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A DEVELOPMENT OF NEW TYPE SPEAKER FEATURING VARIABLE RESONANT FREQUENCIES BY UTILIZING A MAGNETO-RHEOLOGICAL FOAM

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In this work, a new type of speaker which features variable resonant frequencies is proposed utilizing a magneto-rheological (MR) foam, and its performance is evaluated in terms of the change of the field-dependent sound pressure level. In order to achieve this goal, a whole concept of the speaker system is firstly discussed and subsequently a stiffness controllable diaphragm is constituted using MR foam whose material properties are controllable by the magnitude of magnetic field. Then, the proposed speaker system consisting of the coil structure and the shear mode effect of MR foam is established and the variable stiffness of diaphragm is experimentally evaluated at different magnetic field conditions. Afterward, the corresponded effectiveness of the proposed speaker system is verified by hardware test. Hereby, it is shown that the sound pressure level at different sound source can be controlled by the applied magnetic field in speaker structure which is not able to achieve using one conventional speaker system.

Keywords: magneto-rheological foam, speaker diaphragm, resonant frequency variation

1. Introduction

In order to improve acoustical performance of the loudspeaker, the extensive researches have been conducted for a long time. In the previous decades, the parametric optimization of sound quality factor of speaker system have been undertaken to improve the intrinsic acoustic feature. Cheistensen *et al* determined the shape optimization of a diaphragm for the directivity of the sound emission, and showed that it was possible to obtain a nearly uniform directivity pattern for three different frequency range [2]. Pawar *et al* investigated the electroacoustic (Thiele-Small) parameters of the miniature loudspeaker, then improved the acoustic performance by tuning the each variable [3]. Also, Noreland *et al* presented the efficient acoustic horn designed by gradient-based shape optimization to make a virtually perfect impedance matching properties by the axisymmetric Helmholtz equation [4]. Most recently, on the other hand, the smart material like as piezoelectric has been utilized for the performance improvement in a different way. Rosensweig *et al* presented the audio speakers containing ferrofluid to achieve the voice coil centering which can reduce the sound distortion [5]. Kim *et al* proposed the film type piezoelectric speaker using cellulose electroactive paper to simplify the structure and minimize the size of the speaker [6]. Additionally, Jin *et al* proposed the stretchable loudspeaker using liquid metal coil and a neodymium magnet [7].

In spite of the many literature reviews, the prominent research is not reported yet to actively solve the physics constraints of diaphragm which restricts the reproducing frequency ranges or to control the frequency band of speaker according to the sound source. Consequently, the main technical originality of this work is to propose a novel loudspeaker featuring variable resonant frequency of the diaphragm by utilizing a smart material, magneto-rheological (MR) foam. The structure of the novel speaker with MR foam is firstly designed and manufactured. The stiffness variation of its MR foam is verified and the resonant frequency change under different magnetic flux densities is evaluated by experimental work.

2. Design of MR speaker

Fig. 1 presents the manufactured MR speaker modules. Because the MR foam is an open structure, it has less design constraints than magnetorheological fluids. It is also suitable for systems with small scale forces and it is resistant to sedimentation, which is a permanent problem of magnetorheological fluid [8]. When the current is applied to the coil structure, the stiffness of the MR foam is increased due to the generated magnetic flux density and resonant frequency of diaphragm can be increased as follow the equation:

$$f_n = \sqrt{\frac{k}{m}}\,. \tag{1}$$

Therefore, the frequency band can be shifted with resonant frequency of diaphragm through the applied current in coil. That is, the frequency band range of the speaker can be controlled with overcoming the physics constraint of diaphragm by making the different frequency band range according to the main frequency of a sound source. In this work, the diaphragm is made of magnesium which is considered as a paramagnetic material to prevent to be affected by magnetic intensity generated from the coil structure. And an extra vibration speaker is used to shake the diaphragm instead of the sound driver modules including the voice coil and permanent magnet.

