Frequency Characteristics of Acoustic Emission Waveforms 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, first of all the effect of the pinhole diameter on AE characteristics during gas leak was investigated. The larger the pinhole diameter became, the lower the peak frequency of detected AE waveforms became over the critical gas pressure (0.22 MPa), because the source of AE was associated with the screech tone in a transonic jet stream. Secondly, the effect of straight and stepwise pinholes on AE characteristics was examined. When the pressure reached to about 0.11MPa in the case of the stepwise pinholes, AE amplitude tends to go up and down, the peak at about 150kHz was observed. It is considered to be due to the self-exited vibration at the bottom of the stepwise part. It was found to be easy to detect gas leak from the stepwise pinholes, as compared with the straight pinholes. Finally, the effect of the slit shape on AE characteristics was also investigated. Two peak frequencies of AE that corresponded to the screech tones generated at the each edge of the slit decreased with increase of the gas pressure over the critical gas pressure.

INTRODUCTION

The leak detection for piping is important to inspect various types of industrial equipments. There are problems that consist of necessity of many processes for the inspection and difficulty to inspect a gas pipe placed under the ground. AE monitoring is one of the well-established non-detective technologies that may be put to practical use in future. However, the method has not been used 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. AE studies on the attenuation of elastic waves in pipelines and the acoustic noise environment associated with leak detection [1, 2] have been mainly conducted under the opinion that the AE amplitude is proportional to the leak energy [3]. In recent work, it was reported that the characteristic frequency of acoustic emission due to gas leak was 10kHz [4]. However, there are no reports on acoustic emission source. If the AE source is identified, it is expected that the method progresses. In this study, the effect of pinhole diameters and shapes on AE peak frequency detected during the gas leak over the critical pressure has been investigated. The AE source was discussed about whether to be associated with the screech tone in the jet stream at the subsonic velocity.

EXPERIMENTAL PROCEDURES

A pipe was 20mm in outer diameter and 150mm in length as designated by SGP20A. The pipes were reduced to wall thickness of 1.0mm to obtain a flat surface and to attach an acoustic emission sensor. The surface was mechanically polished to #1000 grain, and a pinhole was made in the wall. The diameters of the straight pinhole were 0.3mm, 0.5mm and 3.0mm, and the stepwise pinholes in these diameters were made to obtain divergent profiles. The slits of different shapes were made as mentioned afterward. The specimen and the overall view of the apparatus used in the experiment are illustrated as shown in Fig. 1. V1 and V2

