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Study on the effect of vent on the electroacoustic absorber

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ABSTRACT

Electroacoustic absorber (EA) with a sealed enclosure has limitation of sound absorbing performance due to the resonance characteristic of a loudspeaker that works as its actuator. Specifically, the sound absorbing performance of EA decreases at the lower and higher frequency range on the basis of the resonance frequency of the loudspeaker. To overcome this limitation, it suggests to utilize a vented enclosure rather than the sealed enclosure in the EA system. First of all, the effect of the vent on the EA is analyzed through the related formulas and simulation results. Then, the corresponding experiment is conducted to verify the aforementioned analytical results. Finally, this paper reveals that the vented enclosure increase the performance of EA up to a certain point at frequencies below the resonance frequency of the loudspeaker. From the user's point of view, this passive method using the vented enclosure leads to put it to better use.

Keywords: electroacoustic absorber, vented enclosure   I-INCE Classification of Subjects Number(s): 37.7

1. INTRODUCTION

This paper deals with a method of EA aiming to reduce actively noise in an enclosed sound field by matching the specific acoustic impedance of a loudspeaker acting as an actuator of EA with that of air, rather than the method of active noise cancellation. The EA in the preceding studies [1]-[4] has following features. The sound absorbing performance and specific acoustic impedance of the EA decline in the low frequency and high frequency bands with a resonance frequency of a loudspeaker acting as an actuator in whole EA system as the center. This is unavoidable phenomenon caused due to a limit to control the specific acoustic impedance of the EA through the DIC technique. To overcome this limitation, this paper proposes to apply a vented enclosure to the EA.

2. General EA with the sealed enclosure

2.1 Dynamic modeling

The mechanical dynamics of a loudspeaker is represented as a single lumped model of mass-spring-damper based on Newton's second law. Meanwhile, the electrical dynamics is based on Kirchhoff's laws. These two dynamics can be expressed as (1). The direct impedance control voltage in (2) for the applied voltage in (1), it can be considered as a total dynamic model of the EA.

$$\begin{cases} SP^{+}(s) = \left(sM_{ms} + R_{ms} + \dfrac{1}{sC_{mc}} \right) V(s) - BlI(s) \\ E(s) = \left(sL_e + R_e \right) I(s) + BlV(s) \end{cases} \tag{1}$$

$$E_c(s) = K_P P^{+}(s) - K_V V(s) \tag{2}$$

Based on this dynamic model, Fig. 1 shows an equivalent circuit of an EA coupled with a sealed enclosure. Next, an equation of the specific acoustic admittance using the mechanical impedance and the electrical impedance through the simple operations between (1) and (2) can be expressed as (3).

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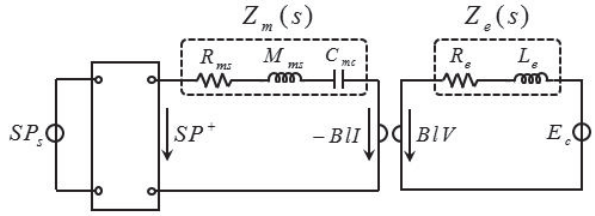


Figure 1 – The equivalent circuit of the EA coupled with a sealed enclosure

$$Y_s(s) = \rho c \frac{V(s)}{P(s)} = \rho c \frac{SZ_e(s) + K_P Bl}{Z_m(s)Z_e(s) + (Bl)^2 + K_V Bl} \tag{3}$$

The specific acoustic admittance of the typical loudspeaker can be derived by removing the terms of $K_P Bl$ and $K_V Bl$ in the numerator and denominator in (3) respectively. Finally, by substituting (4) indicating a reflection coefficient $\gamma(s)$ for the incident sound wave into (5), a sound absorption coefficient $\alpha(s)$ indicating the sound absorbing performance of the EA can be calculated.

$$\gamma(s) = \frac{1 - Y_s(s)}{1 + Y_s(s)} \tag{4}$$

$$\alpha(s) = 1 - |\gamma(s)|^2 \tag{5}$$

Fig. 2 is a simulation result of the specific acoustic admittance and sound absorption coefficient through (3)-(5) using the nominal parameters of the loudspeaker used in this paper.

