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A NOVEL METHOD FOR THE DETECTION OF LEAKAGE AND BLOCKAGE IN PIPELINES

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Abstract
A novel method for the remote detection of leakage and blockage in pipelines will be discussed. Experimental results obtained in air and water filled pipes, with and without flow, and from 40 to 305 mm diameter, will confirm the validity of the method. Interrogation distances in excess of 1 km appear to be achievable.

Many techniques for the detection and location of pipeline failures have been proposed. Unfortunately, none is entirely satisfactory because of poor sensitivity, slow response, susceptibility to external noise, or inability to operate remotely.

An alternative approach, based on acoustic wave propagation through the fluid, has merits, although the complicated nature of the acoustic wave reflections generated by the internal features of the pipe makes interpretation of the signal extremely difficult. The results of an on-going experimental study are discussed in this paper. It is shown that the new method eliminates many of these difficulties and is well suited to remote operation.

INTRODUCTION

The prevention of leakage has never been of greater importance because of the economic and environmental consequences of even a small loss but, despite this, disastrous events involving pipeline leakages are reported with monotonous frequency. In the United States, the Office of Pipeline Safety records incidents involving pipeline leakages centrally and, for 2004 alone, reported the loss of 3.5 million gallons of hazardous material, five deaths and US$76 million worth of property damage (http://ops.dot.gov).

Monitoring the health of a pipeline or, more particularly, detecting leakage, blockage and corrosion, is important in the transportation of hazardous materials and also in the monitoring of water distribution systems. The problems posed in the distribution of fresh water are highlighted by recent studies indicating that thirty-six states in the USA are likely to suffer water shortages in the next ten years [1]. The only sensible way to alleviate this problem is to minimise water losses from pipeline distribution systems.

Many methods for detecting leakages in liquid and gas pipelines have been proposed. These include, but are not limited to, volume balance, inverse transient analysis, acoustic detection methods, thermographic, radar and tracer gas techniques. More recently, acoustic devices have been used as a method for detecting leakages within pipelines. The principal acoustic devices are referred to as listening devices and noise correlators. The disadvantage of these acoustic approaches is that the equipment often requires a highly skilled operator and, under normal conditions, the techniques perform poorly because background noise from process equipment and traffic interferes with the accuracy of the devices [2].

In this paper a novel approach to detecting leakage and blockage in single pipelines and pipeline networks is described and demonstrated. The approach is based on the observation that the propagation of acoustic waves in a fluid medium is very sensitive to any discontinuity in its properties. Discontinuities will occur whenever there is a change in the static pressure level of the fluid, or a variation in the cross-sectional area of the pipe, such as may occur at a flange, T-piece, orifice plate, valve, a deposition of wax, or a pipe wall failure leading to leakage.

The following section of this paper describes the theory of the proposed acoustic pipeline monitoring system. This is followed with a series of results that illustrate the ability of the technique to detect and locate leakages and blockage in steel and plastic pipe of varying lengths and diameters. Finally a list of conclusions is provided.

THEORY

Background

The basis for the leakage detection method described in this paper is the observation that the propagation of acoustic waves in a fluid medium is very sensitive to any discontinuity in the properties of the fluid. If an acoustic wave is injected from the left into the pipe then it will be partially reflected at the interface, producing reflected and transmitted acoustic components. For weak plane waves of the type considered here, the waves propagate at the local speed of sound, which will vary depending up on the local conditions of the fluid. Reflective waves will occur wherever there is a change in the cross-sectional area of the pipe [3]. In industrial pipeline systems this will occur wherever there is a valve, 'T' piece or blockage, for example. Further to this, it was reported in [3] that any leakage within a pipe would act like a change in the cross-sectional area and hence a fraction of the incident acoustic energy would be reflected. This was demonstrated this principle, to a limited extent, in [3] by using reflected signals to identify small leaks in a musical wind instrument.

This paper describes an acoustic leakage detection method that exploits the fact that any leakage present within it will reflect acoustic waves. A detailed discussion of the theory behind the proposed approach is available in [4].