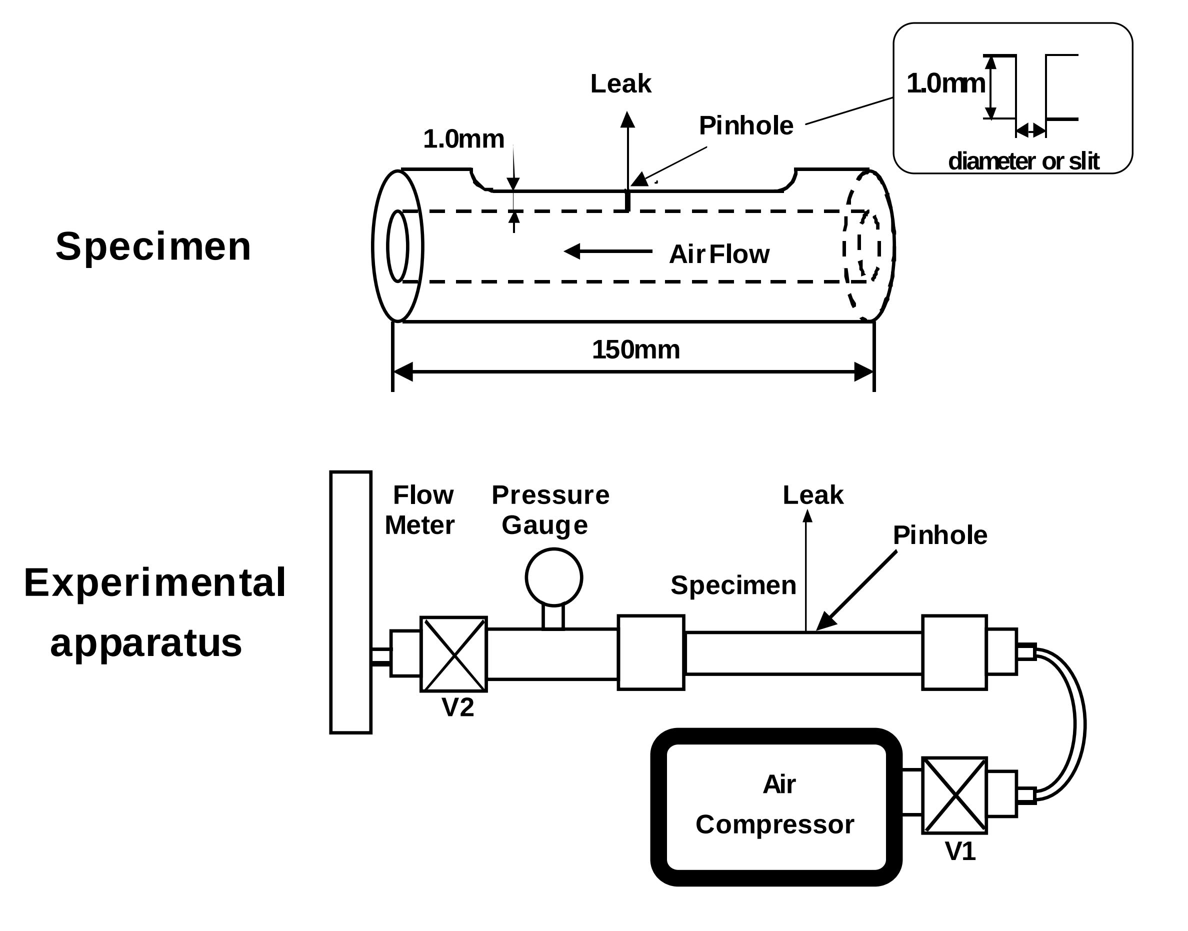

Fig.1 The specimen and the overall view of the experimental apparatus

valves controlled the pressure. Each AE sensor with broad frequency response (AE-900M) and resonant frequency of 48 kHz (S2SG) was placed at 10mm from each pinhole to detect leak signal. The test pressure was from 0.10MPa to 0.30MPa. The total gain of detected signal was 60dB through a band-pass filter of 100 to 1200kHz or 20kHz to 100kHz, respectively. Threshold level was 40dB that corresponded to 100 µV at the preamplifier input voltage. AE signal was detected continuously from 0.10MPa to 0.30MPa. If the energy release process due to air leak changes, the detected AE activity will probably also changes. If AE is generated near the pinhole, continuous type signals are reportedly obtained [5]. The distance between a sensor and the pinhole was fixed to be 10mm. In order to clarify the energy release due to air leak, mean amplitude was numerically calculated from the digitized AE waveform. As a result, the calculated mean amplitude is certain to be the relative energy release due to air leak. On the other hand, the frequency spectrum of the AE waveform due to air leak is considered to be able to make clear the behavior of AE sources in detail [6]

RESULTS AND DISCUSSION

Typical frequency spectra of detected AE waveforms at the pressure of 0.20MPa and 0.25MPa in the pinhole diameter of 0.3mm are shown in Fig. 2. A peak frequency can be seen

