The Use of Transmission Line Modelling for Detection of Leakage in Pipeline

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ABSTRACT

Transmission Line Modelling (TLM) is a technique, computationally very efficient and versatile, for solving variety of engineering application regarding to wave and diffusion phenomena. This paper implemented a TLM modelling to detect and locate leak in pipeline networks. The original data from the TLM modelling were analysed using time-frequency representation (TFR). A well-known and established signal processing method of TFR based wavelet transform was chosen for the data analysis. The results presented two different cases; pipe network without leak and the second one with existing of leak. From the study, features in the pipe networks such as inlet, valve, leak and outlet were successfully detected and located using TLM and wavelet analysis.

Keywords: *Transmission Line Modelling, Leakage, Pipeline*

Introduction

Leak detection in pipeline

Leak can be described as an unintentional release of fluid from internal medium to outside such as water leakage from pipelines. In the case of water loses, pipeline leakage phenomena were more often as it was not unattended during several years back due to the insignificant value of water as well as the minimum costing of energy for transporting the fluid. This condition however is positively changing as people and organisations take serious

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attention towards this issue to minimise the effects of economics and environmental factors. Consequently, in recent years there are a lot of researchers committed in this problem as to solve and improve it towards maximum level by reducing the number of fluid losses due to pipe leakage.

It has been acknowledged that all human creatures have limitations although the quality is amended by the moving time. Pipe leakage is one of the structure defects that cannot be avoided from occurring, but it can be controlled up to optimum level. For example, by doing an extensive and scheduled maintenance including immediate fix or replacement of old and damaged components.

Pipeline leakage possibly happens due to several factors; for example, bad workmanship and maintenance deficiency, mechanical defects such as erosion, corrosion, and gouges in the pipe wall, failure to early detect and repair or replace the defective pipe section and accidental impact during production, installation or operation.

Accidental fluid losses from leakage pipelines apparently will sacrifice to badly consequences such as economic losses, environmental damage and most dangerously, it possibly causes fatality and injury due to fire, explosion and pollution. Currently and a few years back, the number of severe leakage pipeline incidents around the world keeps arising since the demand of using pipeline to transfer fluid increases due to several beneficial factors, as an example for economic reason. Previously on November 22, 2013, an abrupt explosion impacted in Qingdao, China. The tragedy killed 62 people and 136 were injured while about 18,000 people were evacuated. Report by the pipeline owner, Sinopec Group, revealed that the explosions were caused due to oil leaking out from underground corroded pipeline which produced a starting ignition. The ignition triggered from the sparks of hydraulic hammer handled by workers during operation. Besides injuries and fatalities, the blast caused a direct economic loss of about $124.9 million.

Wave propagation in pipeline

As defined by Chaudhry [1], hydraulic transients phenomenon is an unsteady flow, also known as water hammer, in which the physical process is transmitted as a pressure wave in the medium such as pipeline system. In different physical meaning, the transient conditions are originated when the conditions of steady state are disturbed; hence, the condition at a given point in pipeline starts changing with time. Examples of usual activity that generates pressure transient that disturbs the flow in pipeline are pump start up or shut down, failure of pump and valve manoeuvres.

In mathematical expression, depending on the kind of analysis, hydraulic transient can be defined by means of one dimensional, two dimensional or three dimensional models. One dimensional flow is basically used as an assumption to calculate hydraulic models in pipeline networks [2]. More complicated and in particular case, two dimensional and three dimensional models are applied for instance to calculate unsteady-shear stress [3] and deal with the rapid propagation of a crack when a pipe is instantaneously loaded [4]. Until recently, many researchers have investigated a variety of numerical approaches to establish the methods of solving hydraulic transient analysis. Such methods include method of characteristics [5, 6], bond graph modelling [7, 8], modal analysis [9], [10] and the transmission line modelling technique [11, 12]. In this study, transmission line modelling was employed to get the output signal of the transient wave propagation. In spite of the fact that the method of characteristics is the most commonly popular approach for handling hydraulic transients in pipeline networks, TLM has also been proven by previous study in literature [11, 12] to sufficiently model this kind of problem successfully.