EXPERIMENTAL RESULTS

In the experimental results presented in this paper, the signal generated by an acoustic pulse generator was passed through an amplifier to drive a loudspeaker, which transmitted the signal into a pipe. A microphone was then used to measure the transmission and reflection of this wave through the pipe. Prior to there being any leakage in the pipe, the wave will be reflected from every discontinuity in the pipeline, for example where there is a valve or orifice plate. If similar acoustic waves are transmitted in to the pipe then the measurement made by the microphone should remain unchanged. If however, the signal recorded by the microphone does differ then this will indicate that there is a new discontinuity in the pipe, which may have been caused by a leakage or blockage.

The ideal frequency component of the acoustic signal injected in to the pipe is the subject of current research. However, in this work a short period square pulse has been used.

Effect of Leakage

To illustrate the basic application of the proposed technique a length of PVCu pipeline, with an internal diameter of 150mm was used. The basic configuration of the pipeline is illustrated in figure 1.

In this pipeline system, a loudspeaker is connected to one end of a straight, open-ended pipe of length 39.84m, with a 90^0 bend at 30m. A microphone mounted in a tapping in the pipe wall was located 6.11m from the loudspeaker. An acoustic wave was injected from the loudspeaker and the reflection response of the pipe was measured using the microphone. The measurement from the microphone is recorded for a sufficient length of time for the acoustic wave reflected at the end of the pipe to return to the microphone. The microphone was sampled at a rate of 50 kHz. This measurement is referred to here as the reference signature of the pipeline. A leakage was then introduced into the pipeline. This leakage was simulated by drilling a circular hole of diameter 20mm in the pipe wall. The leakage was located 22.91m from the loud speaker. With the leakage present, a second acoustic wave with the same amplitude and frequency content used earlier was injected in to the pipeline. The measurement made by the microphone with the leakage present, referred to as the leakage signature, was then recorded and compared with the original reference signature. Figure 2 shows a time trace of the two signatures measured by the microphone.

The acoustic waves were transmitted into the pipeline at time 0s, and as figure 2 shows the two traces are very similar. The first peak which occurs in the traces at approximately 0.018s represents the passage of the acoustic wave across the microphone. Note that the speed of sound in air is approximately 342m/s. Hence it takes approximately 0.018s for the acoustic wave to travel the 6.11m between the loudspeaker and microphone. The subsequent peaks recorded in the traces are the reflected signals produced whenever the acoustic wave encounters a discontinuity within the pipeline. The peaks labelled A, B, C, D and E result from reflections from various features in the pipeline. For example, the peak at point A is the reflection of the acoustic wave from the first T-section along the pipeline.

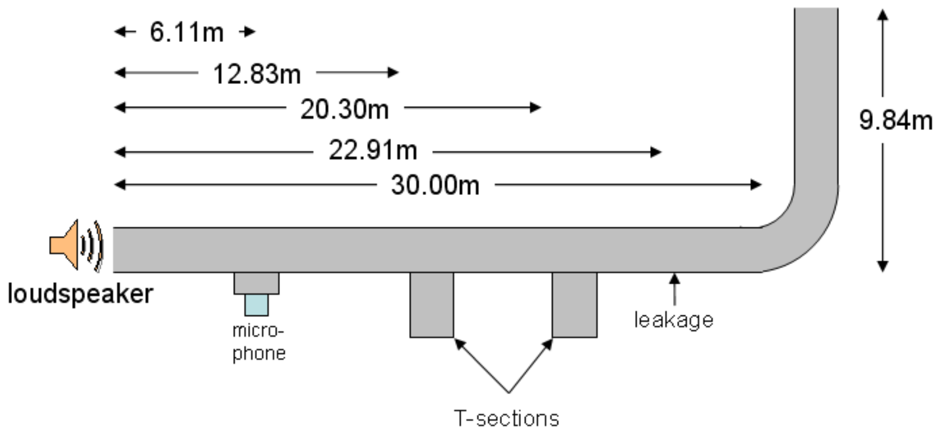

Figure 1: Experimental configuration with leakage

Careful examination of figure 2 shows that the reference and leakage traces are virtually identical until approximately 0.12s when the two traces begin to differ slightly. This difference is a result of the leakage that has been introduced in to the pipeline. To highlight this difference further, figure 3 shows a trace which is the difference between the reference and leakage traces, this is referred to as the *difference trace*. Note that the x-axis has now been converted to a distance measurement. This is the distance from the loudspeaker and is obtained by multiplying the time value in figure 2 by the speed of sound. This figure shows that the first significant difference in the observed trace, which is caused by the leakage, occurs after 39.68m. After this point the two signatures are clearly different. This result means that in travelling from the speaker to the leakage and then back to the microphone, the acoustic wave has travelled a distance of 39.68m. Given that the distance between the speaker and microphone is 6.11m then the distance between the microphone and leakage is calculated to be: $d_{leakage} = \frac{39.68 - 6.11}{2} = 16.79m$.