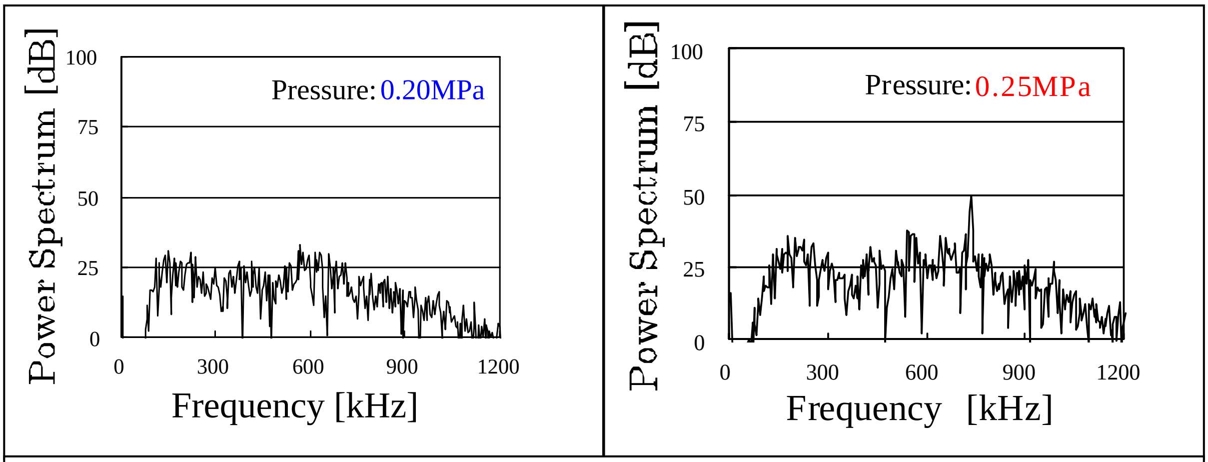

Fig. 2 Frequency spectra of detected AE waveforms at the pressure of 0.20MPa and 0.25MPa from the pinhole diameter 0.3mm

at 700kHz from the pinhole diameter of 3.0mm at the pressure of 0.25MPa. The amplitude increases with increase of the pressure. The amplitude increases rapidly, when the pressure increases from 0.20MPa to 0.30MPa. It is observed that the high frequency component becomes predominant. The higher the pressure is, the more the flow volume through the pinhole is. Therefore, Mach number that designates the ratio of the flow velocity to the sound velocity can reach to 1 in the cross-sectional area in steady flow [7]. Based on the assumption that the pinhole is a converging nozzle, the critical pressure at which the flow velocity reaches to the sound velocity was calculated in the previous paper [8]. The critical pressure became 0.22MPa. When pressure is over critical value, 0.22MPa, expansion wall, namely, shock cell outside the pinhole occurs and screech tones also occur. The screech tones are known to mean feedback loops driven by the large-scale instability waves of the airflow [9]. We have also considered that screech tones are generated. It is reported that the screech tone generated from the converging nozzle of 11.0mm in diameter is characterized to show the peak frequency at less than 20kHz and that the peak frequency decreases with increase of the pressure [9]. In order to make clear the discrepanct between these peak frequencies in the both experiments, we measured the AE signal during gas leak at the middle size pinhole of 3.0mm in diameter. Frequency spectra of detected AE waveforms at the pressure of 0.30MPa in the frequency range of 20kHz to 100kHz and 100kHz to 1200kHz from the pinhole diameter of 3.0mm are shown in Fig. 3. We can see the peak frequency at 60kHz and 120kHz as the typical second harmonic. The peak frequency decreases with increase of the pressure as shown in Fig. 4, which is characteristic of the screech tone. The region of the AE frequency is considered to be in less than 400kHz in the case of the pinhole diameter of 3.0mm. As a result, the relation between the pinhole diameter and the peak frequency of the screech tone is shown in Fig.5. The peak decreases steeply to 0.5mm in diameter and afterward gradually to 3.0mm in diameter with increase of the pinhole diameter. The high frequency band for the AE signal is clearly useful to detect the pinhole of less than 1.0mm in diameter difficult to visualize. If a pinhole is stepwise, it is considered that the expansion wall becomes difficult to form because of the large-scale instability of the airflow. The amplitude fluctuates very quickly at the pressure of 0.15MPa. When the pressure is over 0.15MPa, the amplitude continues to increase

