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휴대용 연료전지 시스템의 소음 저감에 대한 연구
A Study on the Noise Reduction of a Portable Fuel Cell System

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ABSTRACT

In this paper, a study on the noise reduction in a mobile fuel cell system is presented. Among various fuel cell systems around 20W capacities designed for mobile electronic devices, the active direct methanol fuel cell (DMFC) systems have been recently developed. In such systems, the primary noise source is the air pump which provides sufficient air flow (5~6 liter/min) for electrochemical reaction with methanol fuel while the noise contributions from other auxiliary parts are relatively small. Especially, the discrete noise tones generated by the air pump are dominant and those frequency peaks related to the rotor harmonics are needed to be suppressed by a silencer. Therefore, the Herschel-Quinke (HQ) tubes, which use the out-of-phase cancellation of acoustic waves propagating through direct and indirect pathways, are applied to the inlet of the air pump. Performance of noise reduction with HQ silencer is analytically estimated by calculating the transmission. The length and number of thin HQ tubes are optimized to decrease the radiated noise. As a result, the sound pressure level could be successfully reduced by about 10 dB after applying three serially connected HQ tubes.

1. Introduction

The recent advances on the future energy for mobile devices are focused on the enhancement of mobility, durability, and performance. Because the conventional Lithium-Ion batteries are known to have the energy density limitation, the new fuel cell systems using electrochemical reactions have been developed as shown in Table 1. Among those systems, the direct methanol fuel cell (DMFC) system as shown in Fig. 1, using a solid polymer membrane electrolyte and methanol fuel, is highlighted because this type of fuel cell offers the unique advantages of a lower volume and weight, a simpler design and better dynamics as well as lower operating costs compared with other power sources.

However, the noise problem in a DMFC system is very critical to the quality of mobile devices because the air pump is used to increase the power capacities. In this paper, the Hershel-Quinke (HQ) silencer with thin ducts is applied to the inlet of air pump to reduce the radiated noise. In general, the HQ silencer has a strong merit in size and volume because it simply uses the out-of-phase cancellation of acoustic waves propagating through direct and indirect pathways [2,3]. Especially, it is very easy to control the frequency peaks related to the rotor harmonics of the air pump.

Performance of noise reduction with a HQ silencer is analytically estimated by calculating the transmission loss between inlet and outlet ports. Consequently, the length and number of thin ducts in HQ silencer can be optimized to reduce the radiated noise according to the blade passage frequency (BPF) peaks of the air pump.

2. DMFC System

2.1 System Overview

In general, a DMFC system is consisted of a stacked membrane electrolyte assembly (MEA) for electrochemical reaction between air (O_2) and methanol fuel (CH_3OH), pumps controlled by electrical circuit board as shown in Fig. 2. The overall electrochemical reaction over the stack region in the DMFC is expressed as follows [1]:

Cathode: $CH_3OH + H_2O \rightarrow CO_2 + 6H^+ + 6e^-$, (1a)

Anode: $3/2O_2 + 6H^+ + 6e^- \rightarrow 3H_2O$, (1b)

Overall: $CH_3OH + 3/2O_2 \rightarrow CO_2 + 2H_2O$. (1c)

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	Direct Methanol	Polymer Electrolyte	Phosphoric Acid	Molten Carbonate	Solid Oxide
Fuel	CH_3OH	H_2, CH_4	H_2, CH_4, Natural Gas	CH_4, Natural Gas	CO, CH_4, Natural Gas
Electrolyte	Ion Exch. Membrane	Ion Exch. Membrane	Phosphoric Acid	Liquid Molten Car.	Ceramic
Catalyst	Pt-Ru/Pt	Pt/Pt	Pt/Pt	Ni-Cr/NiO	Ni-ZrO_2/ $LaMnO_3$
Oper. Temp. (°C)	50-80	80	200	650	1000
Power Density (W/cm^2)	0.1-0.25	0.3-0.9	0.2-0.29	0.2-0.24	0.2-0.27
Efficiency (%)	40	40	40-45	50-60	50-60
Applications	Mobile, Portable	Home App., Automobile	Industry	Industry	Industry

Table 1. Comparison of fuel cell systems [1].

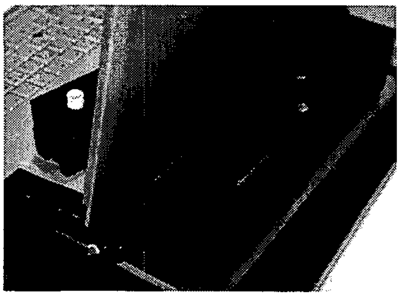

Fig. 1. Picture of a DMFC system.

Since energy of reaction is determined by the reactants, the voltage of 1.18V is theoretically obtained in the DMFC system by Eq. (1).

