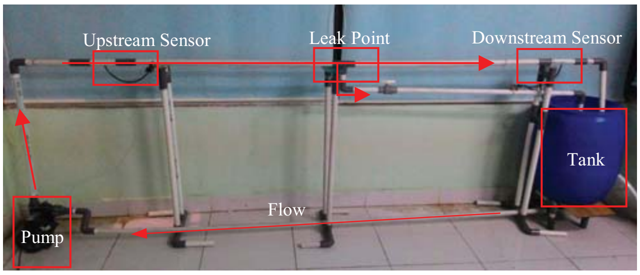

Fig. 2. Installation Systems Pipe Leaks

In the initial conditions, the pump will distribute water into the main pipe. After a while, the system monitors the pressure inside the pipe. The pressure generated from upstream sensors and downstream sensors. Both sensors will produce the same pressure if the pipe condition is in normal condition.

B. *Design of Pressure Sensors*

Both sensors are installed in the upstream and downstream pipes. The power supply circuit of the sensor is designed with a filter. This circuit is designed based on the recommendation of the pressure sensor datasheet. Figure 3 shows Upstream and downstream sensor supply circuits.

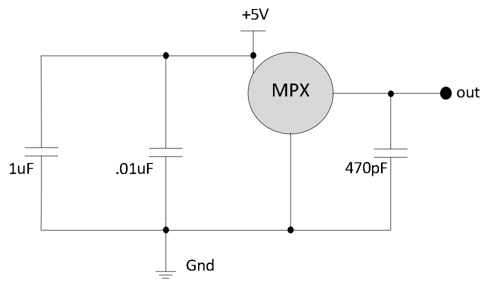

Fig. 3. Power Supply circuit Upstream and downstream sensors

C. *Pressure Sensor Testing*

This stage tests the two sensors that have been installed properly on the piping system. The distance between the two sensors influences the pressure inside the pipe. Figure 4 shows the block diagram testing the sensor output voltage.

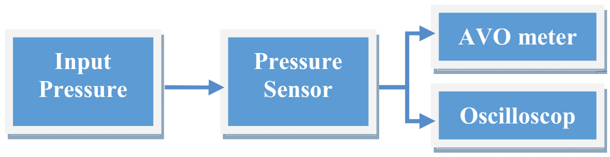

Fig. 4. Block diagram testing pressure sensor output

The test is performed to obtain the output voltage characteristics of both pressure sensors against different pipe pressure. The sensor output is connected to the microcontroller ADC to generate digital data. The sensor signal conversion generates graphs using computer visualization. The block diagram of this pressure sensor testing can be seen in Fig 5.

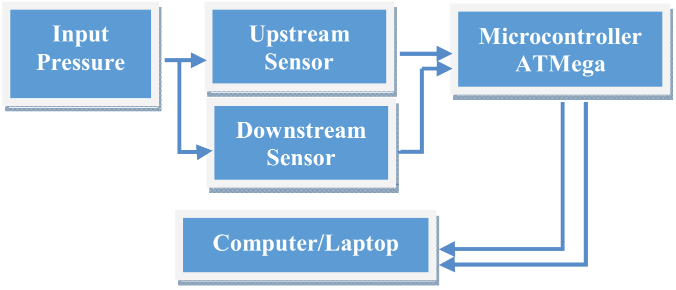

Fig. 5. The Block Diagram Testing Both of Pressure Sensors

At this stage, the pressure sensor is applied to the water-test pipe. The pressure sensor will detect the pressure changes that occur inside the test tube.

IV. Result

The experimental procedure is performed on upstream and downstream pressure sensors on leaking pipes and non-leaking pipes. The experimental pipe is 22mm in diameter with a pipe length of ± 300cm and the leakage distance to the measuring point (upstream) is 150cm. Here are the results of experimental data on upstream and downstream pressure sensors.

