EFFECT OF PINHOLE SHAPE WITH DIVERGENT EXIT ON AE CHARACTERISTICS DURING GAS LEAK

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Abstract

AE technology has been applied to gas leak detection and inspection. However, it is difficult to detect and inspect the gas leak consistently because measured AE waveforms are different from leak pressures and shapes of leak parts. In this report effects of the stepwise and straightforward pinholes on AE characteristics during gas leaking were discussed. When the pressure reached to about 0.11 MPa in the case of the stepwise pinholes, AE amplitude tends to go up and down, the peak at about 150 kHz was observed. It was found to be easy to detect gas leak from the stepwise pinholes, as compared with the straightforward pinholes.

Key Words: Gas leak; AE waveforms; FFT

1. Introduction

The leak detection for piping faces many challenges. Problems mainly consist of the necessity of many processes for the inspection and difficulty to inspect a gas pipe placed under ground. Acoustic emission monitoring as one of the well-established nondestructive technologies may be put to practical use in future for the leak detection technology. However, the method has not been used widely to monitor the gas leak from pipes. Even if there is no defect before operation or some defects are too small to detect during inspection, various defects occur or develop under operation because of temperature, pressure, and environmental condition and become so large that these cannot be neglected. In recent work, it was reported that the characteristic frequency of AE due to gas leak was 10 kHz [1]. However, there are no reports on AE source. If the AE source is identified, it is expected that the method advances. In this study, AE characteristics were investigated at the frequency of more than 100 kHz.

2. Experimental Procedures

A pipe specimen was 20 mm in outer diameter and 150 mm in length and designated as SGP20A. The pipes were reduced to wall thickness of 0.6 to 2.0 mm to obtain a flat surface and to attach an AE sensor. The surface was mechanically polished to #1000 mesh, and a pinhole was made in the wall. The diameters of the straight pinhole were 0.3, 0.5 mm and the stepwise pinholes in these diameters were made to obtain divergent profiles. The overall view of the apparatus used in the experiment is illustrated in Fig. 1. V1 and V2 valves controlled the pressure. An AE sensor with resonant frequency of 100 kHz was placed at 10 mm from the pinhole to detect leak signal. The test pressure was varied from 0.10 MPa to 0.30 MPa. The total gain of detected signal was 60 dB through a band-pass filter of 100 to 1200 kHz. Threshold level was 40 dB that corresponded to 100 \( \mu \)V at the preamplifier input voltage. AE signals were detected continuously from 0.10 MPa to 0.30 MPa. Compressed air flow was stabilized through the pre-flow pipe of 1000 mm length. If the energy release process due to air leak changes, the
detected AE activity will probably also changes. When AE is generated near the pinhole, continuous-type signals are obtained [2]. In order to clarify the energy release due to air leak, mean amplitude was numerically calculated from the digitized AE waveform and represents the relative energy release due to air leak. On the other hand, the frequency spectrum of the AE waveform due to air leak is expected to clarify the behavior of AE sources in detail [3].

Fig. 1  Schematic view of experimental setup.

3. Results and Discussion

Typical AE waveforms detected during leak at the pressure of 0.10 MPa to 0.30 MPa with the pinhole diameter of 0.3 mm and the wall thickness of 1.00 mm are shown in Fig. 2. The waveform at the pressure of 0.10 MPa stands for electrical noise of the system. The amplitude increases with increase of the pressure and increases rapidly, when the pressure increases from 0.20 MPa to 0.30 MPa. It is also observed that the high frequency components become dominant. The higher the pressure, the more air volume flows through the pinhole. Therefore, Mach number that designates the ratio of the flow velocity to the sound velocity can reach unity in the cross-sectional area in steady flow [4]. Based on the assumption that the pinhole is a converging nozzle, the critical pressure, at which the flow velocity reaches the sound velocity was calculated by equation below, where $P_1$ is the pressure in pipe, $\rho_1$ is the air density in pipe, $P_2$ is the ambient pressure, $\rho_2$ is the ambient air density, $A$ is the pinhole area, $\omega_2$ is the flow velocity and $\kappa$ is equilibrium constant [5]. When $P_2$ is 0.10 (MPa), $\rho_1$ and $\rho_2$ are 2.65 and 1.20 (kg/m$^3$), $\kappa$ is 1.4, $\omega_2$ is 343.7 (m/s), respectively, and the critical pressure becomes 0.22 (MPa).

\[
\rho_2 A \omega_2 = \frac{2 - \frac{\kappa}{\kappa - 1}}{- \frac{\rho_2}{\rho_1}} \left( 1 - \frac{P_2}{P_1} \right)^{\frac{\kappa - 1}{\kappa}}
\]

When the pipe pressure is over the critical value of 0.22 MPa, expansion wall (namely, shock cell outside the pinhole) occurs and screech tones are also generated. The screech tones are known to indicate feedback loops driven by the large-scale instability waves of the airflow [6].

