Pressure and Flow Control System to Prevent Drinking Water Pipe Leaks

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***Abstract*– The distribution of water through pipes experienced an average water loss of 35%. This is caused by a lack of pipe management, measurement tool management, and pressure management. In this study, a drinking water company miniplant was made using PVC pipe as a simulation to show the action of the solenoid valve as a pressure controller and water flow rate against leakage. This study monitors pressure differences and flow rates. Global valve acts as an actuator to control flow pressure while ball valve acts as an actuator to control flow rate. The results of the validation of the pressure sensor, on average the four sensors produce an accuracy of 99.587% and an inaccuracy of 0.413%. The results of the flow sensor validation, the average of the four sensors produces an accuracy of 97.558% and an inaccuracy of 2.442%. The results of system testing on the solenoid valve pressure control, work according to the set point in controlling pressure. The results of system testing on the solenoid valve pipe leakage control, work according to the set point in controlling pipe leakage but the ratio is high. The ratio is too high because the flow after the solenoid valve is getting slower, but the flow before the solenoid valve is still moving to fill the empty space in the pipe until there is no water flow.**

***Keywords*–Flow, Leakage, Pressure, PVC pipe, Solenoid valve**

I. INTRODUCTION

Drinking water companies are needed in areas that lack clean water because the water is polluted, especially in urban areas [1]. Serving and distributing clean water to customers requires a distribution network. Maintenance of the water distribution network is very necessary to ensure the distribution of drinking water runs effectively and efficiently until it reaches the customer [2]. Water distribution requires a pipe with pressurized water. A pump is needed to press the water so that the water flow rate will rise so that it can move smoothly. High pressure can cause pipe leakage [3]. According to the Head of the Implementation of the Drinking Water Supply System Improvement Agency (BPPSPAM) and the Director of Drinking Water Supply System Development, that water loss in PDAM throughout Indonesia is mostly due to old or corroded pipes, inaccurate measurements in water meters, and pressure management [4-5]. The drinking water company pipe leaks that were piled under the highway, causing potholes and flooding the road. Holes in highways from PDAM pipe leaks can create accident-prone areas [6]. If the leak is left for a long time it will be very detrimental. The longer the leak is known, the more fluid will be wasted which results in financial losses for the company if the pipe leaks before the customer's meter and financial losses for the customer if the pipe leaks after the customer's meter [7].

In several previous studies, as written by Ni Wawan Sumartini S. entitled "Web-Based Water Pressure Monitoring System at PDAM Gianyar", created a web-based pressure monitoring system to get pressure information faster. Monitoring can be done directly through a manometer, by officers or admins [8].

In another study by Caspar V. C. Geelen entitled "Monitoring Support for Water Distribution Systems based on Pressure Sensor Data", the system evaluates pipe leaks by observing pressure patterns [9]. In a study by Maharani Anastasya Sukmawardini entitled "Hydraulic Evaluation of Beber Syste's Water Distribution Networks of PDAM Tirta Jati Cirebon", made a hydraulic evaluation, and provided recommendations for improvements to the Beber SPAM distribution piping network system using EPANET 2.0. The recommendations offered are adding a pressure reducing valve to pipes that have high pressure and making the district meter area (DMA) method, zoning and installing a water meter to detect leaks [10].

From previous research, the researchers took this topic because of the importance of valve selection in pressure management and preventing leakage. Researchers will make a drinking water company miniplant in pressure management before and after the customer's home meter. The valve used before the meter is a solenoid valve to control the pressure and flow automatically [11]. Valves after branching pipes or before the customer's house meter used is a globe valve and a ball valve to show a comparison of their performance in controlling pressure and flow rate. This miniplant focuses on pressure management before and after the customer's home meter and controlling the flow against pipe leaks that can result in financial losses. The pressure is measured using the SKU237545 pressure sensor which is connected to the microcontroller so that the sensor readings can be displayed [12]. In the miniplant there is a YF-S201 flow sensor to determine the amount of water flowing in the pipe [13]. The solenoid valve is connected to the pressure and flow sensor using an on-off control system. The way the solenoid valve works on this miniplant is that if the pressure drops, the valve will open until the pressure reaches the set point of ±10 psi when the flow is compressed, or the valve is closed. The solenoid valve will close if the level of leakage in the pipe after the solenoid valve and before the sensor reaches 20%. This research is expected to help the problem of pressure and flow management in the process of detecting variations in pipe leaks.

