# System to monitor and locate water leaks using labview software

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**Abstract**. This work presents a system for monitoring and locating water leaks using Labview software. The system describes the mathematical model used to locate the leak, which is implemented in a virtual instrument, obtaining the flow and pressure behavior of the system in the presence and absence of leaks in a transient state through a virtual platform coupled to a data acquisition system. The purpose is to obtain real-time data of the process to detect leaks, guaranteeing their immediate correction.

## 1. Introduction

Water pipeline leaks are a problem due to the scarcity of water resources. Monitoring and locating leaks has become a priority for the water industry due to the costs associated with water loss [1]. In addition to costs related to water production, transport and waste, they also cause secondary financial losses due to supply disruptions, erosion of pipe beds, and damage to buildings and roads. The amount of water lost through leakage usually represents 20-30% of total production. This percentage can even reach 50% for older distribution networks [2].

There are different methods for locating water leaks. They can be broadly classified as external or hardware-based monitoring methods and internal or software based monitoring methods. Mass and energy balance are some of the methods used to locate leaks [3],[4],[5],[6],[7],[8]. The disadvantage of this method is that it is highly sensitive to various disturbances and pipeline dynamics. Hydrostatic testing requires removing the pipeline from operation and injecting pressurized air into the pipeline. By monitoring the pressure in the pipeline for a certain time, the presence of a leak is identified if a drop in pressure occurs.  This concludes the existence of a leak and to locate it, it is necessary to segment, seal, and repeat the test until its position is located. These tests, in which devices are placed directly in the pipes, are known as pre-locators. The information they obtain about the noise level is stored and analyzed to find the leak location by measuring the acoustic resonance. The pressure flow deviation method is used extensively in model-based leak monitoring techniques in combination with a mass-balance approach to cover full-time leak detection for a wide range of operating conditions. Pressure flow diversion methods are essentially a subset of the direct backward transient analysis. The first applied field of the direct backward transient analysis method was the wide use in groundwater transport problems based on a steady state pipe network model [9],[10],[11].

A common problem with the above methods is that the extraction of leakage information is insufficient. The extracted features cannot accurately represent all useful information from the raw pressure signal. Therefore, there is a need to find a more efficient feature extraction method, which can improve the performance of existing leak detection methods [12].

The aim of this work is to propose a mathematical model to locate the length where the leak is exactly located. A data acquisition system was used together with the development of a virtual instrument to obtain information from the pressure and flow sensors to detect and locate the leak in real time.

This document is organized as follows: section 2 presents the mathematical model proposed to locate the leak. Section 3 presents the development of the virtual instrument focused on data acquisition and automatic leak detection. Section 4 shows the results. Finally, section 5 presents the conclusions.

## 2. Mathematical model

The model is composed of the energy conservation equations and is described by spatial and surface equations for a time derivative as shown in Equation 1.

$$\frac{dEsit}{dt} = \frac{d}{dt}\iiint_{vsc1}\left(\frac{v^2}{2} + gz + \frac{P}{\gamma} + h_L g\right) * pdv + \frac{d}{dt}\iiint_{vsc2}\left(\frac{v^2}{2} + gz + \frac{P}{\gamma} + h_L g\right) * pdv$$
$$- \iint_{svc1}\left(\frac{v^2}{2} + gz + \frac{P}{\gamma} + h_L g\right) p\underline{v}AdA + \iint_{svc2}\left(\frac{v^2}{2} + gz + \frac{P}{\gamma} + h_L g\right) p\underline{v}AdA$$
$$+ \iint_{svcf}\left(\frac{v^2}{2} + gz + \frac{P}{\gamma} + h_L g\right) p\underline{v}AdA \ (1)$$

From the continuity equation, which states that the energy entering the system must be equal to the energy going out, Equation 2 is obtained:

$$\dot{m}_1 * \left(\frac{P_1}{\gamma} + \frac{{v_1}^2}{2g}\right) = \dot{m}_2 * \left(\frac{P_2}{\gamma} + \frac{{v_2}^2}{2g}\right) + \dot{m}_f * \left(\frac{P_f}{\gamma} + \frac{{v_f}^2}{2g}\right) + \dot{m}_1 * h_{L1} + \dot{m}_2 * h_{L2} \ (2)$$

The equation is reduced a little to $P_f = P_2 = 0$ as these two pressures are at the atmospheric pressure as shown in Equation 3.

$$\dot{m}_1 * \left(\frac{P_1}{\gamma} + \frac{{v_1}^2}{2g}\right) - \left(\dot{m}_2 + \dot{m}_f\right) * \left(\frac{P_2}{\gamma}\right) - \dot{m}_2 * \left(\frac{{v_2}^2}{2g}\right) - \dot{m}_f * \left(\frac{{v_f}^2}{2g}\right) = \dot{m}_1 * h_{L1} + \dot{m}_2 * h_{L2} \ (3)$$

