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Characteristics of hydrogen leakage sound from a fuel-cell vehicle by hearing

Kiyotaka Maeda[*], *Yohsuke Tamura*

FC-EV Research Division, Japan Automobile Research Institute, 1328-23, Takaheta, Osaka, Shirosato, Ibaraki 311-4316, Japan

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ABSTRACT

Fuel-cell vehicle, run on hydrogen, is known that it has better energy efficiency than existing gasoline cars. The vehicles are designed so that hydrogen leaks from the tank are stopped automatically upon detection of hydrogen leakage or detection of impact in a collision. However, we investigated the characteristics of hydrogen leakage sound from a hydrogen-leaking vehicle and the threshold of discrimination of hydrogen leakage from noise at a crossing with much traffic to examine a method to rescue people safely depending on the sense of hearing in the event of a continuous hydrogen leak. Here, in the discrimination threshold test, we conducted the test by using helium, which is alternative gas of hydrogen leakage sound. We clarified that hydrogen leakage sound from vehicles has directivity, height dependence, and distance dependence. Furthermore, we confirmed the threshold flow rate for distinguishing hydrogen gas when hydrogen leakage is heard at a distance of 5–10 m from the center of the hydrogen leaking vehicle in a 74 dB traffic noise environment.

Introduction

The first mass-produced fuel-cell vehicle (FCV), which has better energy efficiency than existing gasoline cars, was sold in 2014, and other manufacturers are expected to release them in the future. Usually, the FCV will automatically stop hydrogen supply from the hydrogen tank in an accident and collision impact or when a hydrogen leak is detected [1,2]. However, assuming that a hydrogen leak may occur continuously due to an unexpected failure, it is necessary to understand whether hydrogen leakage sound can be recognized or not as well as the volume of hydrogen leak and the distance from the vehicle.

A hydrogen leak detector is a means for recognizing hydrogen leaks but is not always at hand. Therefore, if the risk of a hydrogen leak can be judged by detecting hydrogen leakage by ear, it will become an influential source of information. However, there are few studies of gas leakage sound; only the jet sound of air from a nozzle has been studied [3], and no study has been conducted on hydrogen.

In this study, therefore, we investigated the characteristics of hydrogen leakage sound from a vehicle in order to examine a method to rescue people safely depending on the sense of hearing in the event of a continuous hydrogen leak from the FCV. Furthermore, we investigated the threshold flow rate and distance from the vehicle for discriminating of hydrogen leakage in a traffic noise environment at a crossing with much traffic.

Method

The noise level in towns is always changing, so it is impossible to evaluate thresholds at a constant noise level. Therefore, we

* Corresponding author.
E-mail address: kmaeda@jari.or.jp (K. Maeda).
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safely conducted listening tests by 1) selecting a safe alternative gas for hydrogen leakage sound, 2) recording traffic noise, and 3) letting the alternative gas for hydrogen leakage leak in an anechoic room while reproducing the traffic sound recorded in 2) to reproduce the state in which hydrogen leaks from the vehicle in a traffic noise environment. Furthermore, we converted the flow rate of the alternative gas for hydrogen leakage as the threshold value for discrimination into the flow rate of hydrogen. Discrimination value means flow rate that humans are able to cognize the leakage sound in the traffic noise environment.

Selection of the alternative gas for hydrogen leakage sound

To select an alternative gas that has the closest possible acoustic characteristics to those of hydrogen gas, we measured the sound pressure level (SPL), frequency characteristics, and directivity while hydrogen gas and candidate alternative gases leaked from four different types of pipes and compared the results. Test conditions are shown in Table 1; devices used, in Table 2; examples of leak pipes, in Fig. 1; and a schematic diagram of measurement, in Fig. 2. Leak pipes were 1/4 inch (1/4 in, pipe bore 4.57 mm) and 3/8 in (pipe bore 7.045 mm), both of which are pipe diameters used for FCVs. To simulate cases in which the pipe is crushed and crimped due to a collision, 1/4 in (crimped) and 3/8 in (crimped) pipes, produced by crimping 1/4-in and 3/8-in pipes by pressure, were also used. Crimped pipes were too difficult to judge whether or not the area of 1/4 inch pipe is larger than that of 3/8 inch pipe. Because the areas were too small. However, it is considered that the area of 1/4 inch pipe is larger than that of 3/8 inch pipe, since diameter of 3/8 inch is larger. Because fluid noises increase in proportion with flow velocity [4], fluid noises increase as the pipe diameter becomes smaller if the flow rate is kept constant. In other words, if gas leaks at the same flow rate from non-crimped pipes, the discrimination flow rate is considered to be increases during the listening test. Therefore this corresponds to the worst case. Pipes were installed in parallel with the ground at a height of 1 m. The reason we set pipes at a height of 1 m is that gas leakage sound reflections, which affect the measurements, may be ignorable.