The relations between the pressure of released air and the mean AE amplitude from 0.3 mm and 0.5 mm diameter straight pinholes, and 0.2 mm and 0.8 mm depth stepwise pinholes are shown in Fig. 3 to Fig. 6, respectively. The mean AE amplitude increases monotonically with increase of the pressure to 0.22 MPa as shown in Fig. 3. When the pressure exceeds 0.22 MPa,
Fig. 2 Typical AE waveforms detected during leak at pressures of 0.10 MPa, 0.20 MPa and 0.30 MPa with pinhole diameter of 0.3 mm and wall thickness of 1.00 mm.

The mean amplitude increases as well and continues to fluctuate with an increase of the pressure. This characteristic is consistent with AE waveforms shown in Fig. 2. In 0.5-mm pinhole, the amplitude also increases with increase of the pressure as shown in Fig. 4. When the pressure is over 0.22 MPa, the amplitude also continues to oscillate wildly. Actually, the ranges of amplitudes broadened starting at 0.18 MPa. We believe that this active AE behavior depends on the generation of screech tones.

With a stepwise pinhole of 0.2 mm depth, the amplitude starts to jump as the pressure reaches 0.11 MPa as shown in Fig. 5. When the pressure is above this range, the mean amplitude increases monotonically with increase of the pressure. This is similar to Fig. 3. However, when the pressure is over 0.22 MPa, the amplitude continues to increase gradually without large changes seen in Fig. 3. If a pinhole is shallow stepwise, it is believed that the expansion wall becomes difficult to form because of the large-scale instability of the airflow. This is quite different in deep stepwise pinhole. Here, the amplitude fluctuated very strongly starting at the
pressure of 0.11 MPa and especially at 0.15 MPa as shown in Fig. 6. When the pressure is over 0.15 MPa, the amplitude continues to increase gradually, but still oscillating over a broad range. The mean AE amplitude is supposed to become unstable before the pressure was over the critical value. It is apparent that the simple theory does not apply and the mechanism of AE generation in the stepwise pinholes is different from that in the straight pinhole (shown in Fig. 5 and Fig. 6).

The mean AE amplitude from the stepwise pinhole, whose depth is 0.8 mm, is larger than that from the shallow stepwise pinhole. The amplitude seems to be quite unstable and results from turbulent flow and vortex increase. Four frequency spectra of detected AE waveforms at the pressure of 0.30 MPa are shown in Fig. 7. The power spectrum near 400 kHz is higher than
that near 150 kHz in the straight pinhole but the power spectrum near 150 kHz is higher than any other power spectrum in the stepwise pinhole. We propose a model as shown in Fig. 8 to explain a part of the experimental results.

![Graph](image)

**Fig. 5** Relation between the pressure of released air and the mean AE amplitude from a stepwise pinhole whose depth is 0.2 mm

![Graph](image)

**Fig. 6** Relation between the pressure of released air and the mean AE amplitude from a stepwise pinhole whose depth is 0.8 mm

The leak air flows to adhere to one side of the wall at 0.11 MPa as shown in Fig. 8. In the range of 0.11 MPa to 0.15 MPa, strong turbulent flow and vortex appear along the pinhole wall because of remarkable stepwise effect. When the pressure is over 0.15 MPa, it is expected that the stepwise effect along the pinhole wall diminishes somehow because of increase of air flow.
4. Conclusion

Detection and inspection of AE during gas leak from pipes with straight and stepwise pinholes have been investigated within the frequency range of 100 kHz to 1200 kHz. Results obtained are as follows:
1. In stepwise pinholes, the mean AE amplitude starts to fluctuate when the pressure reaches 0.11 MPa.
2. With the stepwise depth increasing, the mean AE amplitude increases and airflow becomes unstable.
3. In stepwise pinholes, the power spectrum near 150 kHz is higher than any other zones of power spectrum.
Fig. 8 Schematic model of the AE source.

References