Knowing that $\dot{m}_1 = \dot{m}_2 + \dot{m}_f$, the equation is divided by $\dot{m}_1$ as shown in Equation 4.

$$\frac{\dot{m}_1 * \left(\frac{P_1}{\gamma} + \frac{{v_1}^2}{2g}\right) - \left(\dot{m}_2 + \dot{m}_f\right) * \left(\frac{P_2}{\gamma}\right) - \dot{m}_2 * \left(\frac{{v_2}^2}{2g}\right) - \dot{m}_f * \left(\frac{{v_f}^2}{2g}\right)}{\dot{m}_1} = \frac{\dot{m}_1 * h_{L1} + \dot{m}_2 * h_{L2}}{\dot{m}_1} \ (4)$$

As $\dot{m} = p * Q$ where p is density and Q is volumetric flow rate, the equations are transformed to volumetric flow rate since the densities are cancelled out as can be observed in Equation 5.

$$\left(\frac{P_1 - P_2}{\gamma}\right) + \left(\frac{v_1{}^2}{2g}\right) - \left(\frac{Q_2}{Q_1} * \frac{V_2{}^2}{2g}\right) - \left(\frac{Q_f}{Q_1} * \frac{V_f{}^2}{2g}\right) = h_{L1} + \left(\frac{Q_2}{Q_1} * h_{L2}\right) \text{(5)}$$

Now entering Darcy's law for the values of h as described in Equation 6:

$$\left(\frac{P_1 - P_2}{\gamma}\right) + \left(\frac{v_1{}^2}{2g}\right) - \left(\frac{Q_2}{Q_1} * \frac{V_2{}^2}{2g}\right) - \left(\frac{Q_f}{Q_1} * \frac{V_f{}^2}{2g}\right) = \left(f_1 * \frac{L_1}{D} * \frac{V_1{}^2}{2g}\right) + \left(\frac{Q_2}{Q_1} * \left(f_2 * \frac{L_2}{D} * \frac{V_2{}^2}{2g}\right)\right) \text{(6)}$$

Taking the speeds to volumetric flow rate, Equation 7 is obtained.

$$\left(\frac{P_1 - P_2}{\gamma}\right) + \left(\frac{8Q_1{}^2}{\pi^2 D^4 g}\right) - \left(\frac{Q_2}{Q_1} * \frac{8Q_2{}^2}{\pi^2 D^4 g}\right) - \left(\frac{Q_f}{Q_1} * \frac{8Q_f{}^2}{\pi^2 D_f{}^4 g}\right)$$
$$= \left(f_1 * \frac{L_1}{D} * \frac{8Q_1{}^2}{\pi^2 D^4 g}\right) + \left(\frac{Q_2}{Q_1} * \left(f_2 * \frac{L_2}{D} * \frac{8Q_2{}^2}{\pi^2 D^4 g}\right)\right) \text{(7)}$$

As $P_2 = 0$, then the first term remains as $\frac{P_1}{\gamma}$ which will be called $Hm_1$ (pressure head in meters of water column). Simplifying, Equation 8 is obtained.

$$(Hm_1) + \frac{8}{\pi^2 g}\left[\frac{Q_1{}^2}{D^4} - \frac{Q_f{}^2}{D_f{}^4 Q_1} - \frac{Q_2{}^2}{D^4 Q_1}\right] = \left(\frac{8 f_1 L_1 Q_1{}^2}{\pi^2 D^5 g}\right) + \left(\frac{8 f_2 L_2 Q_2{}^3}{\pi^2 D^5 g Q_1}\right) \text{(8)}$$

Subsequently, Equation 8 is divided by $\frac{8}{\pi^2 g D^5}$ and Equation 9 is obtained

$$(12{,}1\ Hm_1 D^5) + Q_1{}^2 D - \frac{Q_f{}^2 D^5}{D_f{}^4 Q_1} - \frac{Q_2{}^2 D}{Q_1} = f_1 L_1 Q_1{}^2 + \left(\frac{f_2 L_2 Q_2{}^3}{Q_1}\right) \text{(9)}$$

$L_T = L_1 + L_2$, where $L_T$ is the total length of the pipe. By replacing $L_T$, equation 10 is obtained.

$$(12{,}1\ Hm_1 D^5) + Q_1{}^2 D - \frac{Q_f{}^2 D^5}{D_f{}^4 Q_1} - \frac{Q_2{}^2 D}{Q_1} = f_1 L_1 Q_1{}^2 + \left(\frac{f_2 (L_T - L_1) Q_2{}^3}{Q_1}\right) \text{(10)}$$

Eqution 11 is obtained by taking the common factor of $L_1$, which is the desired length.

$$(12{,}1\ Hm_1 D^5) + Q_1{}^2 D - \frac{Q_f{}^2 D^5}{D_f{}^4 Q_1} - \frac{Q_2{}^2 D}{Q_1} - \frac{f_2 L_T Q_2{}^3}{Q_1} = L_1\left[f_1 Q_1{}^2 - \frac{f_2 Q_2{}^3}{Q_1}\right] \text{(11)}$$

