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Acoustic simulation for high intensity sound source with Helmholtz resonator

Zinan LI[1]; Bo ZHANG[1,2]; Qiqi CHEN[1]; Liheng WANG[1]; Yutian BAI[1]

[1] School of Mechanical Engineering, Ningxia University, China

[2] CAE Key Laboratory for Intelligent Equipment of Ningxia, China

ABSTRACT

To study acoustic radiation characteristics of high intensity sound source used for the acoustic test of sound absorbing materials, a simulation model in the combination of horn-type loudspeaker and Helmholtz resonator, which are conceived for the design of a high intensity sound source in acoustic impedance tube, is developed by using software COMSOL. Fully couplings among multiple physical fields such as electromagnetic, mechanical, and acoustic ones are considered in this model, letting voltage be the input and sound pressure the output. Without the help of any simplified lumped parameter and only through the acoustic model constructed in COMSOL and accurate material parameters, the signal frequency response characteristics, output sound pressure, and electroacoustic transformation efficiency of the high intensity sound source can be obtained. The results show that the acoustic radiation characteristic of this high intensity sound source depends on the interactions between horn-type loudspeaker and Helmholtz resonator, and its equivalent acoustic impedance characteristics is mainly dominated by Helmholtz resonator. It is also shown from results that the resonances of both horn-type loudspeaker and Helmholtz resonator may not only strengthen sound radiation of sound source system, but enhance its electroacoustic transformation efficiency observably.

Keywords: Sound Source, Acoustic Simulation

1. INTRODUCTION

In recent years, researches on porous metal materials have received more and more attention，and the sound absorption performance of porous metal materials under high pressure and high intensity has become a research hotspot as well. To conduct nonlinear acoustic research of porous metal materials under high sound pressure levels, it is necessary to construct a qualified high intensity sound field, and high intensity sound sources are the key to solve this problem. Cone type loudspeaker is usually selected as acoustic testing sound source, but because it directly generates acoustic radiation through the vibration of cone wall of loudspeaker, which is less efficient and the excited the sound pressure level cannot meet the test requirements. On the other hand, the siren is used as the sound source as well. Although it can generate a large amount of sound power, its biggest disadvantage is that it cannot control the frequency response of the signal. In addition, some researchers have also used the method of adding a horn to sound source system to improve the acoustic radiation of the speaker (1).The Helmholtz resonator is a special kind of acoustic component designed for acoustic amplification (2). In this work, authors adopt COMSOL as tool to build a simulation model, combining the horn-type loudspeaker with the Helmholtz resonator, which provides a new idea for the design of high intensity sound source.

2. COMPOSITION OF SOUND SOURCE

2.1 Compression Driver

Compression driver is the most commonly used acoustic device for the fabrication of sound

[1] zhangb@nxu.edu.cn
[2] 12712580@qq.com

source system that mainly works in high frequency range, as shown in Fig. 1. The acoustic excitation mechanism of compression driver is the same as that of cone type loudspeaker, and the membrane is usually dome shaped. Unlike the cone type loudspeaker, the membrane of compression driver does not directly radiate sound in free air, but through a thin system called the phase plug. The system acts to collect sound radiation energy from different parts of the dome in correct phase relation and to improve the acoustic load and transduction efficiency (1, 3). And horn is connected to outlet of phase plug.

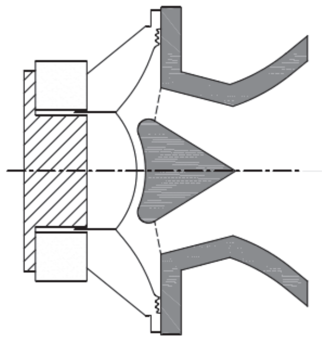


Figure 1 – Internal structure of a compression driver

2.2 Helmholtz Resonator

In engineering applications, Helmholtz resonator is regarded as an acoustic device of locally collecting sound energy for other purposes such as radiation. It usually consists of a cavity and a spool piece, acoustic performance parameters of which are related to the structural configuration. When the sound signal enters the cavity and its frequency is the same as the resonant frequency of the resonator, the air in the cavity will be activated to generate so-called resonance, as a result of enhancing the incident acoustic signal. Consider the typical structure of a Helmholtz resonator, where S is the cross sectional area of inlet hole of the resonator and l is the effective length, and V is the volume of the resonator. Therefore, the resonant frequency f of the resonator is given by Eqn. (1), where c_0 is the sound velocity.

$$f = \frac{c_0}{2\pi}\sqrt{\frac{S}{lV}} \tag{1}$$

This formula is utilized in the following simulation and modeling of high intensity sound source.

2.3 Horn

The sound waves from the output of the resonator radiate into the open space after entering the horn throat and the horn mouth, and the sound radiation is again enhanced.