The actual distance between the leakage and the microphone is 17.89m. Hence the proposed technique is able to detect the existence of leakage and locate this with some accuracy. In this example, the speed of sound has been assumed to be constant at 342m/s. However, this value will change slightly as the operating conditions vary.

Similar results to those obtained for PVCu pipeline were also recorded for steel pipelines.

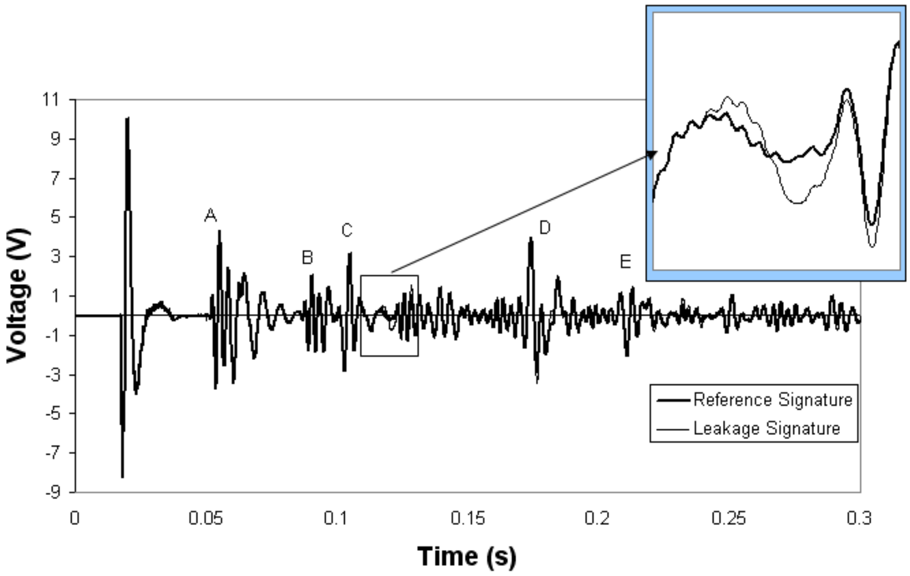

Figure 2: Comparison of reference and leakage signatures

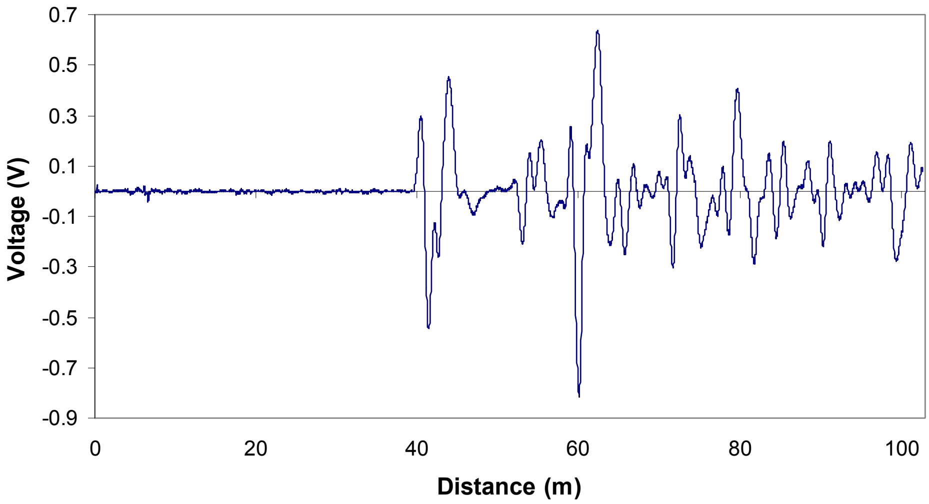

Figure 3: Difference Trace

Effect of Leakage Size

Experiments were performed to determine the effect that the size of the leakage had on the acoustic response of the pipeline. In these experiments the equipment described in the previous section was used again. The only difference in the arrangement was that on this occasion the location of the leakage was moved to a point 11.55m from the speaker, or 5.44m from the microphone. In these experiments, a series of acoustic signatures were recorded when a leakage of varying size was introduced into the pipeline. The leakages were of diameter 5mm, 10mm, 15mm, 22mm and 29mm. Figure 4 shows the difference signatures recorded for each of these leakage sizes. This figure illustrates that as the size of the leakage increases then the amplitude of the difference signature also increases. The difference signature can therefore not only be used to detect and locate the presence of leakage, but can also be used to identify the relative size of the leakage.