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II. METHOD

A. Component and Control System Design

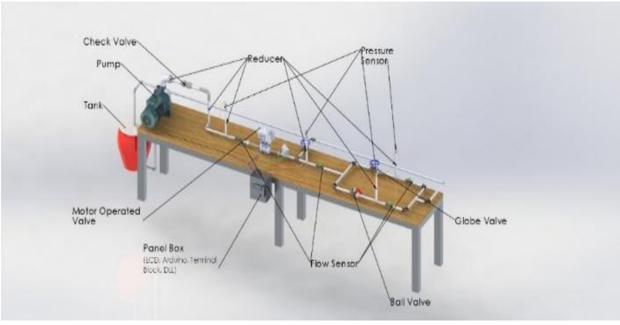

Figure 1. Three-Dimensional Design Components

The three-dimensional design of this study shows some equipment, including the water tank above the ground and other components on the table. On the table there are pipes, pumps, valves, sensors, and panel boxes. The fluid flow starts from the water tank as an inlet to the miniplant with a tank volume of 30 L. The water in the tank will be pumped using a 1-inch pipe to the check valve to prevent back pressure which can damage the pump. Water that passes through the check valve will pass through the ball valve to reduce water flow so that it does not fill the pipe too quickly. Then the water will go through a reducer which will reduce the pipe from 1 inch to half an inch which has been installed with a pressure sensor and a flow sensor. The water that has been measured by the pressure sensor and the first flow sensor will go through the solenoid valve. Solenoid valve for regulating flow and pressure so that it matches the set point or has a pressure of ±10 psi [14] when the water is compressed, or the valve is closed. The flow rate set point is the difference in flow rate at the first and second sensors, the difference is due to a leak. The difference in flow rate on the first and second sensors is 20%. To find out the pressure and flow of water has reached the set point by placing a pressure sensor and flow sensor after the solenoid valve. Controlling the pressure and flow rate using the microcontroller in the panel box. The panel box contains an Arduino Mega microcontroller, I2C LCD, and electrical wiring. The water that is regulated according to this research will go through a branching pipe in which there is a different valve in the pipe. Placing different valves in the form of globe valves and ball valves aims to compare the performance in holding pressure and regulating the water flow. The performance of the two valves is evidenced by two sensors after the valve, the pressure sensor, and the flow rate sensor. Water from branching pipes installed by different valves will be mixed and go to the water tank.

A detailed explanation of the electrical wiring system can be seen in Figure 2. Figure 2 explains that all components except the solenoid valve use 5V DC voltage. The solenoid valve uses a 12V DC voltage. The pressure sensor has an analog output signal so that it is connected to the microcontroller analog pin. The flow rate sensor has a digital output signal so that it is connected to the microcontroller digital interrupt pin. The 20x4 I2C LCD uses a digital signal on the output signal so that it is connected to a special pin for the lcd, namely SDA and SCL microcontrollers. The buzzer is mounted on the digital pin. The relay is connected to the digital pin and the solenoid valve is connected to the relay pin at COM and ground from the power supply.