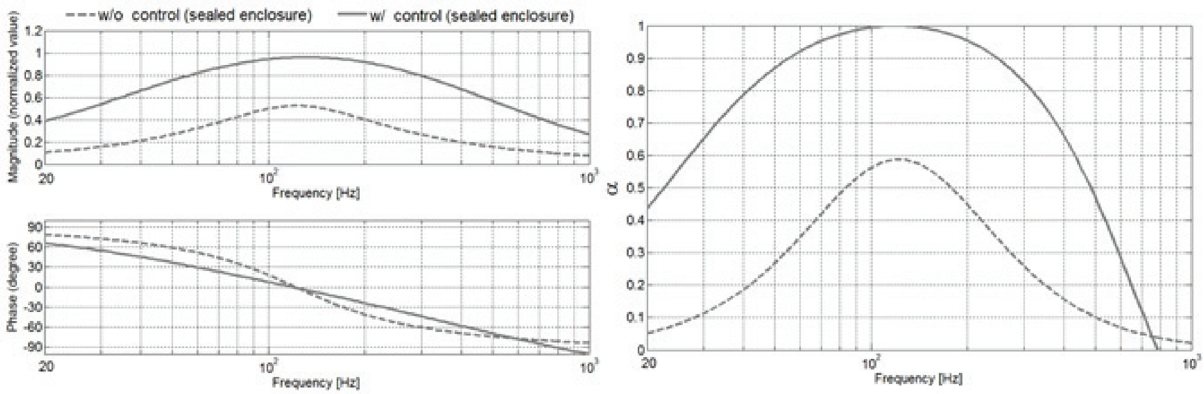


Figure 2 – Simulation results of the specific acoustic admittance (left) and sound absorption coefficient (right) for the EA coupled with the sealed enclosure

In this figure, in both case, the sound absorption coefficient becomes maximum at near the resonance frequency of the loudspeaker. More important is that the performance gradation phenomenon occurs in low and high frequency bands. Thus, to overcome this limitation, it is suggested to apply a vented enclosure, not a sealed enclosure to the EA system.

2.2 Simulation Analysis for the Performance of EA with the vented enclosure

In this paper, in order to account for the effect of a vented enclosure on the EA, the equivalent circuit analysis based on impedance model is used. Comparing the equivalent circuit of Fig. 3 to the equivalent circuit of the EA coupled with vented enclosure (Fig. 1), the followings are noticed. A single equivalent impedance $Z_v(s)$ of the vented enclosure is represented as (6) using an equivalent acoustical impedance $Z_{ap}(s)$ of vent itself and another equivalent acoustical compliance C_{ab} and the diaphragm effective area S. Note that the formulas for the equivalent acoustical elements M_{ap}, R_{ap}, C_{ab} of the vented enclosure are summarized as (7) through the reference paper [5].

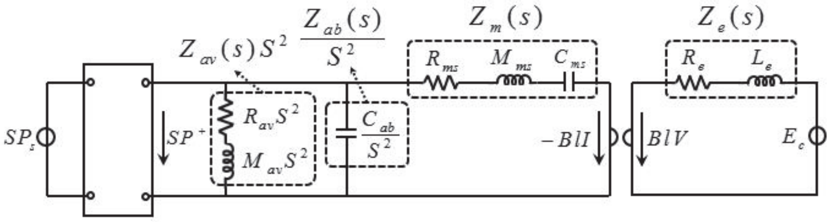


Figure 3 – The equivalent circuit of the EA coupled with a vented enclosure

$$Z_v(s) = \frac{S^2\left(sM_{ap} + R_{ap}\right)}{s^2 M_{ap} C_{ab} + sR_{ap} C_{ab} + 1} \tag{6}$$

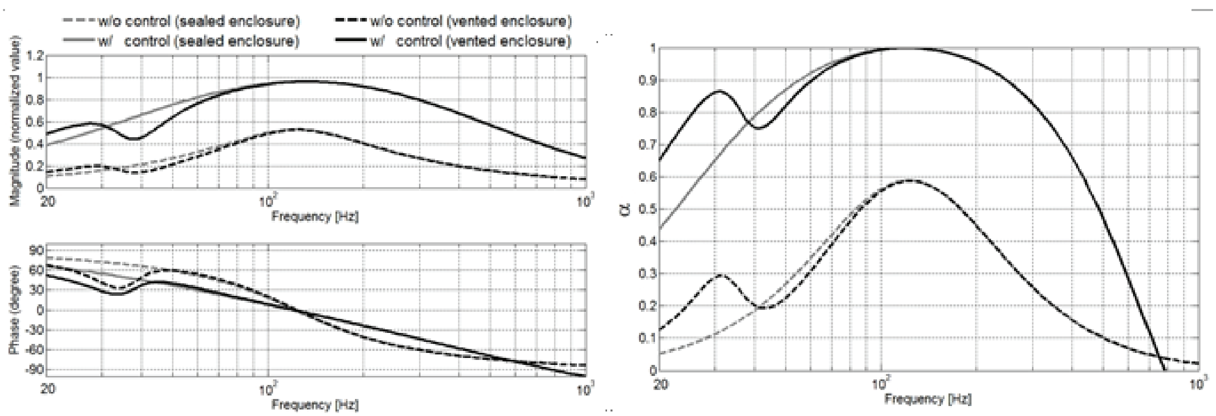
$$M_{av} = \frac{(l_v + 0.6r_v)\rho}{\pi\left(r_v\right)^2},\ R_{av} = \frac{\rho\sqrt{2w\mu}}{\pi\left(r_v\right)^2}\left(\frac{l_v}{r_v} + 2\right),\ C_{ab} = \frac{V_b}{\rho c^2} \tag{7}$$

