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# On-Line Health Monitoring of Underground Pipelines by Source Localization of Leak Damages

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ABSTRACT: This study aims to perform leak detection on an old oxygen underground pipeline in operation. The target pipe is a 220-meter section of nominal diameter 80A steel pipe that supplies oxygen for welding in heavy industrial facilities. In order to observe the response characteristics of the coupled vibration propagating through the pipe, an impact experiment was conducted to experimentally derive the frequency band and propagation velocity of the coupled vibration in the tested compressible fluid transportation pipe. Conventional leak detection methods mainly depend on frequency-domain filtering because it is difficult to improve the signal-to-noise ratio through averaging in the time domain due to the random nature of the leak signal. In this study, we propose a leak detection algorithm with improved detection performance by utilizing an ensemble cross-correlation function that applies averaging in the τ-domain based on the deterministic arrival time difference characteristics of the leak signal. In addition, leak detection using two sensors is likely to misjudge the leak source near the sensor due to noise propagating outside the detection range, and a single damage positioning result is insufficient to determine the leak damage. Therefore, this study proposes a distributed measurement-based leak detection technique and a decision map based on multiple damage localization results. The experimental results confirmed that damage localization using coupled vibration is possible in compressible gas transport pipelines, and experimentally verified that leakage can be effectively detected with a location error rate of approximately 1.37% in industrial sites that are always in operation.

KEY WORDS: On-line monitoring; Underground pipelines; Leaks; Source localization; SHM.

## 1 INTRODUCTION

Acoustical and vibrational signals can be generated by a number of different damage sources in underground pipelines such as growing cracks, corrosion progress, connection part movement, third party interference, direct impact and leakage etc.. On-line monitoring technology for buried pipeline is one of the main concerns for most underground pipeline management systems that maintain buried structures that are difficult to access. There are many factors that can threaten the health of buried pipelines, but among them, leakages by aging and damages by third-party interference are known to be one of the main causes of failure, and it is emerging as a major social problem that causes safety problems such as leakage and ground subsidence due to damage. Ultimately, the pipeline failure owing to these kinds of damage lead to economic loss and huge accidents such as a ground collapse by a sinkhole, an eruption by leakage. Hence, it is extremely important to detect and localize such damages at the very early stage in order to prevent catastrophic failures. However, most of underground pipelines are located in very noisy urban areas, and these harsh conditions inflicted on practical difficulties in measuring meaningful acoustic vibratory signals. Especially, several kinds of background noise such as traffic, natural environment and sound pollution causes difficulty in signal analysis. Therefore, this study proposes a distributed measurement-based leak detection technique and a decision map based on multiple damage localization results and monitoring range information, and implements an algorithm to improve the reliability of damage localization in industrial sites where noise is frequent.[1-6]

## 2 WAVE PROPAGATION AND EXPERIMENT

In this study, acoustic wave propagation coupled with surrounding boundaries including cast iron and steel pipes is theoretically analyzed and the wave speed was confirmed with experiment.

When the impact by foreign damage occurs on a fluid filled pipe, a structural pipe vibration as well as a fluid-pipe coupled vibration will occur. That is, a pipe vibration mode appears in various mode shapes in shown in Figure 1. Also the fluid borne wave, non-dispersive wave in free space, is changed to dispersive wave by coupled vibration. This role is executed by “n=0” mode. In other words, the 'Breathing' mode creates a new wave in the fluid filled pipe domain. This “Breathing” mode is important for detecting a damage sources.[1]

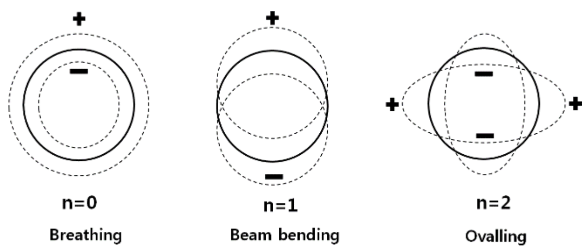


Figure 1. Mode shapes of a circular cylindrical shell [1].

In this study, the buried pipe used in the field experiment was an oxygen supply pipe for welding process, and seven sensors

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were installed in a 220 m section. Several types of impact hammer and accelerometer were used as the artificial impact source and sensors. To examine the possibility of damage location markers in compressible fluid transport pipelines, the velocity change characteristics were compared for compressible and incompressible fluids. Steel pipes with a nominal diameter of 80A, which is the diameter of actual pipelines installed in the field, were used. Basically, one-dimensional source location algorithm was used to estimate the time delay with the cross-correlation method.

