PERFORMANCE EVALUATION OF AN OIL LEAKAGE MONITORING SYSTEM USING ULTRASONIC SENSORS

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ABSTRACT

An oil leakage monitoring system (OLMS), which is used for monitoring oil leakage in a conduit, is tested in this study. The OLMS consists of a pair of ultrasonic flow sensors and a test conduit which is vertically branched from the main conduit located underground. The OLMS can detect fault signals from the ultrasonic sensors to decide if the signals come from oil leakage in the conduit. Leakage detection is enabled by detecting signal quality of transmitted and received ultrasonic signals between the two ultrasonic sensors. The ultrasonic signals can be influenced by working fluid such as air and oil. The OLMS with various conduit diameters (40 mm, 50 mm, 80 mm and 100 mm), materials (SUS 304 and carbon steel) and working fluids (oil and water) was evaluated systematically. 100 random tests were performed to see whether the ultrasonic signals can indicate the instance of air bubble entrainment. The performance evaluation showed that all the OLMS showed the accuracy less than 5 mm with confidence level of 95 %.

INTRODUCTION

An oil leakage monitoring system (OLMS) is used for monitoring environmental pollution due to oil leakage. Every gas station in South Korea is equipped with OLMS due to government restriction. Rail road companies also have their own team to monitor oil leakage from diesel trains since the soil pollution problem gives a social issue to the residential area. Restoration costs from the oil leakage are enormous more than 150 million US dollars per year in South Korea. OLMS is essential to detect the amount oil leakage, which can reduce such restoration costs.

There are a lot of technologies to implement the OLMS. Many products relies on height measurement techniques using a float, a magnetostrictive sensor, or an ultrasound sensor. Pressure drop method can be also used for leak detection since the working fluid are conveyed by high pressure in the conduit. However, if vacuum technology is applied for conveying the working fluid in the conduit, the pressure drop method cannot be used any more. In this case, the height measurement techniques are useful because this method can be used in the vacuum environment in the conduit.

This research focuses on the ultrasound technique to detect the amount of oil leakage by reading height change in a vertical conduit. The ultrasound technique should be essential since many conduits are made with carbon or stainless steel and it is not transparent materials. Nevertheless, the ultrasound technique can access the flows in the conduit non-invasively. Particularly, communication between two ultrasonic sensors are a useful technique if there are air bubbles inside oil flows in the conduit. It is because the air comes into the vertical conduit if oil in the conduit is leaked. Then, the ultrasound waves, which constituted an ultrasonic path between two ultrasonic sensors, are reflected due to impedance mismatch at the interface between air and oil. Therefore, an on/off signal can be generated with the two sensors whenever oil leakage happens.

The purpose of this study is to attain the performance of ultrasonic OLMS with detection probability more than 99 %. Toward this end, the minimum detection length of 5 mm was defined. 100 measurements were performed to test the reliability of the ultrasonic OLMS. Such measurements were repeated with respect to the conduit diameter and the flow rate in the conduit. The experimental setup for this study and its results are explained as follows.

EXPERIMENTAL SETUP

The schematic diagram of the ultrasonic OLMS is as shown in Fig. 1. Two ultrasonic sensors, of which frequency is 1 MHz, are attached at the surface of a vertical conduit. The two sensors form an ultrasonic path considering the Snell's law, which states the reflection and the refraction of ultrasonic waves in acoustic media such as oil flow in the conduit. If the oil in the conduit is not leaked out, oil surrounds the ultrasonic path such that ultrasonic pulse signals can be transmitted and received between the two ultrasonic sensors. However, if there is an oil leakage, the oil height is reduced to interfere with the ultrasonic path. Then, the receiving signals of an ultrasonic sensor start to be reduced. It is because the mismatched impedance at the air-oil interface can deteriorate the signal quality. If the oil level is so lowered to disconnect the ultrasonic path, there are no receiving signals from the ultrasonic sensor indicating that oil leakage is happened. Thus, the ultrasonic receiving signal can be used as an on/off signal for oil leakage monitoring.