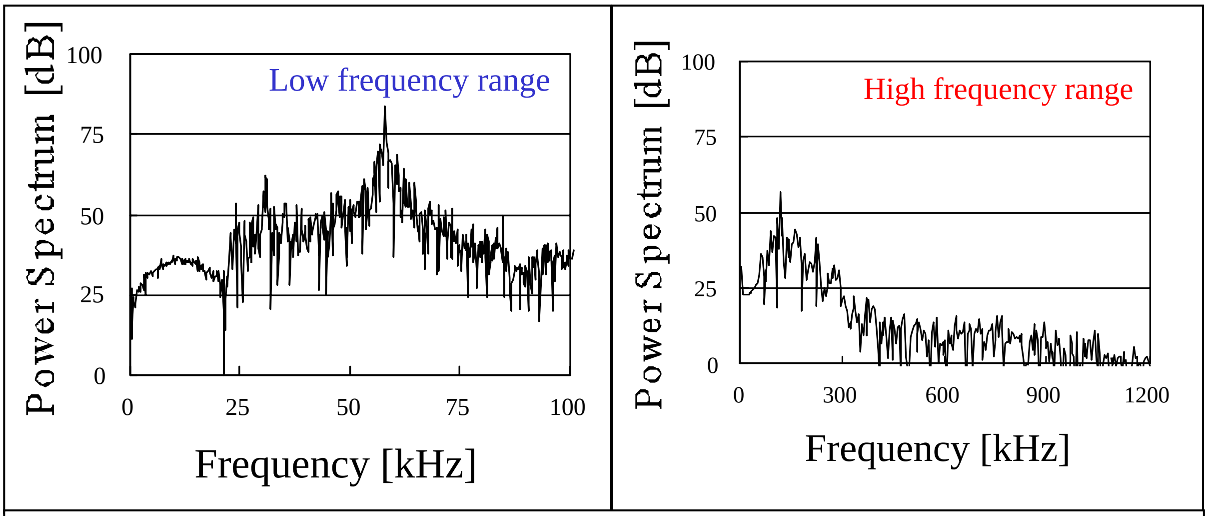

Fig. 3 Frequency spectra of detected AE waveforms at the pressure of 0.30MPa in the frequency range of 20kHz to 100kHz and 100kHz to 1200kHz from the pinhole diameter of 3.0mm

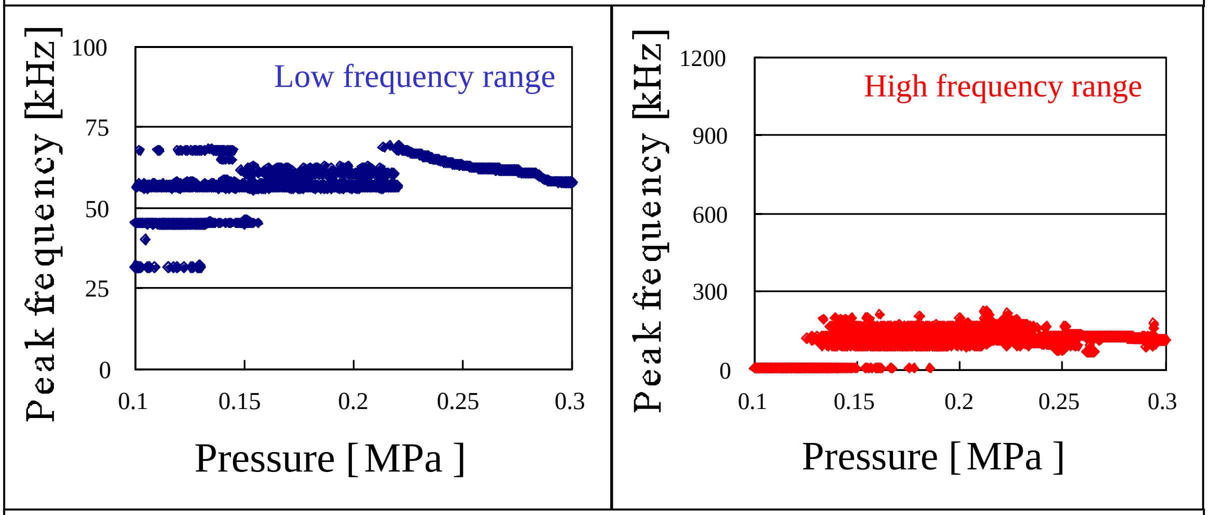

Fig. 4 Relation between the pressure and peak frequency in the frequency range of 20kHz to 100kHz and 100kHz to 1200kHz for the pinhole diameter of 3.0mm