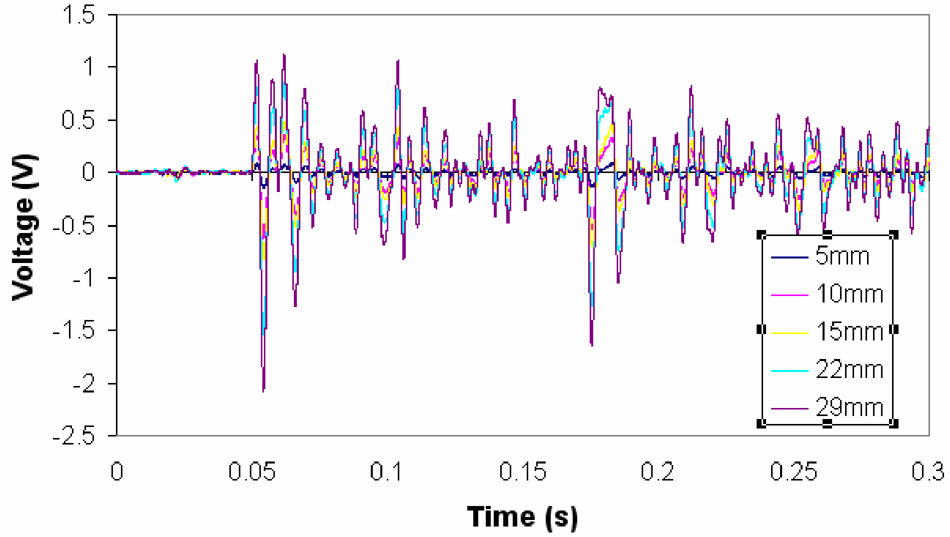

Figure 4: Difference trace for leakages of varying size

Experimental Results for Blockage

In this experiment a small moulded piece of dental plaster was inserted in to a straight length of PVCu pipeline of 150mm internal diameter. The plaster insert created a partial blockage that corresponded to approximately 20% of the total pipeline cross-sectional area. The difference between the acoustic traces recorded before and after the insertion of the partial blockage is presented in figure 5. As with the leakage examples, the location of the blockage can be clearly identified as the point on the trace at which the signal begins to deviate significantly from zero. This point corresponds to a total distance of approximately 20.86m, which corresponded to an error of approximately 0.09m.

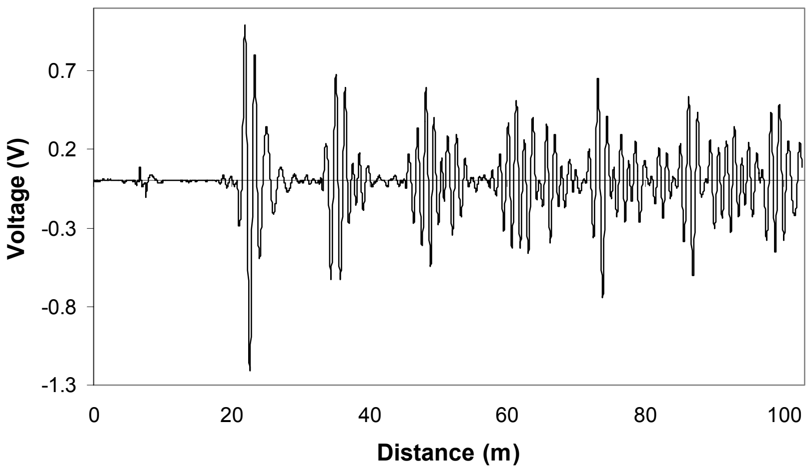

Figure 5: Difference trace for partial blockage

Results for pipeline networks

In this section, the applicability of the technique to the more difficult but practically important case of pipeline networks is discussed. For networks it is necessary to record the reflection response of the network using more than one microphone. To illustrate the results obtained for a pipeline network, tests were conducted on the pipeline circuit displayed in figure 6. The pipeline material for these tests was PVCu of 42 mm internal diameter.

