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GAS LEAK DETECTION STUDY IN A CUBE USING ULTRA-SONIC SPECTRAL SOUND FIELD VARIATION

Kang-Ho Park, Sung Q Lee

Convergence Sensor Research Group, Electronics Telecommunication Research Institute (ETRI), 218 Gajeong-no, Yuseong-gu, Daejeon 34129, Republic of Korea
email: pkh@etri.re.kr

The ultrasonic spectral sound field variation at multi-tone frequencies in a cube is investigated for the early detection of gas leak. The sound pressure field generated by an ultrasonic transmitter is measured by an ultrasonic receiver installed within a 6cm cube. The sound pressure level spectral patterns with multi-tone frequencies around 25 kHz are measured according to the amount of gas leak such as helium and HCFC and they are analysed in comparison with 3-dimensional finite element analysis simulation results. We found that the spectral position of interference peaks and the spectral pattern shift to higher or lower frequency are observed depending on the sound velocity with a relation to the species of gas molecule and concentration, and this kind of technique can be applied for the early detection of gas leak in the confined space.
Keywords: gas leak detection, ultrasonic spectral sound field variation, cube

1. Introduction

There are various kinds of gas leak detection method [1]. Among them there are two kinds of methods based on the ultrasound technology. First, the gas leak can be detected by measuring the speed of sound using ultrasonic pulses [2], and secondly it can be detected by monitoring the ultrasonic sound generated by the gas leak as well [1]. However the method based on the direct measurement of the ultrasonic sound velocity is limitedly used for small confined chambers, and the method based on the ultrasound hearing has limitation because silent gas leak is not able to be detected and the gas leak in a covered area could not be easily detected. We propose a new gas leak detection method based on ultrasonic sound field spectra variation. By using this method we can detect any kinds of gas leak even in various kinds of spaces.

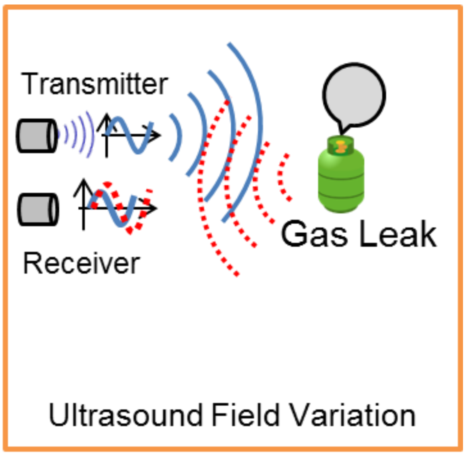

Figure 1: Gas leak detection using ultrasound field spectra variations.

In this paper, we report the ultrasonic spectral sound field variation study for the gas leak detection in a cubic box. We used the similar concept with the fire detection based on sound field spectral variation as reported previously for gas leak detection [3,4]. We measured the ultrasonic sound pressure level spectra with a variation of the magnitude of the leaked gas such as helium and HCFC, and the ultrasound spectral change is analysed by the change of sound velocity depending on the gas composition and the resultant sound transfer function change within the confined cubic box.

2. Theoretical analysis

The peak and dip patterns in ultrasonic sound pressure spectra are shifted to the higher frequency depending on the gas composition within a cubic box, because sound velocity depends on the gas composition. It is 343.5 m/s for air at room temperature, and they are 972 m/s for helium and 179 m/s for HCFC respectively [5]. From the spectral frequency shift, the change of the gas composition is detected and the information about the gas element and the magnitude of the leaked gas can be obtained. The frequency shift in the ultrasonic sound spectra is simply derived by the following simple equation, where f is the sound frequency, c_s is the sound velocity, and δc_s is the sound velocity change [3,4].

$$\delta f = f\,\delta c_s / c_s \tag{1}$$

For the simulation for a gas leak detection study, a cubic box is used as shown in Fig.2. The size of the inner cubic space is 6 x 6 x 6 cm^3. An ultrasonic transmitter and receiver are placed at the middle plane as shown in Fig.2 and the diameter of the holes for the inlet and outlet of ultrasound is 1 mm. We assume the gas leak situation such as helium and HCFC in order to investigate the spectral dependence on the sound velocity change according to gas composition.