In order to experimentally verify the speed of the coupled vibration propagating in the compressible fluid transport pipe, an impact hammer(086D20, PCB Piezotronics, United States of America) was used to generate coupled vibration at an arbitrary location to reproduce the impact damage situation, and vibration accelerometers(393A03, PCB Piezotronics, United States of America) were installed at distances of 42.15 m and 220 m from the damage location, respectively. Additionally, the pressure applied to the buried pipe during the experiment was 55.154 Pa. Theoretically, it can be confirmed that incompressible fluids exhibit propagation velocity dispersion characteristics starting from a lower frequency band than compressible fluids. The velocities at 0 Hz are approximately 1381 m/s, 1319 m/s, 444 m/s, and 326 m/s, respectively.At this time, the theoretical propagation speed of the coupled vibration is approximately 326.5 m/s.

## 3 VERIFICATION AND RESULTS

First, we defined a ‘time history frame’ as each separated intrinsic parameter of input time signal. Then we obtained a couple of parameters such as frequency and intensity from time signal. We proposed a leak detection algorithm with improved detection performance by utilizing an ensemble cross-correlation function that applies averaging in the τ-domain based on the deterministic arrival time difference characteristics of the leak signal. Figure 2 shows typical raw signal based on ensemble cross-correlation function.

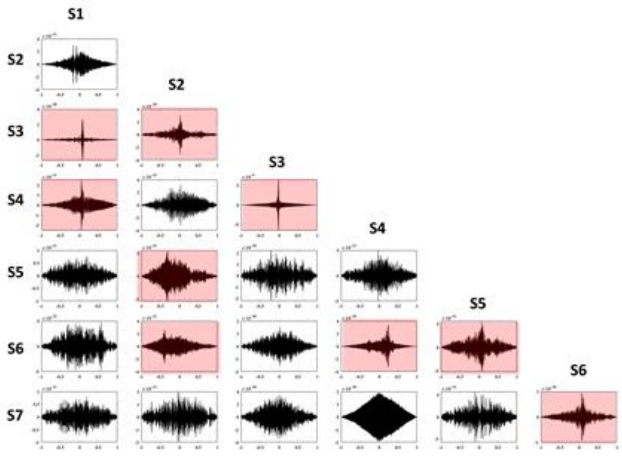


Figure 2. Typical raw signal based on ensemble cross-correlation function.

In addition, leak detection using two sensors is likely to misjudge the leak source near the sensor due to noise propagating outside the detection range, and a single damage location positioning result is insufficient to determine the leak damage. Therefore, this study proposes a distributed measurement-based leak detection technique and a decision map based on multiple damage localization results and monitoring range information, and implements an algorithm to improve the reliability of damage localization in industrial sites where noise is frequent. Among these results, in the case of 100 m, the possibility of an abnormal location is ambiguous because the result is from only a single combination, whereas in the case of the range of 55~60 m, the result is judged to be significant because the results from multiple combinations are the same. Figure 3 shows that the result of a distributed measurement-based source localization.

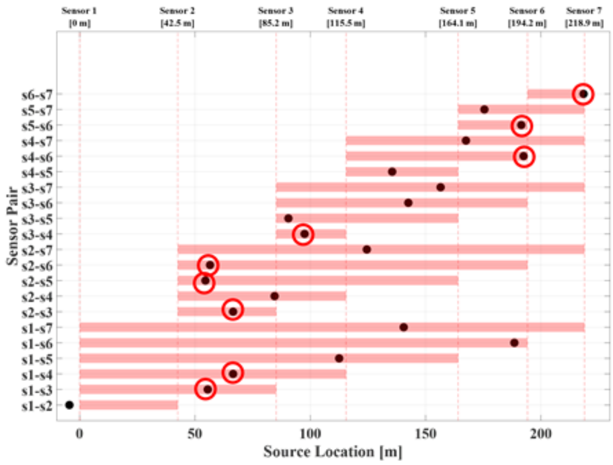


Figure 3. Distributed measurement-based source localization.

## 4 CONCLUSIONS

In this study, seven sensors were installed in a 220 m section, and micro-leakage was detected in a 55-60 m section by applying the proposed algorithm. The experimental results confirmed that damage localization using coupled vibration is possible in compressible gas transport pipelines, and experimentally verified that micro-leakage can be effectively detected with a location detection error rate of approximately 1.37% in buried pipelines in industrial sites that are always in operation.

## ACKNOWLEDGMENTS

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