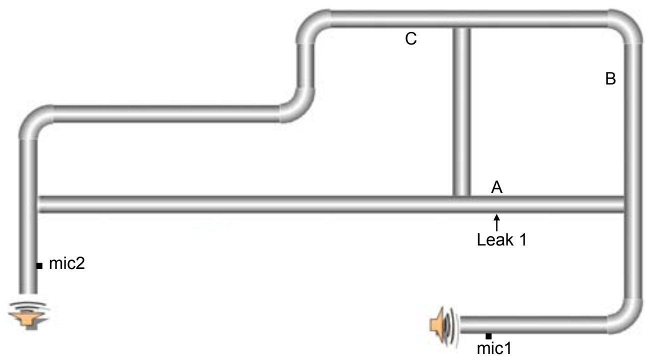

Figure 6: A schematic drawing of the pipe network

The network used in this experiment contained two independent loudspeakers and two microphones, labelled *mic1* and *mic2*. An acoustic wave was injected into the pipeline network using the two loudspeakers in turn and the resulting acoustic trace was recorded from each of the microphones. The network contained a leakage at the point marked *leak 1*, which was a distance of 1.90m from *mic1*. The size of the hole was approximately 10mm in diameter.

The first step in the experiment was to record the reference trace of the pipe network. This was achieved by injecting an acoustic pulse in each loudspeaker in turn and recording the signal measured by *mic1* and *mic2*. The leakage was then introduced in to the network and the signals measured by *mic1* and *mic2* were again recorded. The difference trace recorded by *mic1* is provided in figure 7. This signal shows that there is no difference between the two signals until approximately 0.025 seconds. From knowledge of the speed of sound and the distance between the speaker and microphone, it is possible to identify the location of the leakage as being approximately 1.92m from *mic1*. Referring back to figure 6, this means that the leakage could either be at point A or B. By analysing the signal recorded by *mic2* it is then possible to identify the distance between the leakage and that microphone. In this experiment this indicated a leakage at point A or C. Hence the location of the leakage is isolated to point A. Thus the experiment has identified the location of the leakage to within 2cm of its actual location.

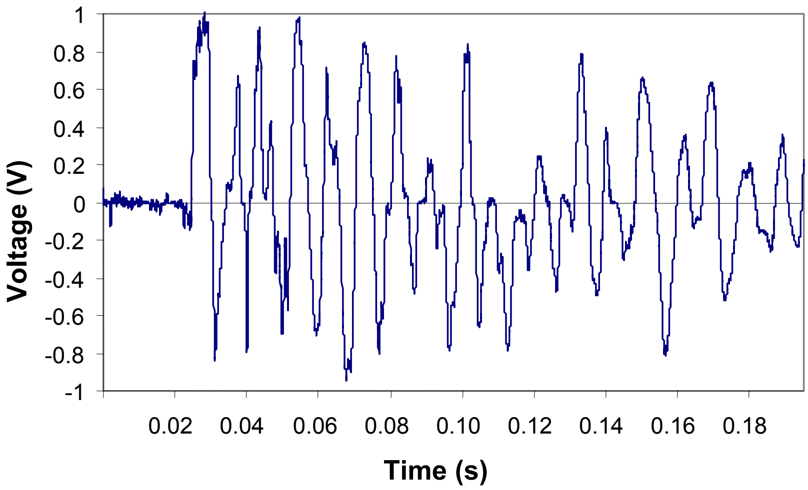

Figure 7: Difference trace for Pipeline Network

CONCLUSIONS

The primary conclusions from the work which has been completed so far are:

- The method has been shown to work well in both steel and PVCu pipelines.
- The method provides an indication of the relative size of any leakage.
- Initial results indicate that the approach is unaffected by ambient noise conditions.
- The approach has been demonstrated to work in pipelines filled with stagnant and flowing fluid, and experiments using both liquid and gas have been performed.
- A particularly strong advantage of the method is that it enables blockage to be detected as readily as leakage.
- The use of multiple acoustic sources, multiple sensors and directionally sensitive processing techniques enables leakage and blockage to be detected and located in complex pipeline networks.
- Linking the source and the sensors into a SCADA system enables the health of the pipeline to be monitored continuously and remotely.

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