Background of TLM

Transmission line modelling is one of the numerical techniques that computationally have good capability for solving a physical problem regarding to wave and diffusion phenomena. It was formulated by Johns and Beurle, with the first publication found in 1971, [13] in the field of computational electromagnetic. The fundamental principal of TLM is originally in the basis of the equivalence between electromagnetic field and mesh of transmission lines [14]. Fast growing in technology has encouraged scientists and researchers to further develop TLM in various fields of engineering. From literature, instead of electromagnetic study, this method has been well proven employed in the field of mass and heat transfer [15], sound propagation [16] and hydraulic analysis [11, 12]. It was recently extended to the biomedical field [17-19]. This technique at the early stage classified to the class of time domain differential methods, but then it was upgraded to a new version of a frequency domain [20].

In the field of hydraulic system, a simple analogy from electrical system is that the voltage and current are equivalent to pressure and flow respectively. While in the TLM, the fundamental assumption is that the single consequence of a wave travelling to downstream region of a lossless pipe is a delay. In other words, every pipe section is simply a time delay and all hydraulic processes occur at the junctions of the pipe with no change of wave that moves downstream in the pipe.

In general, derivation of the wave equation typically is the substance of two bidirectional waves [21]. Since the transmission lines are subjected as pure delays as mentioned above, in which all the processes take place at the junctions, part of waves at the junction is absorbed due to friction, part of it is transmitted to other pipes section and part of it is reflected back to upstream region. All these events (absorption, transmission and reflection) at the junction are a function of geometry and other mechanical devices such as valves, strainer, nozzle, turbine, etc. Meanwhile, the intensity level of these events relies upon the admittance, Y, at each junction of pipe sections as well as geometry of the feature [22].

The governing equations of a moving wave in a transmission line can be composed by transfer equation as [23]:

$$\begin{vmatrix} P_1 \\ m_1 \end{vmatrix} = \begin{vmatrix} cosh\left(\frac{l}{c_o}\right)\frac{d}{dt} & \left(\frac{c_o}{A}\right)sinh\left(\frac{l}{c_o}\right)\frac{d}{dt} \\ \left(\frac{A}{c_o}\right)sinh\left(\frac{l}{c_o}\right)\frac{d}{dt} & cosh\left(\frac{l}{c_o}\right)\frac{d}{dt} \end{vmatrix} \begin{vmatrix} P_2 \\ m_2 \end{vmatrix} \quad (1)$$

where P_1 and m_1 represent for upstream pressure and flow respectively, while P_2 and m_2 represent for downstream pressure and flow respectively. I is the length of the pipe, A is the cross-sectional area of the pipe section and c_o is the speed of the pressure wave.

TLM in Pipe Leakage Detection

The use of TLM in this study was developed from the previous work of Auslander [24]. Wave scattering methods and bond graph were employed for solving the hydraulic problem numerically. With the current progress of computer performance, this approach provides a relatively well operation for complex variation of geometry without excessively complicating the formation of a mathematical model.

In current simulations, the computer program employed for modelling hydraulic transient is known as SUNAS (Sheffield University Network Analysis Software), formulated by a group from Sheffield University [25]. SUNAS is a powerful one dimensional network modelling tool based on the transmission line modelling to simulate pipeline networks. The detail explanation of the program and its application were presented in a previous published paper by Beck [21].

Two different models were simulated in this study; the first model was a pipe with no resistance (no leak) and the second one was a pipe with resistance (with a leak) as shown in Figures 1 and 2 respectively. The former consisted of two sections pipe which was divided by the valve. While for the second model, an additional resistance (junction and leak) was included.

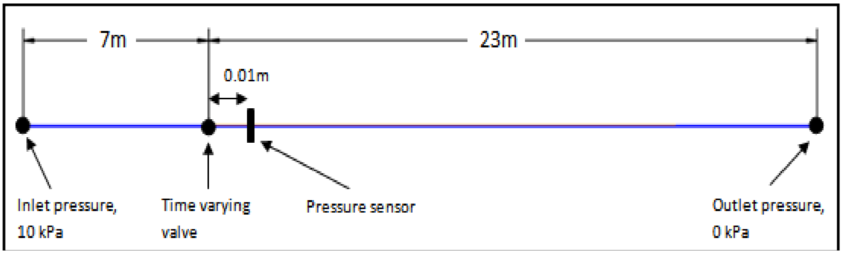

Figure 1: Pipe network model without resistance (no leak)