A. *Testing Pressure Sensor Upstream and Downstream*

The experimental results have shown that the upstream and downstream pressure sensor has an output voltage between 0.212V up to 0.26V. The sensor voltage output is obtained based on the 10bit ADC value change by using (3).

$$V_{12} = \frac{adc_{12}\, x\, v_s}{1023} \tag{3}$$

where, V_{12} is the output voltage of the upstream and downstream pressure sensor, adc_{12} is the ADC value of the upstream and downstream sensor, Vs is the initial voltage.

Table I and table II shows the measurement data of upstream and downstream pressure sensors. Based on the data table I and table II shows that the change in ADC_{12} value is proportional to the output of the pressure sensor.

TABLE I. Upstream Pressure Sensor Measurement Data

ADC_1 Value (bit)	The output of sensor upstream (volt)
39	0.201
40	0.216
41	0.219
42	0.224
43	0.229
44	0.234

TABLE II. Downstream Pressure Sensor Measurement Data

Nilai ADC_2 (bit)	The output of sensor downstream (volt)
39	0.22
40	0.225
41	0.229
42	0.234
43	0.239
44	0.249

As the ADC_{12} value increases causing the sensor voltage to rise. Figure 6 and Figure 7 shows the upstream and downstream sensor output response to the ADC_{12} value.

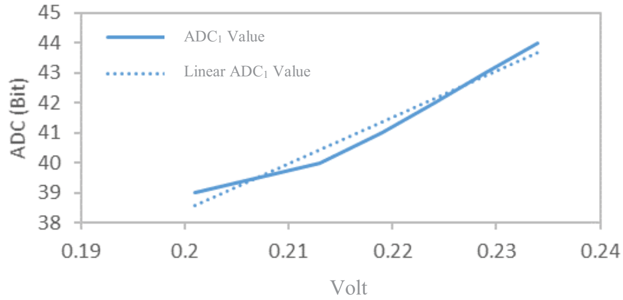

Fig. 6. Response Output Sensor upstream to the ADC_1 Value.

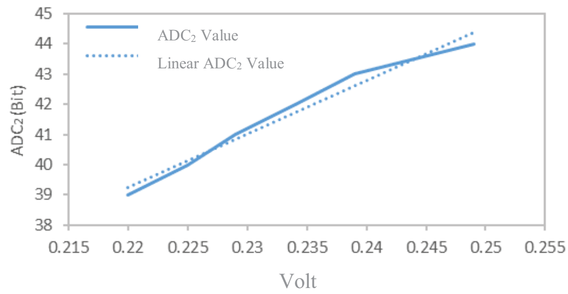

Fig. 7. Response Output Sensor Downstream to the ADC_2 Value.

B. *Testing Point of Leakage*

The experiments performed at this stage are by opening and closing the faucet stop on the pipe test. The initial phase of water is distributed into the main pipe for several minutes using the pump. This process shows the level of stability of both sensors when detecting pressure on non-leaking conditions. If the system is functioning properly then subsequently open the stop faucet that has been designed as a leak condition as shown in Fig 2. Table III shows the leak point testing data.

TABLE III. Point of Leakage Testing Data

Time (s)	Output Sensor Up (kPa)	Output sensor Down (kPa)
0.01	0.986	0.848
0.02	0.986	0.848
0.05	0.966	0.828
...	...	...
59.97	0.67	0.453
59.98	0.789	0.512
59.99	0.789	0.512
60	0.789	0.512
60.01	0.848	0.749
60.02	0.848	0.749
60.03	0.848	0.749
...	...	...
120.21	0.927	0.729
120.22	0.927	0.729

Data from the testing that has been done for 120 minutes as shown in Table 3 prove that sensor data from the pressure decreases an average of 0.84 kPa to 0:45 kPa minute 50-60 minutes (shown in red). This proves that the leak has occurred at a time when it is assumed as a point of leakage. Fig 8 below shows the results of testing of leak points.