gradually, taking the broad change. The mean AE amplitude is considered to become unstable before the pressure was over the critical value. It is apparent that the mechanism of AE generation in the straight pinhole is different from that in the stepwise pinhole. The mean AE amplitude from the stepwise pinhole whose depth is 0.8mm is larger than that from the stepwise pinhole whose depth is 0.2mm. The former amplitude seems to be unstable. Therefore, it is considered that turbulent flow and vortex increase when the depth of the stepwise pinhole increases.

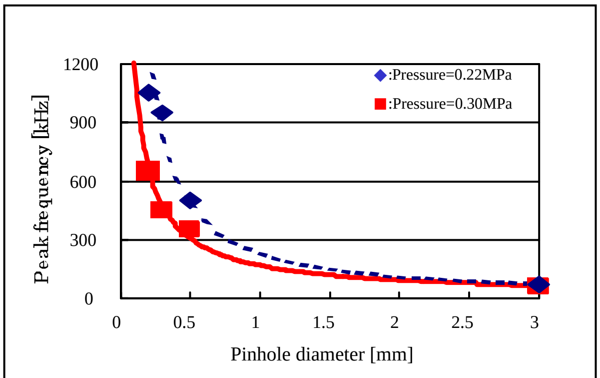

Fig. 5 Relation between the pinhole diameter and the peak frequency of the screech tone

Many defects that give rise to abrasion, stress corrosion cracking, creep fracture and fatigue fracture occur under cruel environmental condition. Now that these defects are formed, they progress in the slit shape perpendicularly to stress direction. Detection of gas leak from slit defects is important for field application. The same experiment has been conducted using four types of slits as shown in Fig. 6. The frequency spectra of detected AE waveforms at the pressure of 0.3MPa from slit shapes of type A, B, C and D, respectively, are shown in Fig.7. We can see the peak frequencies at 430kHz in type A, 330kHz in typa B, 130kHz in type C and 140kHz in type D, and also each second