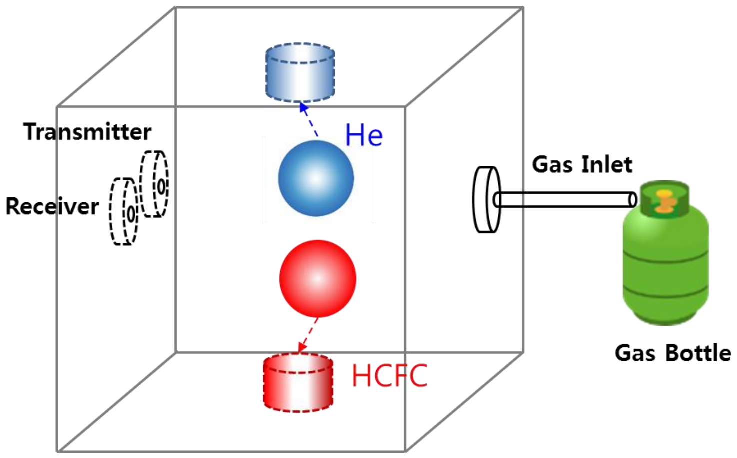

Figure 2: Schematic figure for gas leak detection using ultrasound field spectra variations in a cubic box.

The realistic configurations of the gas mixture between air and leaked gas are not considered in this paper. In order to get the simulation result of sound pressure spectra for the gas leak situation, the spatial distribution of gas is assumed to be spherical or cylindrical shape for the simplification of the simulation condition as shown in Fig.2. The volume of cylinder is set to be equivalent to one of the sphere in order to study the dependence of the spectra on the variation of the shape of leaked gas.

The sound pressure spectra with 257 channels from 23976 Hz to 26024 Hz with a frequency step of 8 Hz are obtained with COMSOL simulation program. The peak and dip structures of the sound spectra as a function of sound frequency are shown in Fig.3. It is found that they move to the higher frequency direction in case of the leakage of helium gas regardless of the shape, but they move to the lower frequency direction in case of the leakage of HCFC gas. In this case the radius of the sphere and the cylinder are set to be 2.4 mm and the height of the cylinder is set to be 3.2 mm.

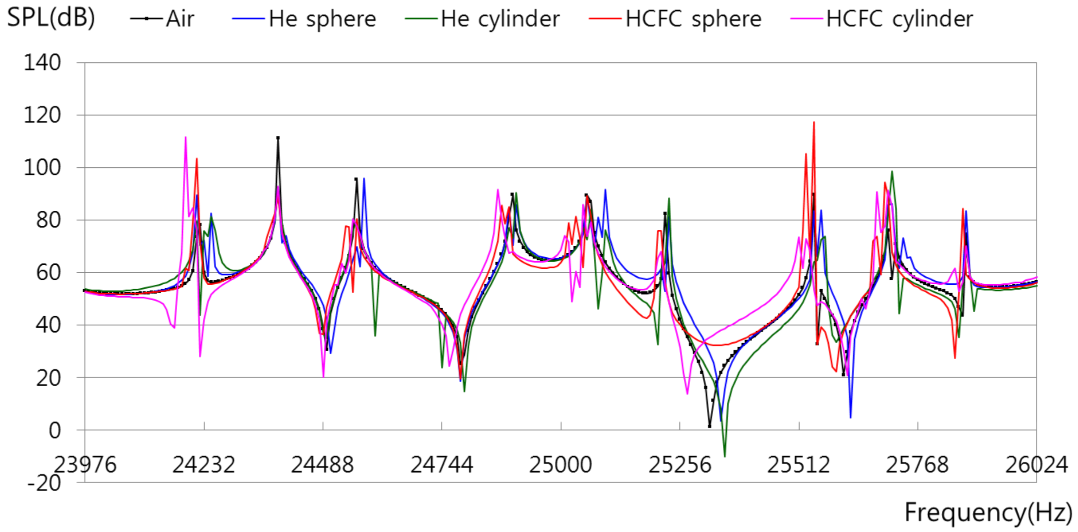

Figure 3: Simulation results for gas leak state of helium and HCFC in comparison with pure air.