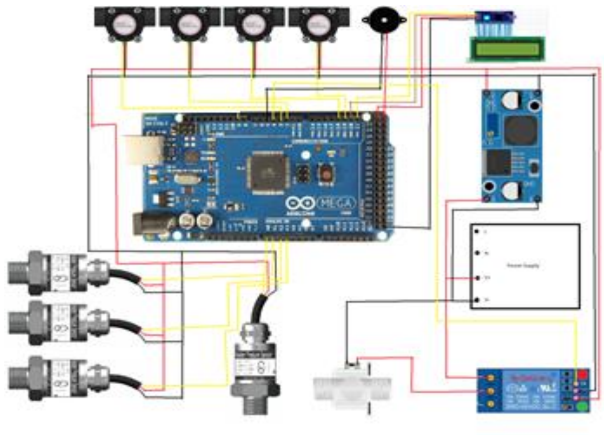

Figure 2. Electrical Wiring Design

The control block diagram starts from the input of the physical quantity of pressure and flow rate through consideration or error correction which means that there is a measurement variable setting. Physical quantities (inputs) will be controlled using the Arduino Mega microcontroller which will be used in this study. The microcontroller gets the value of the electrical quantity to make error correction from the pressure and flow rate sensor [15]. Sensors convert physical quantities into electrical quantities [16-17]. The microcontroller will send a command signal in the form of an electric quantity to the actuator on the PDAM miniplant in the form of a solenoid valve. The output is the pressure and flow rate according to the setpoint.

The set point of the flow rate parameter is the calculation of the water loss up to 20%. If it is less than 20%, then the solenoid valve is fully open. While more than 20%, the solenoid valve becomes full close. The pressure parameter set point is a pressure of 10 psi. If it is more than 10 psi, then the solenoid valve is fully closed. While the pressure is less than 10 psi the solenoid valve is fully open. Each parameter and leak status will be sent a signal to the display in the form of a 20x4 I2C LCD as a Graphic User Interface (GUI) so that it can be seen by observers.

III. RESULTS AND DISCUSSION

A. Sensor Test Results

1) SKU237545 Pressure Sensor Validation

Pressure sensor testing is carried out to validate the sensor measurement results with a digital pressure gauge as a validator for comparison of sensors to get sensor accuracy. The test is carried out by pumping water in the tank into a pipe that has a pressure sensor installed with a validator as the tool being tested and a globe valve as a pressure variation provider. The globe valve is fully closed then water is pumped into the pipe so there is pressurized water in the pipe. The next variation is to open the globe valve and then close it again until the water pressure in the pipe runs out.

The test was carried out three times with seven times data collection. There are four pressure sensors located before the solenoid valve, after the solenoid valve and the leak point, after the ball valve, and after the globe valve. The pressure sensor readings listed are the average of three repetitions.

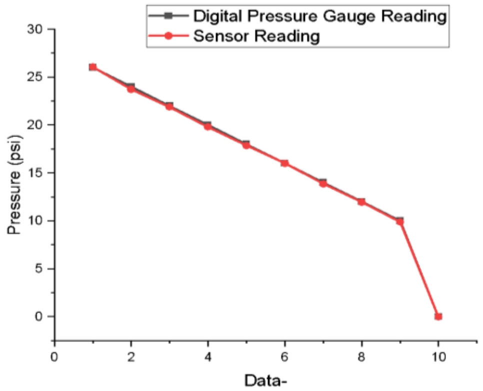

Figure 3. Pressure Sensor Validation Hart, Before Solenoid Valve

Based on Figure 3, the pressure sensor before the solenoid valve has an average accuracy of 99.421% and an average inaccuracy value of 0.579%. The inaccuracy of the pressure sensor is still below the limit of the inaccuracy value in the datasheet of 1.5%, so that the pressure sensor is still considered valid.

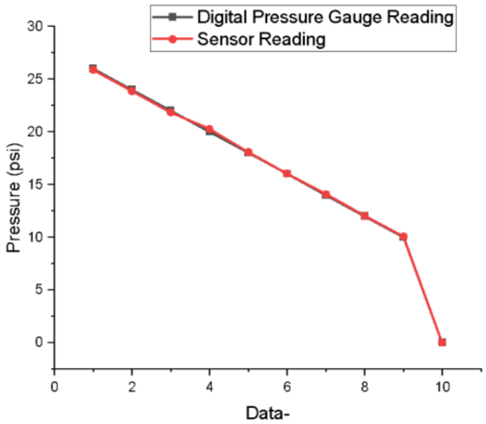

Figure 4. Pressure Sensor Validation Chart, After Solenoid Valve

Based on Figure 4, the pressure sensor after the solenoid valve has an average accuracy value of 99.484% and an average inaccuracy value of 0.516%. The inaccuracy of the pressure sensor is still below the limit of the inaccuracy value in the datasheet of 1.5%, so that the pressure sensor is still considered valid.