Table 1 – Hydrogen alternative gas selection test conditions.

Area	JARI* test course dirt track area
Candidate gases	Helium, air, argon
Pipe shape	1/4 in, 1/4 in (crimped), 3/8 in, 3/8 in (crimped)
Flow rate	Hydrogen: 1000, 750, 500, 250, 118, 60, 30 NL/min Candidate gases: The flow rate was set equal to the noise level of the hydrogen flow rate
Measurement distance	1.0 m
Measurement height	1.5 m
Measurement direction	7 (every 30°)
FFT analysis	
Frequency analysis range	20 to 40,000 Hz
Sampling frequency	96 kHz
Average number	200

JARI*: Japan Automobile Research Institute.

Table 2 – Instruments used in the test.

Instrument	Manufacturer	Model
Mass-flow controller	Azbil	MQV0200
		MQV1000
Microphone	RION	UC29
	B&K	4939
Pre-amplifier	RION	NH-17
	B&K	2669
Amplifier	RION	NA-42
	GRAS	12QA
Noise-level meter	RION	NA-28

Gases that are relatively easily available and safe were used as alternative gases for hydrogen. The maximum allowable hydrogen leak volume in a collision as specified in Global Technical Regulation (gtr) is 118 NL/min, and this was used as the standard [5]. For the flow rates of alternative gases, the flow rate at which the noise level in the 0° direction is equal to that of hydrogen leak was used as the standard. Guidelines of noise levels are listed in Table 3 for your reference [6]. . The frequency range of measurement is 20–40,000 Hz, but the human audible frequency range is 20 to 20,000 Hz.

The measured frequency dependence of sound pressure level when hydrogen leaks from the 1/4 in pipe at a flow rate of 118 NL/min is shown in Fig. 3. Here, the figure following each measurement direction is the overall sound pressure level and BGN represents Back Ground Noise.

In Table 1, the frequency range of analysis is stated as 25 Hz to 40 kHz. ISO 3744 specifies that the sound pressure level to be measured shall be at least 6 dB lower than background noise and preferably 15 dB or more [7]. In Fig. 3, we set the lower limit of the analysis frequency range to 500 Hz for the tests that follow because the frequency where the highest noise level exceeds the background noise by 6 dB or more is over 800 Hz.

The flow rate of a candidate alternative gas for hydrogen at which the noise level in front of the leaking piping (0°) is equal to that of hydrogen for a 1/4 in pipe was 125 NL/mi for helium, 82 NL/min for argon, and 82 NL/min for air. The measured frequency characteristics of helium, argon, and air when they leak at these flow rates and the differences in SPL from hydrogen are depicted in Figs. 4–6.

Helium has sound characteristics that are closest to those of hydrogen leaking when hydrogen leaks from the 1/4 in pipe at a flow rate of 118 NL/min. We therefore decided to use helium as the alternative gas for hydrogen. Figs. 7 to 9 depict the frequency analysis results for hydrogen and helium leaking from the 1/4 inch, 1/4 in (crimped), 3/8 in, and 3/8 in (crimped) pipes at a flow rate of 118 NL/min.

These results indicated that the difference in SPL between hydrogen and helium is 5 dB or less for most combinations of pipe diameters and directions. However, the difference is 4 dB or more in some combinations. Therefore, relevance was also compared when hydrogen and helium leaked from pipes installed in the vehicle. The results will be described in "2.4.1. Verification of the relevance of helium."

The relationships between hydrogen flow rate and helium flow rate when the noise levels of hydrogen and helium are equal in front of the pipe are plotted in Fig. 10.