Next, in the same manner with derivation of (3), the total specific acoustic admittance of the EA coupled with a vented enclosure can be obtained as (8).

$$\begin{aligned} Y_t(s) &= \rho c \frac{SZ_e(s) + K_P Bl}{\left\{Z_m(s) + Z_v(s)\right\} Z_e(s) + (Bl)^2 + K_V Bl} \\ &= \rho c \frac{a_3 s^4 + a_2 s^3 + a_1 s^2 + a_0 s}{b_5 s^5 + b_4 s^4 + b_3 s^3 + b_2 s^2 + b_1 s + b_0} \end{aligned}$$

$$\begin{cases} a_3 = C_{ms} L_e M_{av} C_{ab} S \\ a_2 = C_{ms} L_e R_{av} C_{ab} S + C_{ms} M_{av} C_{ab} R_e S + C_{ms} M_{av} C_{ab} K_p Bl \\ a_1 = C_{ms} L_e S + C_{ms} R_e S R_{av} C_{ab} + C_{ms} R_{av} C_{ab} K_p Bl \\ a_0 = C_{ms} R_e S + C_{ms} K_p Bl \\ b_5 = M_{ms} C_{ms} L_e M_{av} C_{ab} \\ b_4 = M_{ms} C_{ms} L_e R_{av} C_{ab} + R_{ms} C_{ms} L_e M_{av} C_{ab} + M_{ms} C_{ms} R_e M_{av} C_{ab}, \\ b_3 = M_{ms} C_{ms} L_e + R_{ms} C_{ms} L_e R_{av} C_{ab} + L_e M_{av} C_{ab} + L_e M_{av} C_{ms} S^2 + M_{ms} C_{ms} R_e R_{av} C_{ab} + \ldots \\ R_{ms} C_{ms} R_e M_{ap} C_{ab} + C_{ms} M_{av} C_{ab} Bl^2 + C_{ms} M_{ap} C_{ab} K_V Bl, \\ b_2 = R_{ms} C_{ms} L_e + L_e R_{av} C_{ab} + L_e R_{av} C_{ms} S^2 + M_{ms} C_{ms} R_e + R_{ms} C_{ms} R_e R_{av} C_{ab} + R_e M_{av} C_{ab} + \ldots \\ C_{ms} R_e M_{av} S^2 + C_{ms} R_{av} C_{ab} Bl^2 + C_{ms} R_{av} C_{ab} K_V Bl, \\ b_1 = L_e + R_e R_{ms} C_{ms} + R_e R_{av} C_{ab} + C_{ms} R_e R_{av} S^2 + C_{ms} Bl^2 + C_{ms} K_V Bl, \\ b_0 = R_e \end{cases} \tag{8}$$

The followings can be deduced through the simulation result of Fig. 4 based on (8). The fact that a sound absorbing performance is improved in a low frequency range of approximately 20-32Hz where either the magnitude is increased or the phase is decreased in terms of its specific acoustic admittance, so as to enhance the degree of acoustic impedance matching with air, is confirmed. As opposed to this, there is also a frequency range of approximately 32-50Hz where the degree of acoustic impedance matching with air is declined, and which leads to degrade the sound absorption coefficient. Consequently, it can be mentioned that there are both frequency ranges where the sound absorbing performance is clearly improved and slightly degraded due to the vented enclosure in the EA. In other words, a kind of trade-off phenomenon occurs.



(a) (b)

Figure 4 – Simulation results of the specific acoustic admittance (left) and sound absorption coefficient (right) for the EA coupled with the vented enclosure

3. EXPERIMENTAL RESULTS

3.1 Experimental Setup

In this section, the simulation analysis of the influence of the vented enclosure on the EA's performance in previous section is verified through the related experiments. For this experimental verification, the experimental setup used in this paper is shown in Fig. 5. Loudspeakers of Peerless 830860 5-1/4" PPB cone HDS woofers are used as an actuator of the EA and a noise source in the experiment setup. An audio amplifier of INTER-M QD 4480 is used to supply the driving power to the loudspeakers. The dimension of the sealed enclosure's internal volume is made as $260 \times 205 \times 260 mm^3$ with MDF material of 20mm thickness. A vented enclosure is made by a way to produce a vent required for the experimental verification on the top face of the sealed enclosure. The measurement process of the specific acoustic admittance is conducted as follows. A noise source loudspeaker generates a noise signal received from NI cDAQ. The noise shakes a diaphragm of a control loudspeaker acting as an actuator of an EA and simultaneously has a dominant influence on a vicinity the diaphragm, propagating through a duct having 0.13m of diameter and 1.93m of length in the form of a plane wave. For measurement of the specific acoustic admittance representing the acoustic characteristics in the vicinity of the control loudspeaker diaphragm, the neighboring pressure is measured by a 1/2 inch pressure field microphone (B&K type 4192) installed in front of the diaphragm and the diaphragm velocity is measured by a velocity sensor (ESV-200 laser vibrometer) installed outside of the duct, respectively.