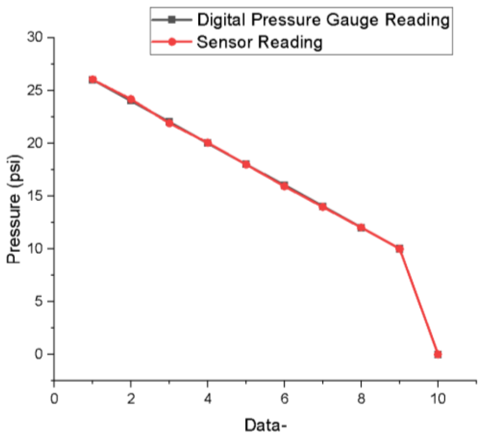

Figure 5. Pressure Sensor Validation Chart, After Globe Valve

Based on Figure 5, the pressure sensor after the globe valve has an average accuracy of 99.708% and an average inaccuracy value of 0.292%. The inaccuracy of the pressure sensor is still below the limit of the inaccuracy value in the datasheet of 1.5%, so the pressure sensor is still considered valid.

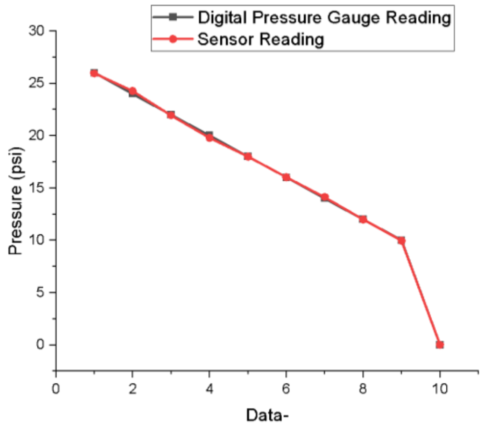

Figure 6. Pressure Sensor Validation Chart, After Ball Valve

Based on Figure 6, the pressure sensor after the ball valve has an average accuracy of 99.556% and an average inaccuracy value of 0.444%. The inaccuracy of the pressure sensor is still below the limit of the inaccuracy value in the datasheet of 1.5%, so that the pressure sensor is still considered valid.

2) YF-S201 Flow Rate Sensor Validation

Flow rate sensor test to validate sensor measurement results with flowmeter K24 as a comparison validator so that sensor accuracy is obtained [1]. The test is carried out by pumping water in the tank into a pipe that has a pressure sensor installed and a validator as the tool being tested, with a globe valve as a flow rate variation provider. The first step is to fully close the globe valve and then pump water into the pipe so that the pipe is filled with water. The next variation is to open the globe valve with various valve openings.

The test was carried out three times and data were collected six times, with four flow rate sensors located before the solenoid valve, after the solenoid valve and the leak point, after the ball valve, and after the globe valve. The sensor and validator readings listed are the average of three repetitions.

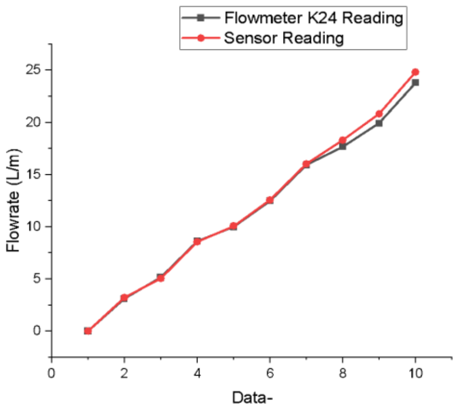

Figure 7. Flow Rate Sensor Validation Chart, Before Solenoid Valve

Based on Figure 7, the flow rate sensor before the solenoid valve has an average accuracy of 97.764% and an average inaccuracy value of 2.236%. The inaccuracy of the flow rate sensor is still below the limit of the inaccuracy value in the datasheet of 5%, so that the flow rate sensor is still considered a valid.