Type	A	B	C	D
W[mm]	0.2	0.2	0.5	0.5
L[mm]	3.2	5.2	3.5	5.5

Fig. 6 Slit shapes used

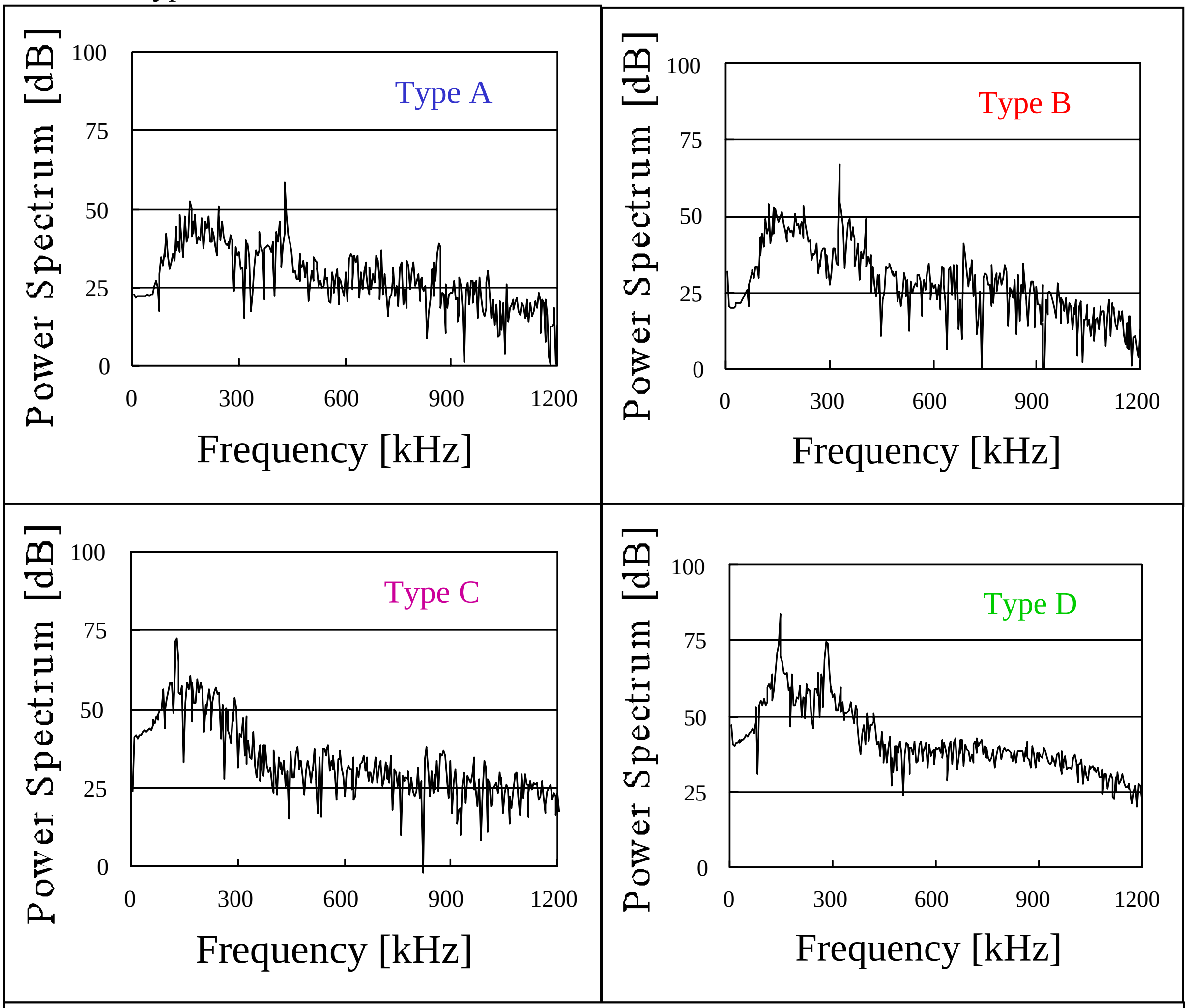

Fig. 7 Frequency spectra of detected AE waveforms at the pressure of 0.30MPa from slit shapes of type A, B, C and D, respectively

harmonic in each slit. The relations between the pressure and the peak frequency for slit shapes of type A, B, C and D, respectively, are shown in Fig. 8. Over the critical pressure, the peak frequencies decrease from 520 to 430kHz in type A, from 550 to 330kHz in type B, from 250 to 130kHz in type C and from 370 to 140kHz in type D with increase of the pressure, respectively. Overlapping two peak frequency curves exists over the critical pressure because of the screech mode change in the slit nozzle [10]. That also clearly indicates the expression of the screech tone.