3. Experimental work

Fig. 2 shows the experimental apparatus to measure the stiffness variation and frequency band range of speaker when different current is applied to coil. The laser sensor is used to measure the motion of diaphragm and the signal amplifier is utilized to extend the computer signal. In order to verify the stiffness variation of MR foam in this system, the deformation of diaphragm is measured when the weight is loaded in the different current. In this test, 0A, 0.1A, 0.3A, 0.5A, and 0.7A are applied to coil structure. The result of the stiffness variation of MR foam in diaphragm can be defined as shown in Fig. 3. The stiffness of MR foam is increased from 12.48 to 28.95 kN/m as applied current, therefore it can be deduced that the resonance frequency shifting can be derived from this system. In order to determine the resonance frequency variation of the speaker, sound frequency is swept from 40 to 320 Hz. And a measured result is presented as shown in Fig. 4. In this figure, it can be checked that the resonance frequencies are definitely increased from 116 to 123 Hz, from 127 to 145 Hz, from 207 to 216 Hz, and from 252 to 261 Hz respectively. And the frequency band range is also shifted as follow the resonance frequency variations by the applied current.

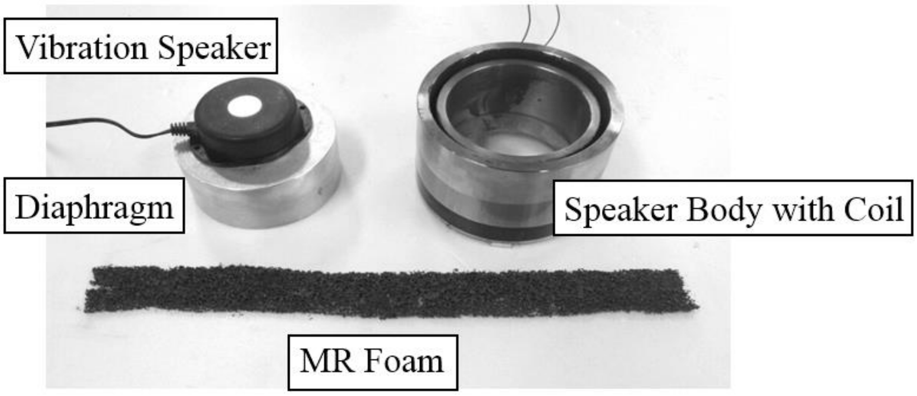

Figure 1: Manufactured MR speaker modules.

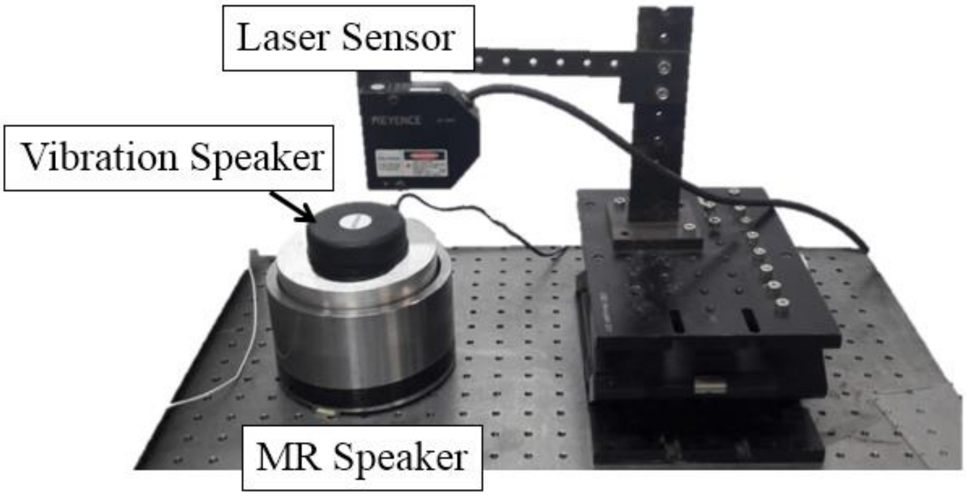

Figure 2: Experimental apparatus to measure frequency band range of speaker.

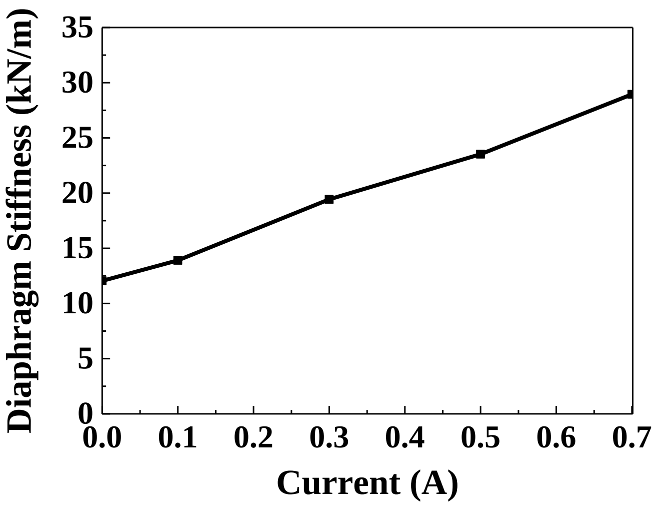

Figure 3: Experimental result of stiffness variation by applied current.