3. Experimental setup

A cubic box of 6 x 6 x 6 cm^3 is used for the experiment as shown in Fig. 4. We used the ultrasound transducer products of Pro-Wave Electronics for the frequency range around 25 kHz. The central positions of ultrasonic transducer are located at the upper distance of 2mm and 2cm from the central position of left plane of the cubic box respectively. We used the transmitter of 112 dB SPL (measured upon 10 Vrms sine wave at 30cm distance), and the receiver of the sensitivity of 7.9 mV/Pa. In order to get the information of the temperature, two thermometers are used for the correct measurement of the temperature which gives a significant effect on the sound field spectra.

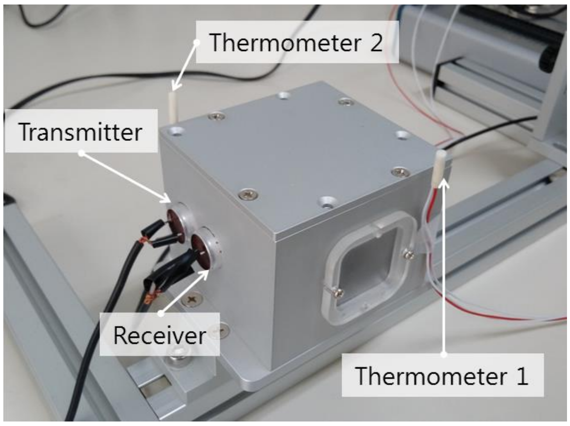

Figure 4: A cubic box for gas leak experiment using ultrasonic sound field variation.

The ultrasound spectral data are acquired by a NI DSA USB-6356 module, and the data are processed using the LABVIEW program. The multi-toned ultrasound composed of 257 channel with the central frequency of 25 kHz and the frequency interval of 8 Hz is generated by the transmitter, and the ultrasound signal of 0.5 s are generated by the transmitter with a sampling frequency of 12.5 MHz. 6.25 M sampling data are obtained by the receiver, and resultantly the frequency resolution is

2 Hz for the FFT spectra. The ultrasound field spectra of 257 channels are measured from 23976 Hz to 26024 Hz with a frequency step of 8Hz.

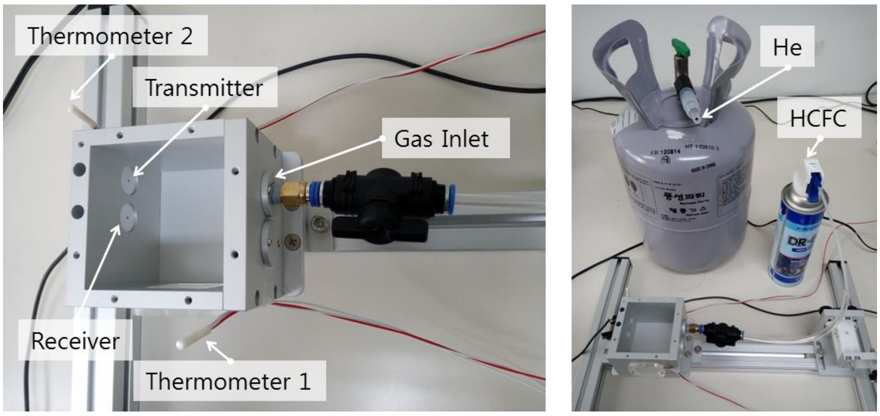

Figure 5: A cubic box with gas inlet and gas bottles for the experiment.

Helium and HCFC gases are flowed in the cubic box through the gas inlet located at the opposite plane to the ultrasound transmitter and receiver pair for the gas leak experiment as shown in Fig.5. The time dependence spectra for 52 s and 104 s are recorded in comparison with the initial spectra.

4. Results and discussion

The spectral shifts of sound field spectra are obtained with a variation of gas element, and they are studied by the viewpoint of sound velocity change according to the leaked gas element and their amounts.

4.1 Experimental results

As shown in Fig.6, it is found that the spectral patterns move to higher direction depending on the amount of the leaked helium gas without the significant change of the spectral shape in accordance with the simulation result. The spectral pattern does not shift or changed after termination of the gas leak. These spectra were obtained at the temperature of 20.7 °C.