Equation 12 is obtained by clearing $L_1$.

$$L_1 = \frac{(12{,}1\, Hm_1 D^5) + {Q_1}^2 D - \frac{{Q_f}^2 D^5}{{D_f}^4 Q_1} - \frac{{Q_2}^2 D}{Q_1} - \frac{f_2 L_T {Q_2}^3}{Q_1}}{f_1 {Q_1}^2 - \frac{f_2 {Q_2}^3}{Q_1}} \quad (12)$$

The mathematical model was applied in the labview software to find the is leak location. To check the mathematical model, an experimental pipe test bench was made, as described in reference [13],[14], and a virtual instrument was developed for automated leak acquisition and detection as described in section 3.

## 3. Development of the virtual instrument focused on data acquisition and automated leak detection.

For the development of the research, a user interface was created, which provides the operator with flow and pressure data, as well as graphs and controls for the correct visualization and automation of the leak detection system[15].

Figure 1 shows the splash screen where a schematic of the actual prototype can be seen and presents two options. The option to acquire flow and pressure data from the system, and the option to locate the leak using the automated system.


**Figure 1.** Virtual instrument splash screen.

Figure 2 shows the real-time data acquisition screen of the pipeline leak detection prototype. Figure 3 shows the physical prototype with the data acquisition system.


**Figure 2.** Data acquisition screen

**Figure 3.** Physical prototype with data acquisition system

## 4. Results

The mathematical model described in section 2 was applied obtaining a simulation model that was applied without problems in Matlab and labview software.

Figure 4 shows the front panel where the virtual instrument detects the leak. The simulation was performed for a single leak at the position of the first valve in the pilot line.

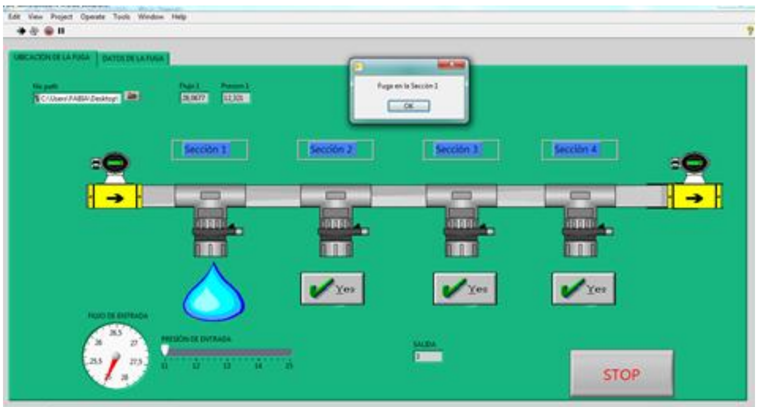


**Figure 4.** Front panel Leakage simulation

Figure 5 shows the virtual instrument screen. The software validates the algorithm used to detect the leak.


**Figure 5.** VI Graphic Interface for Leak Detection

Figure 6 shows the flow behavior in the leak detection system before and after the leak obtained through the virtual instrument designed for the project. This figure shows the drop in flow when the leak occurs.

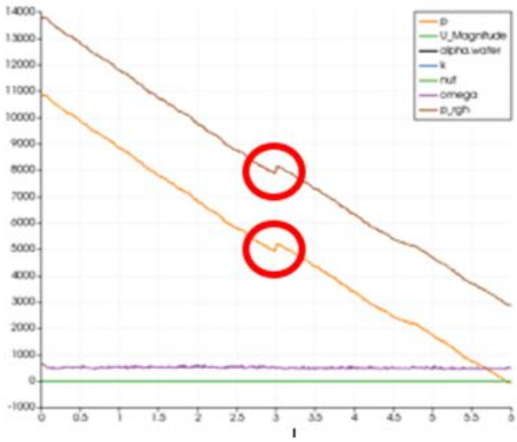


**Figure 6.** Flow behavior of the system.

## 5. Conclusions

The results showed consistency and good Accuracy with respect to the proposed algorithm for detecting leaks in the experimental pipeline. Regarding the results obtained with the automated detection system using the virtual instrument, we can say that it allows real-time leak detection, ensuring its immediate correction. As a result, the problems that arise behind a leak can be reduced.

Based on the information collected, which was aimed at developing a system to automatically detect leaks, both the system and the most suitable sensors were selected, meeting the established operating requirements.
The selected data acquisition system is completely suitable for collecting the information established by the sensors, allowing the good development of the project.
The construction of the pipe test bench was completed, achieving the expected results in its implementation.
It was observed that a pipe affected by a leakage hole internally generates a gradient jump in the fluid pressure. For the data of this simulation, a gradient before the hole equivalent to -2024 was obtained and for the rest of the pipe equal to -1769 for a deviation of 14%.

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