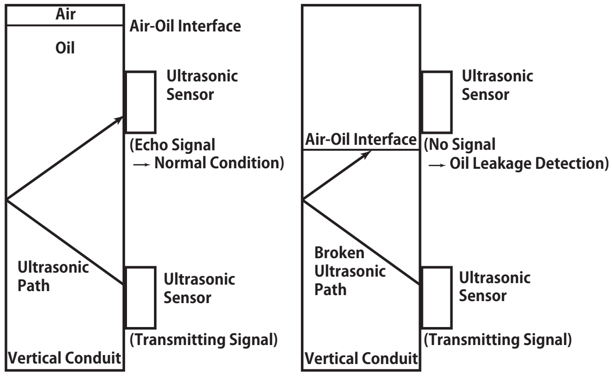

Figure 1. Schematic diagram of the ultrasonic OLMS

An experimental setup for an ultrasonic OLMS is as shown in Fig. 2. Oil, e.g., calibration-K oil by Castrol Inc., is circulating in the experimental rig to generate steady oil flow along the vertical conduit. If a leak valve is opened, the flow rate in the vertical conduit is reduced and the oil level starts to go downwards. For leakage detection, two ultrasonic sensors are operating to generate pulse signals. The pulse signals continue while the oil level are located above the ultrasonic path. However, when the oil level is located in between the ultrasonic path, the pulse signals are not generated to indicate the oil leakage. A camera is installed in front of a small and transparent conduit connecting the vertical conduit. The camera takes a picture of the oil level at the same time when the pulse signals are not generated any more. Because there is a ruler along the transparent conduit, the minimum detection length can be measured by comparing the instance with the leak detection and the height of the oil level.

For repeatable experiments, 100 repetitive measurements were grouped as 1 experimental run. Each experimental run was designed to change parameters such as 4 conduit diameters (40, 50, 80, 100 mm), 2 conduit materials (carbon steel and stainless steel), and 2 kinds of working fluids (water and calibration-K oil by Castrol Inc.). One failure among the 100 repetitive measurements in this experimental run indicated the reliability of 99 %. The viscosity of the oil was 3.33 cSt at 20 °C.

EXPERIMENTAL RESULTS

The ultrasonic signals for leak detection are exemplified as shown in Fig. 3. The above figure shows when the oil level is not interfering with the ultrasonic path, and the below figure shows when the oil level is interfering with the ultrasonic path. In the oil flow along the vertical conduit, the ultrasonic echo signal is detected at (90 - 100) μs clearly. If there is oil leakage, the echo signal is no longer clear and is detected at (40 - 60) μs. This can be different acoustic impedance and sound speed between air and oil.

If the ultrasonic signal is normally transmitted and received, it can be transformed into pulse signals. From Fig. 4, it can be noticed that there is a triggering level by defining the start and the end time of the echo signals. The start time is defined as the time when the echo signal becomes more than 10 % of its maximum peak. Likewise, the end time is defined as the time

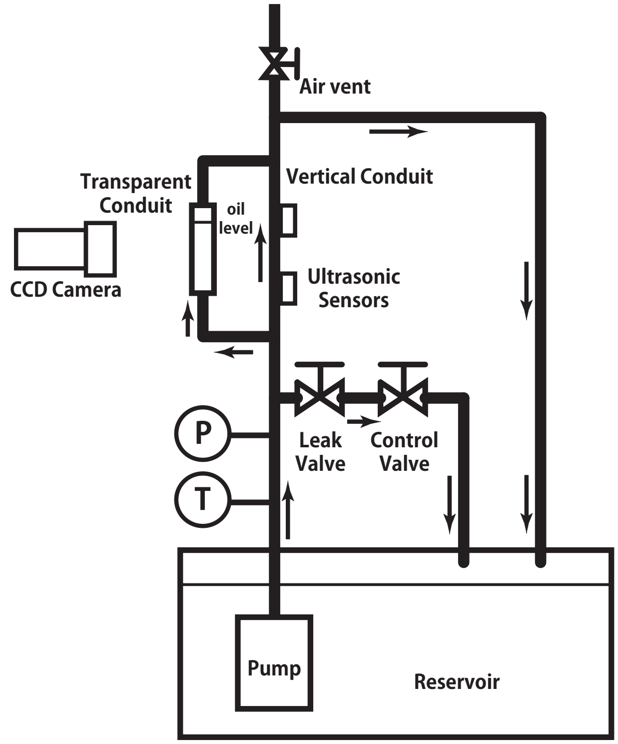

Figure 2. Experimental setup for an ultrasonic OLMS

when the echo signal becomes less than 10 % compared with its maximum peak.