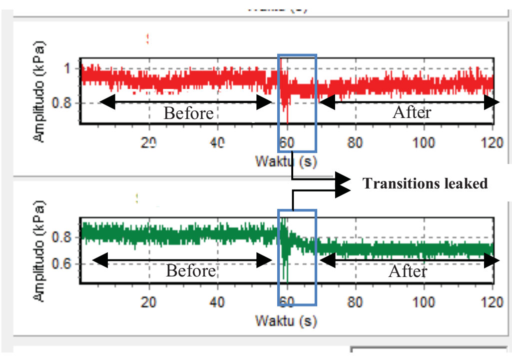

Fig. 8. Results of testing the leak point

Fig 8 proves that the pressure signal on the upstream sensor (Red color) and downstream (Green color) decreases the pressure so that it is said to be leaking pipe. The signal generated in Fig 7 is the original pressure signal that has noise. To reduce the noise then do the filtering using moving average. The result of the moving average filter can be seen in Fig 9.

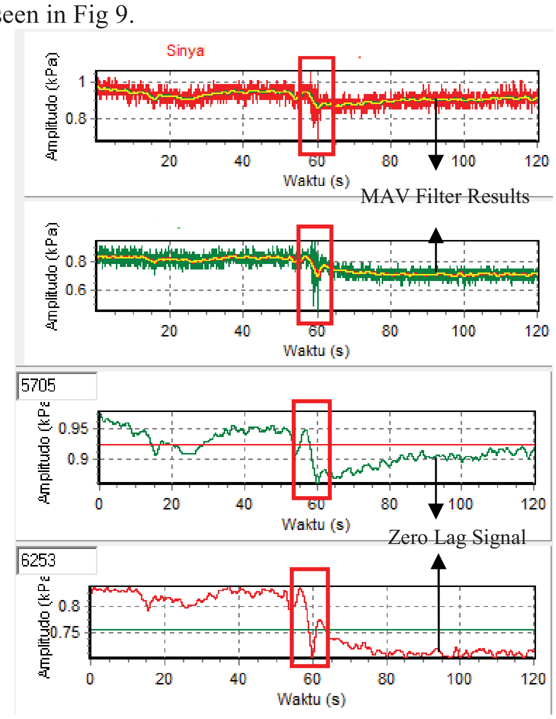

Fig. 9. Results of Signal Filter Moving Average

The filter is shown in Fig 9 is then analyzed using the continuous wavelet transform (CWT) method. Results from CWT indicate frequency difference before and after leakage. The CWT segmentation results are plotted based on signals that have passed the moving average filter. Figure 10 shows the CWT results of the upstream sensor signal.

Based on Figure 10 the most dominant frequency in leakage condition to upstream sensor signal is ±4.71 Hz on a scale of 8 with reference by (1).

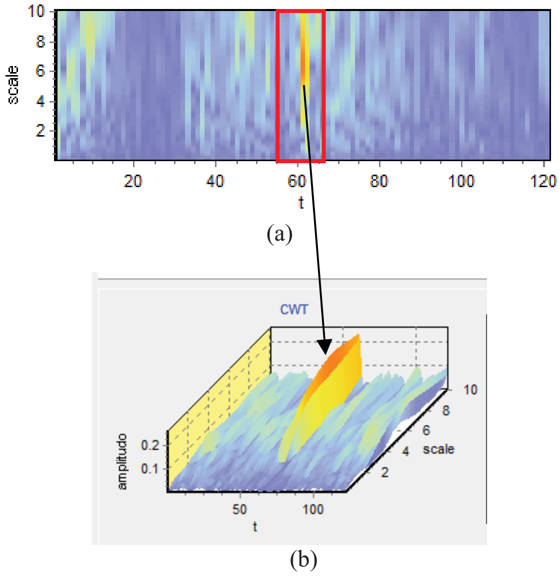

Fig. 10. CWT extraction results on upstream sensor signals; 2D shape (a), 3D shape (b)

V. Conclusions

The experiment result proves that the pipe leakage detection system can be identified correctly based on the pressure difference between the two sensors (see Table III). During that pipe obtains leaking the pressure in the pipe decreases. When there is no leakage the pressure remains stable (see Fig.8). That also can be analyzed using the CWT method. The experiment results represent that frequency during leakage always become smaller rather than frequency before it leaks (see Fig.10).

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