2.2 Noise Sources

Figure 3 shows the comparison of noise levels of pumps and a fan for heat exchanger. It is known that among system parts the primary noise source is the air pump used for supplying sufficient air at a high flow rate (5~6 liter/min) while the noise contributions from other auxiliary parts are relatively small. Since the rotary vane in an air pump is time-harmonically rotating, the characteristic of noise spectrum varies with the blade-passage frequency (BPF). When the driving voltage of air pump is 10.5V, the fundamental BPF (C_1) of the system occurs at 160 Hz as shown in Fig. 4 and its harmonic peaks (C_2, C_3,···, etc) are also dominant. The noise reduction of such peaks will be demonstrated in next section.

3. Herschel-Quinke Silencer

3.1 Formulations

Consider a Hershel-Quinke silencer having n-parallel ducts connecting inlet and outlet ports as shown Fig. 5.

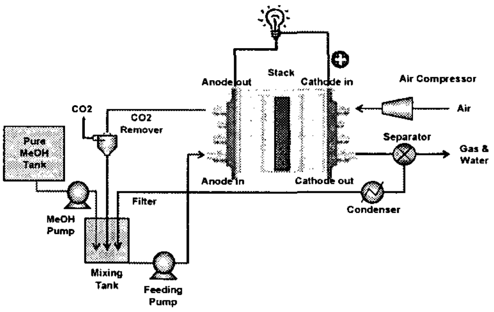

Fig. 2. Schematic diagram of a DMFC system.

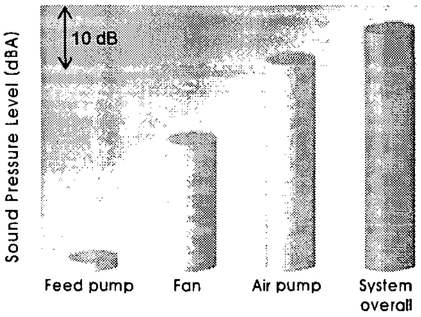

Fig. 3. Comparison of the radiated sound pressure levels of system parts in a DMFC system.

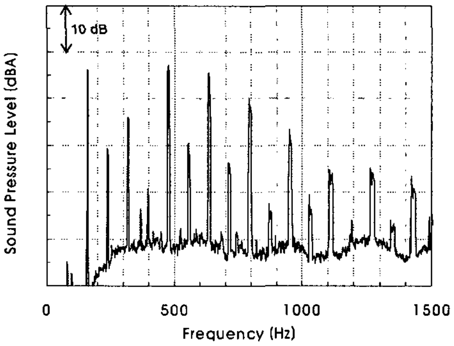

Fig. 4. Noise spectrum of a DMFC system.

Assuming the plane wave propagation, the relationship of acoustic pressures and particle velocities between inlet (upstream) and outlet (downstream) ports can be written by [2]

$$\begin{Bmatrix} p_u \\ v_u \end{Bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{Bmatrix} p_d \\ v_d \end{Bmatrix} \equiv \mathbf{T} \cdot \begin{Bmatrix} p_d \\ v_d \end{Bmatrix}. \tag{2}$$

Here, **T** represents the transfer matrix between upstream and downstream ports. If the areas of the inlet and outlet ducts are the same, the expression for the transmission loss (TL) is given by [3]

$$\mathrm{TL} = 20\log_{10}\left|\frac{i}{2S_u}[A + (S_u - iB)/A]\right|. \tag{3}$$

Here, S_u is the area of upstream duct and the constant values are given by

$$A = \sum_{j=1}^{n} S_j / \sin kL_j, \quad B = \sum_{j=1}^{n} S_j \cos kL_j / \sin kL_j, \tag{4}$$

where k is the wave number, L_j is the length of jth tube and resonances in Eq. (3) occur when A=0.

For the special case of same length ducts (L), the expression for transmission loss in Eq. (3) reduces to

$$\mathrm{TL} = 20\log_{10}|1 + (r - 1/r)\sin^2 kL/4|, \tag{5}$$

where the area ratio r is

$$r = \sum_{j=1}^{n} S_j / S_u. \tag{6}$$

This expression is the same as that of the simple expansion chamber. If the areas of two HQ tubes are the same, the resonance frequencies are calculated as

$$f_m = \frac{c(2m-1)}{2\Delta L} \quad (m = 1, 2, \cdots), \tag{7}$$

where c is the speed of sound, m the positive integer, and ΔL the length difference between duct pathways. When the HQ tubes are serially connected (i.e., q-serial HQ tubes), the total transmission loss of the system is given by

$$\begin{bmatrix} p_u \\ v_u \end{bmatrix} = \mathbf{T}_1 \cdots \mathbf{T}_q \begin{bmatrix} p_d \\ v_d \end{bmatrix}. \tag{8}$$

3.2 Silencer Design

Once the C_1 peak of the system is identified or measured, the optimal length difference between two pathways can be determined from Eq. (7). Because the fundamental frequency of this system is 160 Hz, C_1, C_3 and C_5 peaks can be reduced by using the 'HQ_1' silencer having L_1=5 cm and L_2=112.1 cm with the duct diameter of 3 mm as shown in Table 2. In addition, C_2 and C_4 peaks can be reduced by the application of 'HQ_2' and 'HQ_4' silencers, respectively. Therefore, the overall TL of a three-serially connected HQ silencer (HQ_1, HQ_2 and HQ_4) can be calculated by Eq. (8) and the calculated TLs are shown in Fig.6. Consequently, a silencer using three HQ tubes would be effective in control of the BPF peaks up to C_7 frequency.