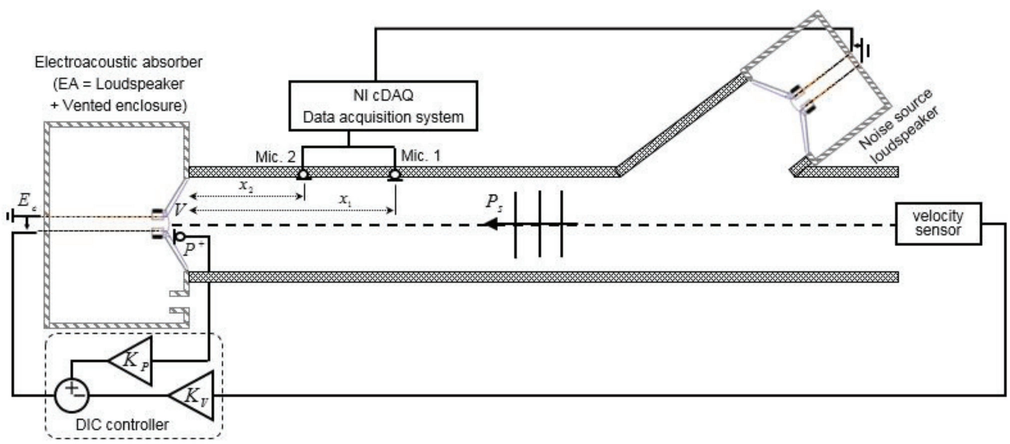
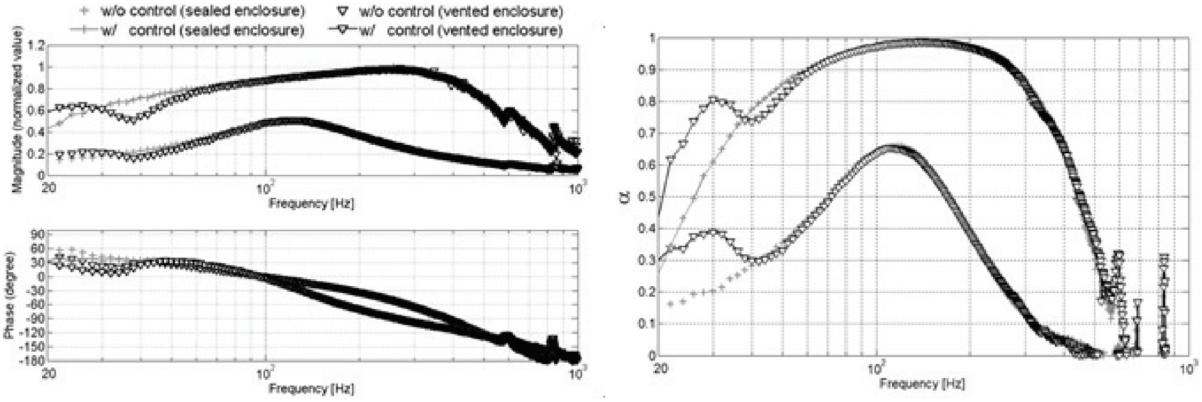


Figure 5 – Schematic of experimental setup

3.2 Experimental Verification

The feasibility for improvement of sound absorbing performance of the EA using a vented enclosure in a low frequency band is verified through the experiment result of Fig. 6(a). A fact that this experiment result has a similar tendency with the simulation result of Fig. 4(a) is confirmed. Next, Fig. 6(b) showing the experimental result of the sound absorption coefficient is analyzed as follows. This experimental result is also checked to have a similar tendency with the simulation result of Fig. 4(b).



(a) (b)

Figure 6 – Experimental results of the specific acoustic admittance (left) and sound absorption coefficient (right) for the EA coupled with the vented enclosure

4. CONCLUSIONS

In this paper, it is suggested to apply a vented enclosure to an EA system instead of the conventional sealed enclosure. It is theoretically and experimentally verified that the vented enclosure can improve the sound absorbing performance in a low frequency band below the resonance frequency of the control loudspeaker by being coupled with the EA.

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