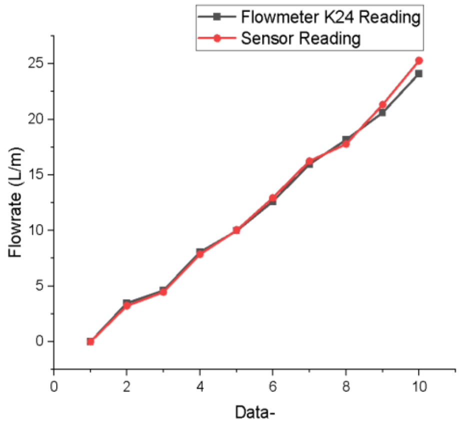

Figure 8. Flow Rate Sensor Validation Chart, After Solenoid Valve

Based on Figure 8, the flow rate sensor before the solenoid valve has an average accuracy of 97.302% and an average inaccuracy value of 2.698%. The inaccuracy of the flow rate sensor is still below the limit of the inaccuracy value in the datasheet of 5%, so that the flow rate sensor is still considered a valid [18].

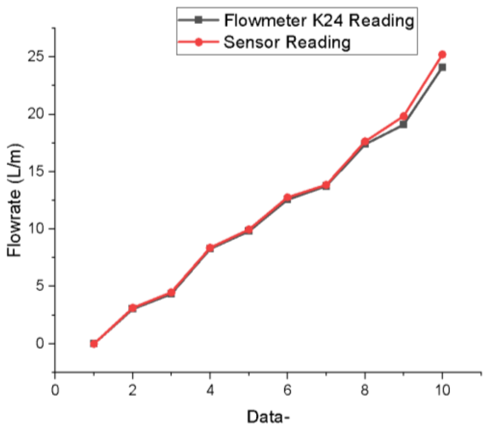

Figure 9. Flow Rate Sensor Validation Chart, After Globe Valve

Based on Figure 9, the flow rate sensor before the solenoid valve has an average accuracy of 98.009% and an average inaccuracy value of 1.991%. The inaccuracy of the flow rate sensor is still below the limit of the inaccuracy value in the datasheet of 5%, so that the flow rate sensor is still considered a valid.

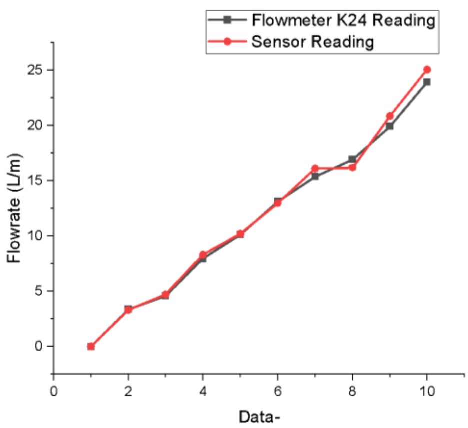

Figure 10. Flow Rate Sensor Validation Chart, After Ball Valve

Based on Figure 10, the flow rate sensor before the solenoid valve has an average accuracy of 96.993% and an average inaccuracy value of 3.007%. The inaccuracy of the flow rate sensor is still below the limit of the inaccuracy value in the datasheet of 5%, so that the flow rate sensor is still considered valid.

B. Performance System Test

There are two system performance tests consisting of monitoring the results of the pressure and flow rate sensor measurements, and the response of the control system where the actuator uses a solenoid valve. Testing system performance by running the system that has been installed with mechanics. The first test to test the control work system against pressure by closing the leak testing valve, globe valve, and ball valve. The second test was to test the control work system for pipe leaks by fully opening the globe valve and ball valve and slowly opening the leak testing valve.