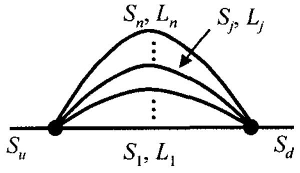

Fig. 5. Schematic description of a HQ silencer.

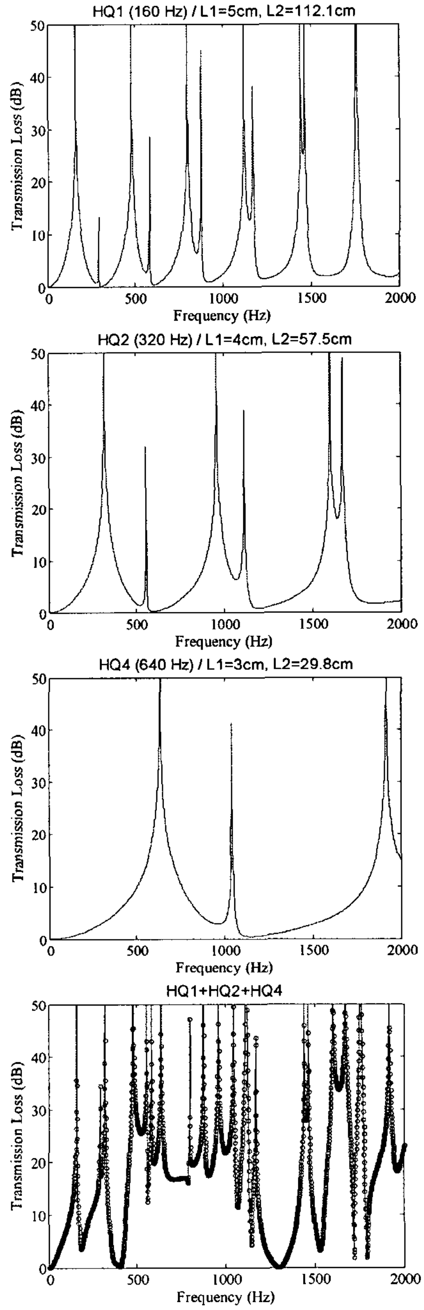

Fig. 6. Calculated transmission loss of the single HQ tubes and the three-serially connected HQ silencer.

Model	L1 (cm)	L2 (cm)	ΔL (cm)	기본주파수
HQ1	5	112.1	107.1	160
HQ2	4	57.5	53.5	320
HQ3	3	38.7	35.7	480
HQ4	3	29.8	26.8	640
HQ5	3	24.4	21.4	800

Table 2. Tube length of HQ silencers and the corresponding control frequencies.

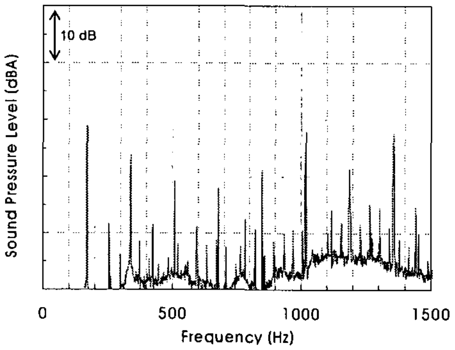

Fig. 7. Noise spectrum of a DMFC system after applying the three-serially connected HQ silencer.

3.3 Experimental Result

In order to evaluate the noise reduction of a DMFC system, a three-serially connected HQ silencer is optimally designed as discussed earlier and it is applied to the inlet port of the air pump. As a result, the sound pressure level was successfully reduced by about 10 dB after applying the optimized HQ silencer (i.e., HQ_1, HQ_2 and HQ_4) and discrete tones were suppressed as shown in Fig. 7.

4. Conclusions

In this paper, the noise reduction of a mobile DMFC system is presented. Among system parts, the air pump is the primary target to control the radiated noise. Especially, the discrete noise tones generated by the air pump are dominant and those frequency peaks related to the rotor harmonics are suppressed by a silencer. In general, the HQ silencer has a strong merit in size and volume. Therefore, the transmission loss of the HQ silencer was analytically calculated. When the optimized HQ silencer was applied to the DMFC system, the radiated noise was successfully decreased by more than 10 dB compared with the original DMFC system.

References

[1] J. Larminie and A. Dicks, *Fuel Cell Systems: Explaned*, John Wiley & Sons, Ltd (2000).

[2] J.-G. Ih, “Acoustic analysis and design of exhaust mufflers: I. Operating principle associated with structure,” J. Kor. Soc. Auto. Eng. 16, 37-50 (1994).

[3] A. Selamet and V. Easwaran, “Modified Herschel–Quincke tube: Attenuation and resonance for *n*-duct configuration,” J. Acoust. Soc. Am. 102, 164-169 (1997).