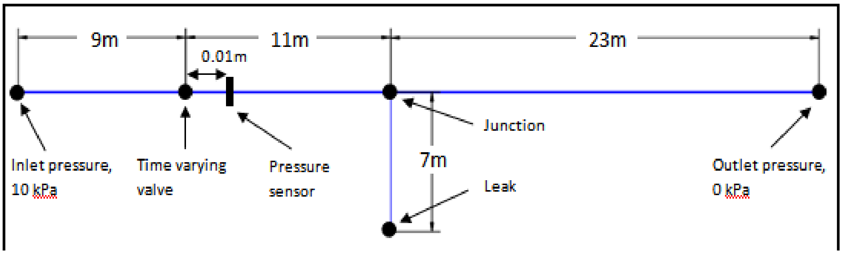

Figure 2: Pipe network model with resistance (leak)

In the SUNAS program, the valve is characterized as a time varying resistance [21, 26] as comparable to opening and closing the valve to create water hammer pulse, which then causes the propagation of wave through the system. The inlet pressure was set to 10kPa and the outlet to 0kPa. For all tests, the diameter of the pipe was set to 15mm. The location of the pressure sensor from the time varying valve was set to a very small distance of 0.01m for both models.

The location of reflection point, *D*, (pipe features) in pipe which correspond to the peak in time/pressure signal can be determined by multiplying the recorded time delay of the peak, t_{peak}, by the speed of sound, *c*, in the fluid-filled pipe network and dividing this value into halves to consider for the return back of the travelling wave.

$$D = \frac{c \times t_{peak}}{2} \tag{2}$$

Result and Discussion

Figures 3 and 4 show the simulated time/pressure response that correspond to model setup of Figures 1 and 2 respectively using SUNAS program. It can be seen in both graphs that it started with highly pressure transient due to time varying resistance modelled in the numerical algorithm. Then the pressure amplitude decayed continuously with time. For the second case (leak pipe), the intensity of pressure transient was higher compared to the first case (without leak) as a result of additional resistances from the leak and thus compensated extra time to achieve normal condition. However, it was hard to recognize any features that present in the pipe network without further analysis using appropriate signal processing. It was not clearly visible what caused the changes in the pressure wave shown (Figure 3 and 4). As a result, the detection and location of reflection points or features in pipe were complicated in practice. In this study, wavelet transform (WT) was utilised to improve the detection and location strategy (Figures 5 and 6).

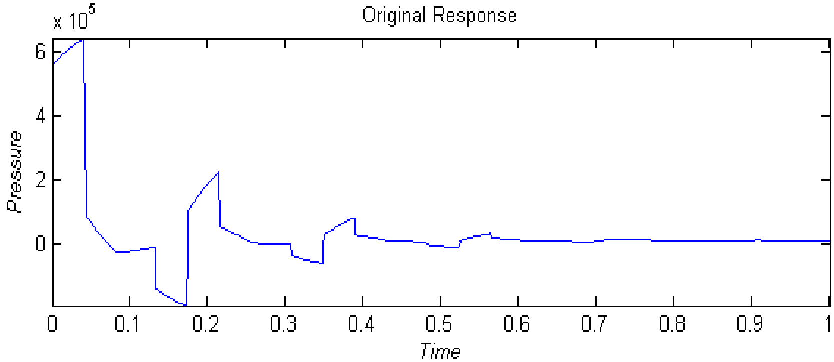

Figure 3: Simulated pressure-time response of the pipeline network system without resistance (no leak)

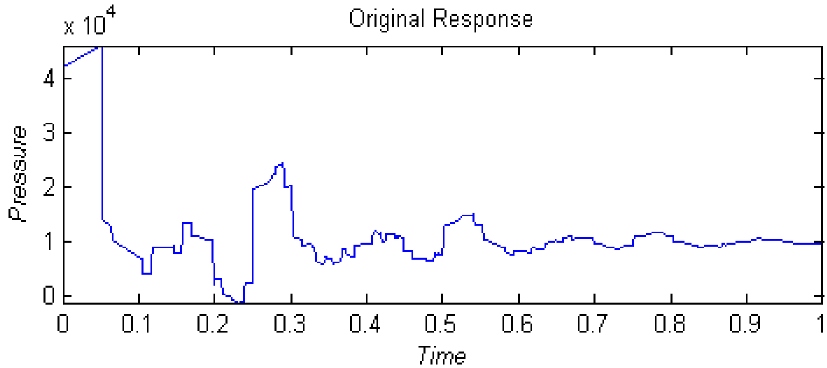

Figure 4: Simulated pressure-time response of the pipeline network system with resistance (leak)