TABLE 1.
SYSTEM TEST RESPONSE TO PRESSURE CONTROL AND PIPE LEAKAGE

No	V2 Condition	Flowrate (L/m)		Pressure (psi)		Control Response V1	Ratio (%)
		F1	F2	P1	P2		
1	No-leak	0	0	0	0	Normal	0
2	No-leak	12	12	18.8	0	Normal	0
3	No-leak	12	12	19	4.5	Normal	0
4	No-leak	11	11	17.2	5.4	Normal	0
5	No-leak	11	11	16.4	6.5	Normal	0
6	No-leak	11	11	21.4	11.3	Stop	0
7	No-leak	10	10	21.4	15.3	Stop	0
8	No-leak	9.5	9.5	21.8	10.6	Stop	0
9	No-leak	2.3	2.3	22.9	9.1	Stop	0
10	No-leak	0	0	23.9	9.3	Stop	0
11	Leak	12	11	17.9	0	Normal	8.3
12	Leak	12	10	15	0	Normal	16.7
13	Leak	12	9	16	0	Stop	25.0
14	Leak	8	5.8	31	0	Stop	275
15	Leak	0	0	30	0	Stop	0

From the data in Table 1, the solenoid valve (V1) works according to the setpoint in controlling the pressure, even though there is an excess of pressure and returns to the setpoint. From data numbers one to ten, the pressure at some time experienced an excess after the solenoid valve (P2) and could return to the setpoint it was possible because when closing the customer's house meter valve (V3 and V4) it was too slow so that there was water that escaped even though it could slightly reduce the pressure. The solenoid valve (V1) works according to the setpoint in controlling pipe leakage, although for some time the flow rate ratio between F1 and F2 is quite high and immediately returns to 0 due to no flow. The ratio is too high because the flow after the solenoid valve (F2) is getting slower but the flow before the solenoid valve (F1) is still moving to fill the empty space in the pipe until there is no moving water flow. Therefore, the flow rate after the solenoid valve (F2) is faster towards 0 than the flow rate before the solenoid valve (F1). The pressure after the customer meter (P3 and P4) always shows a measurement of 0 psi because there is no resistance or flow compression. The discharge after the customer meter (F3 and F4) is almost the same, there is a difference of ±1.5 L/m in the condition that it does not leak and operates normally, which means the valve on the customer's meter is fully open because the full open ball valve and globe valve have different mechanics, the hole where the globe valve disc is smaller than the ball valve. When testing pressure control, the ball valve is closed first because when closing the globe valve slowly the risk of water hammer tends to be smaller, or the pressure is suddenly high due to closing the valve suddenly. Thus, the flow rate after the ball valve (F4) becomes 0 until the ball valve is fully closed and the flow rate after the globe valve (F3) becomes approximately the same as the flow rate before and after the solenoid valve (F1 and F2). After the globe valve begins to close slowly, the pressure after the solenoid valve (P2) rises causes it to reach the setpoint and closes the solenoid valve.

IV. Conclusion

The SKU237545 pressure sensor is said to be valid after being validated with a digital pressure gauge. The result is an accuracy of 99.421% before the solenoid valve, an accuracy of 99.484% after the solenoid valve, an accuracy of 99.708% after the globe valve, and an accuracy of 99.556% after the ball valve.

The YF-S201 flow rate sensor is said to be valid after being validated with a K24 flowmeter. The result is an accuracy of 97.764% before the solenoid valve, an accuracy of 97.302% after the solenoid valve, an accuracy of 98.009% after the globe valve, an accuracy of 96.993% after the ball valve.

Testing the system found that the solenoid valve works to close according to the set point of leakage of 20% and a pressure of 10 psi. The solenoid valve is not suitable for controlling pressure because to get the pressure according to the set point, the valve at the customer's house must be closed slowly. Instead of a solenoid valve to control pressure, a pressure reducing valve or pressure regulator valve can be used. And in the future, it can be done by adding Human Machine Interfacing so that the set point can be changed easily for testing with different pressure set points.

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