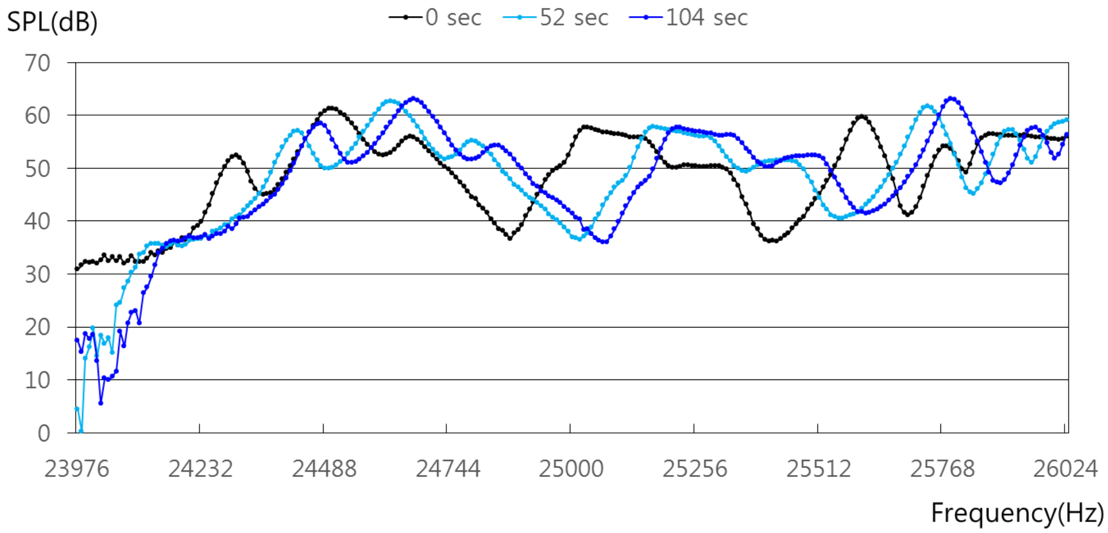

Figure 6: Ultrasonic sound field spectra during the helium gas leak in a cubic box

As shown in Fig.7, it is found that the spectral pattern move to the lower direction depending on the duration time of HCFC gas leak in accordance with the simulation result. These spectra were obtained at the temperature of 20.8 °C.

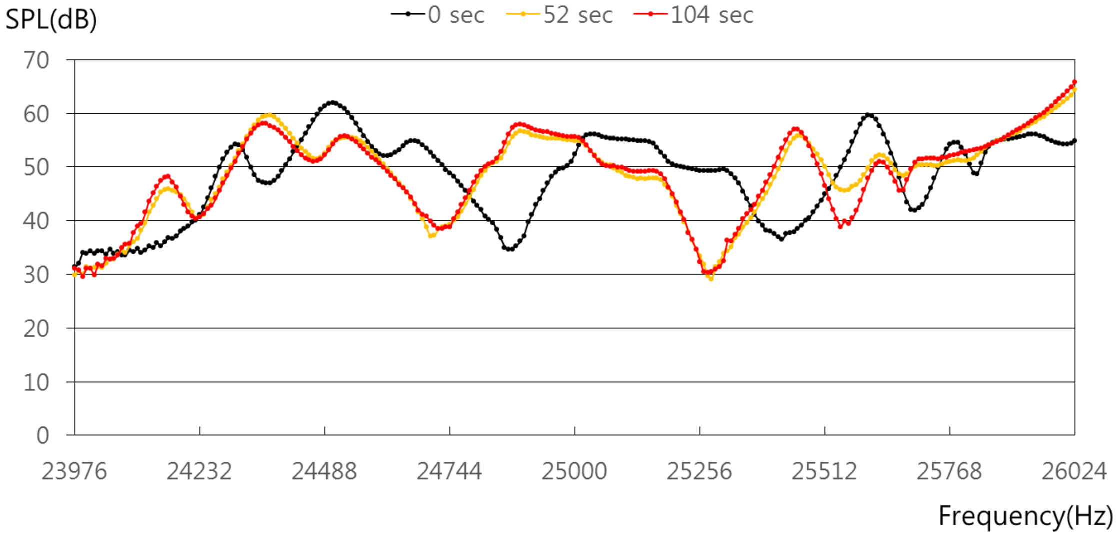

Figure 7: Ultrasonic sound field spectra during the HCFC gas leak in a cubic box.