4. Conclusion

In this work, a novel loudspeaker utilizing MR foam was suggested to make a variable frequency band range by applied input current which generates magnetic flux density in the MR form. After the structure of the MR foam speaker was designed and manufactured, it was experimentally checked that the stiffness of diaphragm is increased by applied current in coil. Consecutively, it was identified that the frequency band range shifting is possible by utilizing the MR foam. However, this experimental work had three problems as follow: (1) the shifting frequency band range was not so wide to cover the broad frequency range, (2) because the stiffness of MR form is larger in compression phase, upward displacement is much larger than downward, (3) the sampling frequency of sensor is not enough to measure the accurate motion of diaphragm in high frequency range.

As a second phase of this work, followed researches will be conducted to resolve these drawbacks: (1) regarding the stiffness variation, more appropriate rheological material such as magneto-rheological elastomer will be utilized instead of the MR foam, (2) the acoustic evaluation method will be used in place of laser sensor like as microphone and sound pressure level (SPL) analyser.

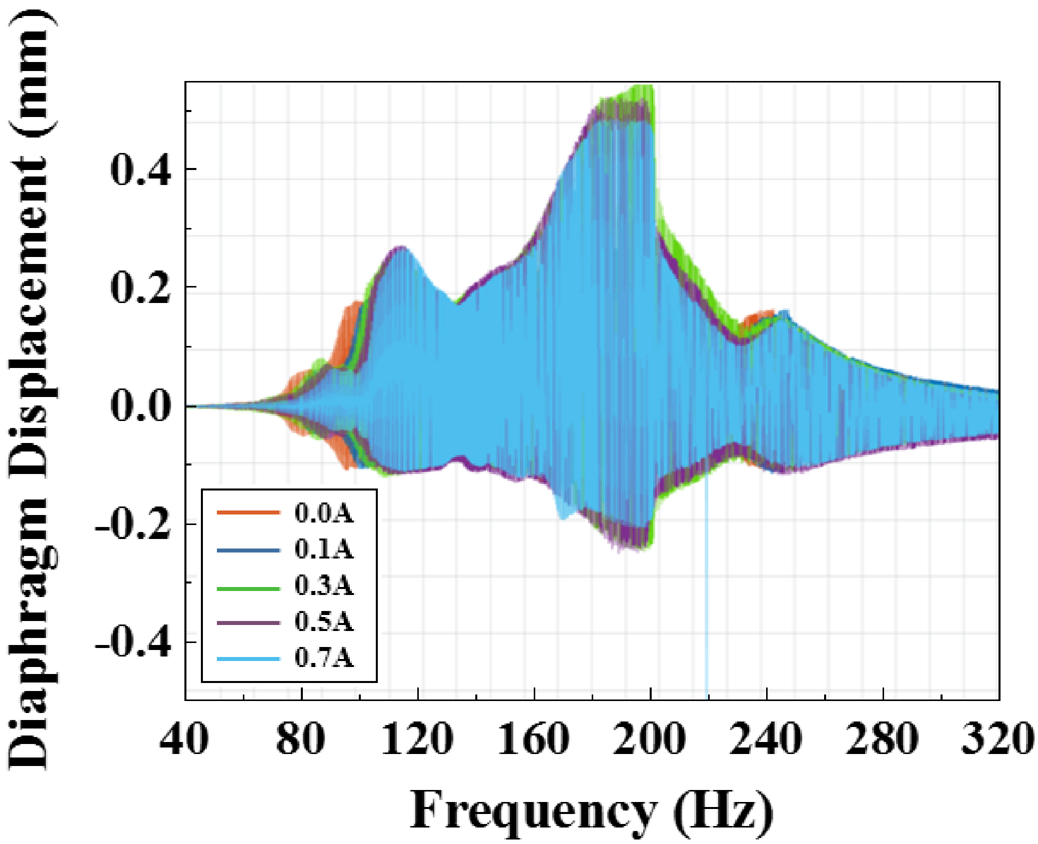

Figure 4: Frequency band shifting by applied current.

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