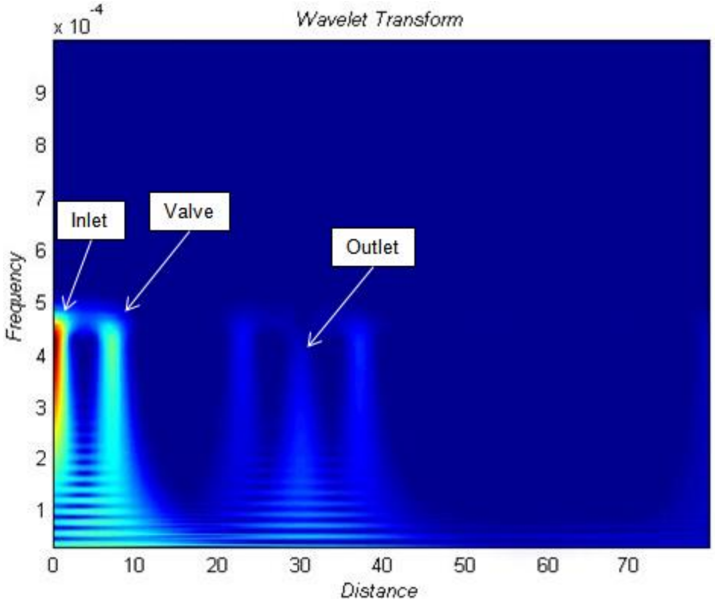

Figure 5: WT spectrum analysis of signal without resistance (no leak).

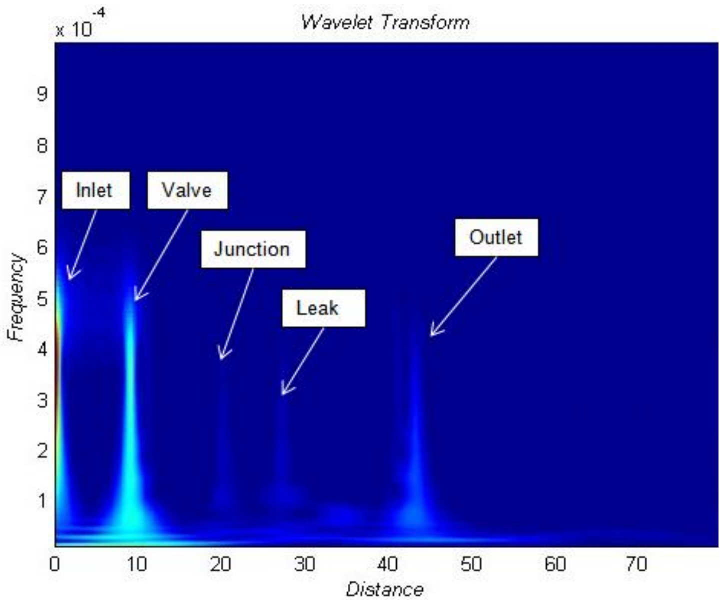

Figure 6: WT spectrum analysis of a signal with resistance (leak).

By using WT, the time-frequency representation of the original signal was obtained as shown in Figures 5 and 6. The first representation (Figure 5) shows the TFR for the system without resistance and the second (Figure 6) for the system with resistance. As it can be seen, three peaks corresponded to inlet, valve and outlet were clearly shown in Figure 5 with the locations at

0m, 7m and 30m respectively. While for leak pipe analysis (Figure 6), additional resistant was clearly recorded which were junction and leak. The locations of the inlet, valve, junction, leak and outlet were at 0m, 9m, 20m, 27m and 43m respectively. Observing these figures, it showed that the time frequency analysis using wavelet transform was accurately capable to map the reflection points of the wave in the signal or features in the pipe network.

Conclusion

As pipe leakage can result in bad consequences; for instance, economic losses and most aftermaths that cause injury and fatality to human being, inspection as well as evaluation of the pipeline system have become a crucial issue to be handled seriously.

This study briefly focused on the identification of pipe leakage using numerical approach accompany by signal processing analysis. The wave signal of fluid flow model in pipe was numerically simulated using transmission line modelling (TLM) and further signal analysis using wavelet transform, a type of time-frequency analysis, was conducted.

From the result of this study, it was proven that the type of numerical approach using transmission line modelling was capable to model hydraulic transient in pipeline region especially in the field of pipe leakage detection. Coupled with wavelet transform analysis, this method was able to perfectly delineate each individual component including the leakage in the signal close to the theoretical value. As a result, these combination approaches were a successful strategy to detect and locate leak in pipeline network computationally.

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