These phenomena can be well explained by the change of sound velocity depending on the compositional change of gas elements such as helium or HCFC with air within the cubic box.

4.2 Discussion

From the average deviation between the ultrasound pressure spectra depending on the gas leakage, the amounts of spectral change and frequency shift are well quantified. The average deviation between the spectra having different leakage time as a function of the relative frequency shift is calculated [4], and the results are shown in Fig. 8 and 9.

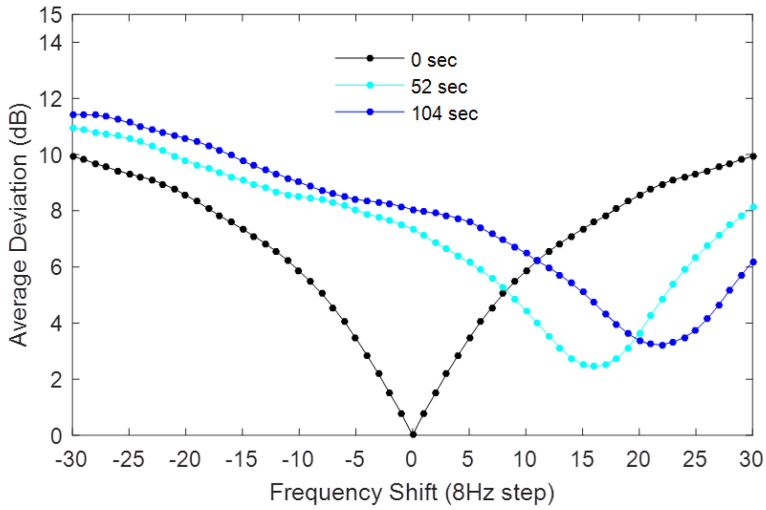

Figure 8: Average deviation as a function of the frequency shift during helium leakage.

The amount of frequency shift during the gas leakage is clearly observed in these figures. This frequency shift value can be used for an estimation of amount of the leaked gas. It is very interesting that the direction of frequency shift is depending on the leaked gas element. The conventional gas leak sensors using the ultrasound are not able to detect the silent leakage as well as the identification of the gas element. However, the gas leak can be well detected by using ultrasound field spectra variation and their elements are categorized into two species in terms of the sound velocity.

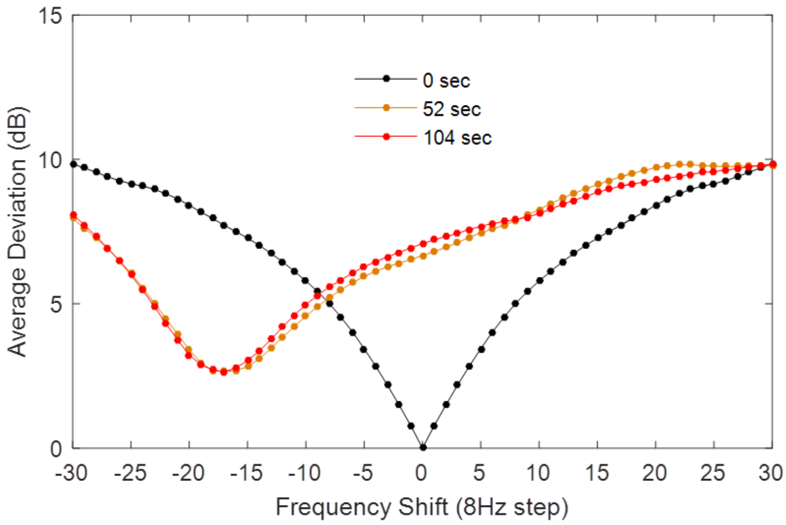

Figure 9: Average deviation as a function of the frequency shift during HCFC leakage.

5. Conclusion

We propose a gas leak detection method using the ultrasound field spectral variation. The ultrasound pressure spectra move to a higher or lower frequency owing to a change in the sound velocity depending on the leaked gas element and the amount of leakage. The proposed method can be applied for the gas leak detection technology even in the case of silent leakage in the covered area. And the gas element can be categorized into two species in terms of the sound velocity in comparison with one in air.

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