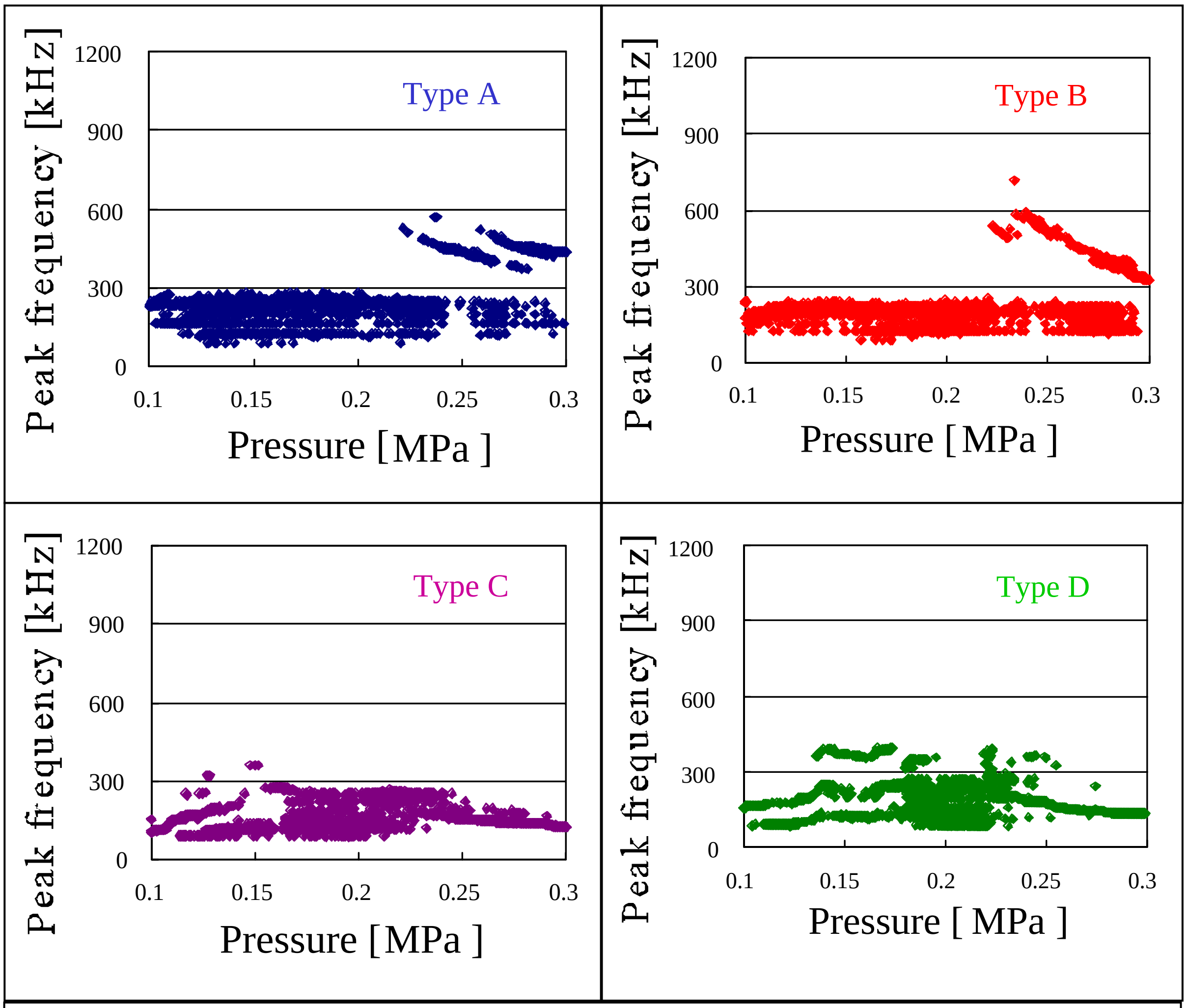

Fig. 8 Relationship between the pressure and the peak frequency for slit shapes of type A, B, C and D, respectively

CONCLUSION

Detection and inspection of AE during gas leak from pipes with straight and stepwise pinholes, and slit shape has been investigated within the frequency range of 20kHz to 1200kHz. Results obtained are as follows:

1. In stepwise pinholes, the mean AE amplitude often fluctuates very quickly before the pressure reaches to critical value.
2. With the stepwise depth increasing, the mean AE amplitude increases and airflow becomes unstable.
3. In straight pinholes, the subsonic noise called the screech tone occurs over the critical pressure.
4. In slit shapes, the screech tone also occurs over the critical pressure.
5. The screech tone characteristics can be made clear using the peak frequency analysis of the AE waveforms.

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