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Analysis of sound absorption performance of an electroacoustic absorber using a vented enclosure

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ABSTRACT

The sound absorption performance of an electroacoustic absorber (EA) is primarily influenced by the dynamic characteristics of the loudspeaker that acts as the actuator of the EA system. Therefore, the sound absorption performance of the EA is maximum at the resonance frequency of the loudspeaker and tends to degrade in the low-frequency and high-frequency bands based on this resonance frequency. In this study, to adjust the sound absorption performance of the EA system in the low-frequency band of approximately 20–80 Hz, an EA system using a vented enclosure that has previously been used to enhance the radiating sound pressure of a loudspeaker in the low-frequency band, is proposed. To verify the usefulness of the proposed system, two acoustic environments are considered. In the first acoustic environment, the vent of the vented enclosure is connected to an external sound field that is distinct from the sound field coupled to the EA. In this case, the acoustic effect of the vented enclosure on the performance of the EA is analyzed through an analytical approach using dynamic equations and an impedance-based equivalent circuit. Then, it is verified through numerical and experimental approaches. Next, in the second acoustic environment, the vent is connected to the same external sound field as the EA. In this case, the effect of the vented enclosure on the EA is investigated through an analytical approach and finally verified through a numerical approach. As a result, it is confirmed that the characteristics of the sound absorption performances of the proposed EA system using the vented enclosure in the two acoustic environments considered in this study are different from each other in the low-frequency band of approximately 20–80 Hz. Furthermore, several case studies on the change tendency of the performance of the EA using the vented enclosure according to the critical design factors or vent number for the vented enclosure are also investigated.

In the future, even if the proposed EA system using a vented enclosure is extended to a large number of arrays required for 3D sound field control, it is expected to be an attractive solution that can contribute to an improvement in low-frequency noise reduction without causing economic and system complexity problems.

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1. Introduction

As a passive method such as using a sound absorbing material has a limitation in dealing with low-frequency noise, several studies using electroacoustic devices such as loudspeakers have been actively conducted. This study deals with an electroacoustic absorber (EA), instead of an active noise cancellation (ANC) method reducing noise by canceling it with a sound wave that has a phase opposite to the noise. In contrast to that of ANC, the noise reduction principle of the EA system can be explained as follows. By matching the characteristic acoustic impedance of the EA system with that of air, the diaphragm of an EA system acts as an acoustic load (of transmission line, e.g. a 1D plane wave field), so that the noise is directly absorbed and reduced. The concept of an active EA was first proposed by Olson and May in the 1950s [1]. It was then practically investigated by Guicking and named as “active sound absorber” [2]. Then, various studies developed this concept using advanced techniques such as “active reverberation control” or “adaptive algorithm” [3,4]. Meanwhile, Bobber proposed the first semi-active EA using a simple electrical resistance [5]. Thereafter, several studies showing an improved performance by connecting a shunt circuit composed not only of electrical resistors but also of capacitors have been conducted [6–8]. Next, Furtoss proposed a new technique called “direct impedance control (DIC),” which uses both sound pressure and flow velocity sensing near the diaphragm to effectively implement acoustic impedance matching of the active EA system [9]. This resulted in an improved sound absorption performance over a wider frequency range. Recently, studies on the active EA using the DIC technique have been actively performed by Lissek [10,11], Boulandet [12], and Rivet [13,14]. Note that this study deals only with the active EA using the DIC technique.

Common to studies related to the active EA using the DIC technique is the following phenomenon: the sound absorption performance of the EA is degraded in both the low-frequency and high-frequency bands based on the resonance frequency of the loudspeaker that works as the actuator of the EA system. This phenomenon is confirmed more clearly in Refs. [11] and [15] and it is inevitable due to the use of the DIC technique. More precisely, it is explained as follows. The EA system becomes unstable owing to the nonlinearity resulting from the suspension stiffness caused by the Laplace force [11], an excessive reactive component caused by the electric inductance of the coil of the loudspeaker itself [12], and strong acoustic coupling with the sound field to be controlled [16–18]. For this reason, there is an upper threshold for the DIC gains to ensure the stability of the EA system. As a result, even if the upper limit is set to the DIC gains, the frequency bands in which the sound absorption performance of the EA is degraded cannot be avoided.

In order to overcome this limitation partly, this study proposes an EA system using a vented enclosure instead of the conventional sealed enclosure. The idea of a vented enclosure was first introduced by Thuras in the early 1930s [19]. Since then, in-depth studies related to this concept have been conducted [20–22]. In these studies, the vented enclosure has been used to improve the radiating sound pressure of a loudspeaker in the low-frequency band. The detailed explanation is as follows. The sound wave radiated toward the rear side of the diaphragm is inverted in phase by the enclosure, and this inverted sound wave is radiated through the vent. As a result, the inverted sound wave radiated from the vent is merged with the front pressure wave generated from the loudspeaker diaphragm, and eventually, the total radiating sound pressure of the loudspeaker is improved. In contrast to the general loudspeaker driven for sound radiation as described above, the EA system works to absorb and reduce the sound. Hence, it can be deduced that when the vented enclosure is applied to the EA system, it is possible to discover its new meaningful effect from the perspective of sound absorption other than the aforementioned acoustic effect.

To summarize, the aim of this study is to present new meaningful results that can contribute to the field of acoustics research by analyzing an EA system using a vented enclosure that has been originally used to enhance the radiating sound pressure in the low-frequency band. Note that an EA using a sealed enclosure is referred to as “EASE,” and that using a vented enclosure is referred to as “EAVE” in this study. For the aforementioned purpose, two acoustic environments to which EAVE is applied are considered. In the first acoustic environment, the vent of the vented enclosure is connected to an external sound field distinct from the sound field coupled to the EA. In the second acoustic environment, the vent is connected to the same external sound field as the EA, which represents the case where EAVE is applied to a 3D sound field such as a room. Finally, the effects of the vented enclosure on the EA system and the corresponding performances are investigated for these two acoustic environments.

The rest of this paper is organized as follows. Section 2 discusses the case in which EAVE is applied to the first acoustic environment described above. In Section 2, the equation for the specific acoustic admittance of EAVE is derived through dynamic equations and the impedance-based equivalent circuit, and the corresponding sound absorption performance is confirmed. In particular, the acoustic mutual coupling relation between the EA and the vented enclosure is defined, and the influence of this physical relation on EAVE's performance is analyzed in detail. These analytical results are verified through numerical and experimental approaches. In addition, case studies that show change tendencies in the sound absorption performance of EAVE according to the critical design factors and number of vents of the vented enclosure are included. Section 3 discusses the case in which EAVE is applied to the second acoustic environment. Similar to that in Section 2, the effect of the vented enclosure on the performance of EAVE is explained through an analytical approach and is finally verified through a numerical approach in Section 3. Lastly, in Section 4, conclusions are drawn.