The results on the reliability tests are as shown in Fig. 4. The averaged height triggering the oil leakage is from -3 mm. This value is within the criterion of $\pm$5 mm. The reliability to detect the oil leakage was 100 %, in that the echo signals were disconnected whenever the oil level was interfering with the ultrasonic path between the two ultrasonic sensors. The height difference for detecting the oil leakage can be statistically distributed as shown in Fig. 5. For each run, 100 measurements were tried. The height difference was distributed between 0 mm and -3 mm, all of which were bounded within the minimum detection length of 5 mm.

CONCLUSIONS

The ultrasonic OLMS was installed in a vertical conduit to test its reliability of oil leakage detection. Two ultrasonic sensors, which were attached on the surface of the conduit, generated ultrasound waves through the oil flows to make an ultrasonic path. When there was no leakage, echo signals were generated indicating the normal condition in the conduit. However, if there was oil leakage, echo signals were not generated because the oil level was interfering with the ultrasonic path. Here, downward motion of the oil level was interpreted as oil leakage. The difference of acoustic impedance between air and oil caused the different shape of echo signals.

The ultrasonic OLMS showed good performance since it operated whenever the oil level was dropped within $\pm$5 mm from the reference height. The probability of leak detection was 100 %. This means that the ultrasonic OLMS can be used as a good

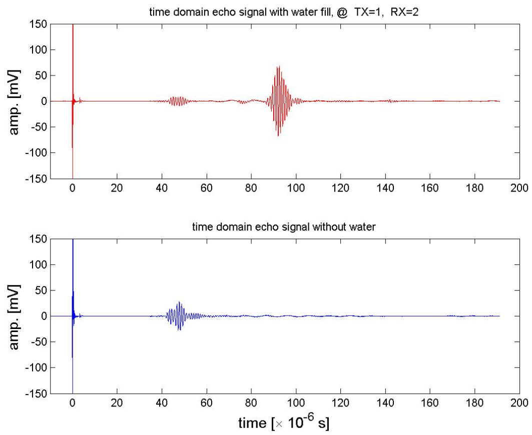

Figure 3. Echo signals along the ultrasonic path of the ultrasonic OLMS

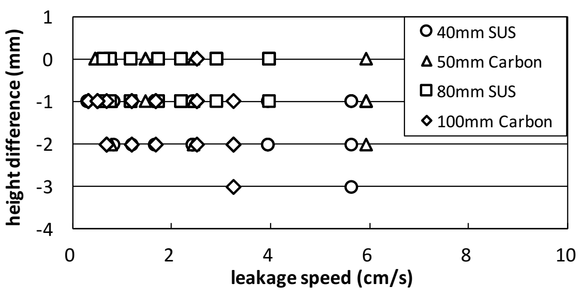

Figure 4. Reliability test on the ultrasonic OLMS

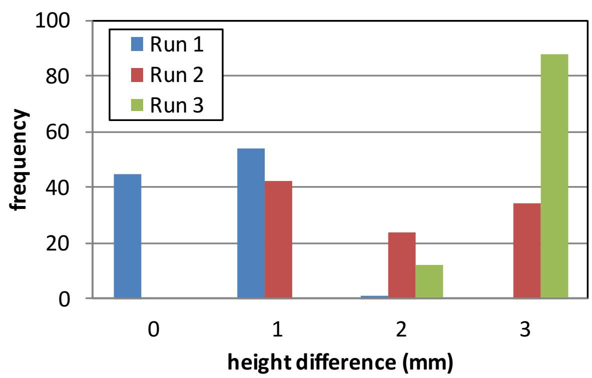

Figure 5. Statistics for the reliability test with the ultrasonic OLMS

indicator of oil leakage detection in a gas station, where an oil reservoir should be constructed under the ground according to the governmental rule in South Korea.

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