When the horn throat radius is a_0 and $f >> f$c, its acoustic impedance is approximately equal to:

$$z_{a_0} \approx \frac{\rho_0 c_0}{\pi (a_0)^2} \tag{2}$$

Provided that horn mouth radius is a_l and $ka_l = 5$, its acoustic impedance is approximately given as:

$$z_{a_l} \approx \frac{\rho_0 c_0}{\pi (a_l)^2} \tag{3}$$

Moreover, the acoustic impedance at point x (being the distance away from the horn throat) is defined as:

$$Z_a(x) = \frac{p}{vS} \tag{4}$$

And particle velocity at position x is written as follows:

$$v = \frac{A}{\rho_0 c_0 k}\left[\left(\gamma - j\frac{m}{2}\right)e^{-j\gamma x} - \frac{B}{A}\left(\gamma + j\frac{m}{2}\right)e^{j\gamma x}\right]e^{-\frac{m}{2}x}e^{j\omega t} \tag{5}$$

The sound pressure at horn mouth is N times as large as that at horn throat, which is expressed by

$$N = \frac{p_l}{p_0} = \frac{Z_{a_l} v_l S_l}{Z_{a_0} v_0 S_0} \tag{6}$$

3. MODEL IMPLEMENTATION ON COMSOL

3.1 2D Model

Considering the typical geometry of a horn loudspeaker, it is simplified and constructed as an axisymmetric 2D model without the phase plug, as shown in Fig. 2. This paper uses the PML domain to calculate the far sound pressure field.

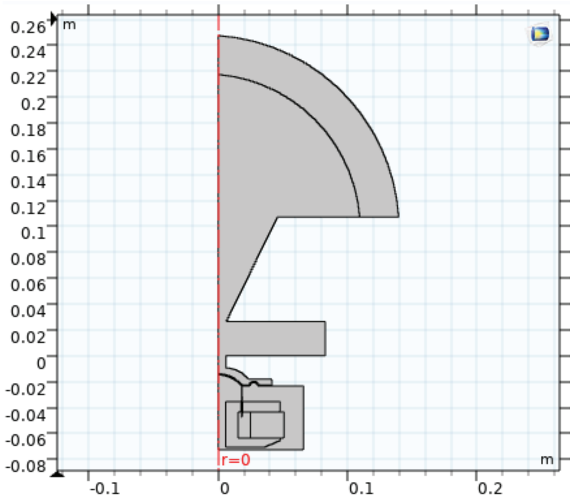


Figure 2 – 2D model without the phase plug

By modeling its electromagnetic, structural and acoustic properties, the model combines the magnetic field interface of the AC/DC module with the acoustic-structure interaction multiple physics interface of the acoustic module, see Refs. (4, 7). The AC/DC module is responsible for simulating the generator, which firstly sets the voltage driven by the system and then calculates the vibrational speed of membrane. The velocity at frequency of analysis is then applied to membrane in pressure acoustic frequency domain.

3.2 Mathematical Description

In this work, one may assume that the excitation voltage V_0 = 4V, the sound source is driven by a time harmonic voltage and finally connected to the voice coil, as follows:

$$V = V_0 e^{j\omega t} \tag{7}$$

For a wire of length l and electric current I in a magnetic field of induction density B, the Lorentz force F generated is given by:

$$F = lB \times I \tag{8}$$

The voice coil consists of N turns of wire, so the resultant driving force on the coil hence becomes:

$$F_e = -I\frac{2\pi N}{A}\int rB_r dA \tag{9}$$

where B_r is the r-component of the magnetic flux density and A is the cross section of coil.

The current through the voice coil is related to the applied voltage, i.e,

$$I = \frac{V_0 - V_{be}}{Z_b} \tag{10}$$

In Eqn. (10), Z_b is the blocking electrical impedance and $-V_{be}$ is the back EMF (the voltage induced in the coil due to its movement through the permanent magnetic field in air gap).

The force factor BL in loudspeaker system is expressed by:

$$Bl = -\frac{2\pi N}{A}\int rB_r dA \tag{11}$$

After arrangement, one may obtain the expression for the driving force F_e:

$$F_e = Bl\frac{V_0 - BLv}{Z_b} \tag{12}$$

3.3 Model Mesh

To mesh such geometries, the main issue is on how to set maximum element size and try to keep the number of elements relatively low to reduce computation time (5, 6).

There are three types of meshes for model meshing. The first is suitable for the static magnetic mode of having very simple geometries. The magnet, pole and the top plate can be easily meshed by manually defining a fine mesh throughout the magnetic circuit. The second is often used for the electromagnetic domain. This is a much more complicated grid that must be considered carefully. The third one is used for the mechanical and acoustic domains because in this case, the two domains are fully coupled with and those neighboring meshes must be tailored to merge.

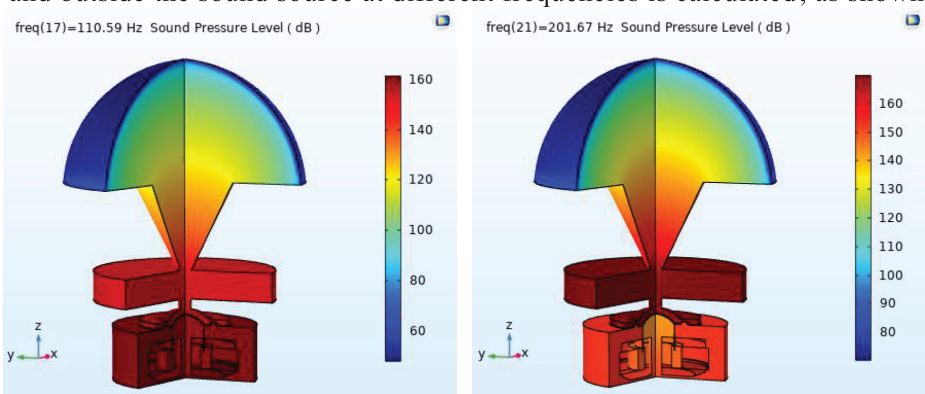
3.4 Multiple-Physics Coupling

Usually, there is a direct coupling relation between magnetic field and mechanics fields. For example, the Lorentz force comes from the voice coil vibration. In return, the vibration of voice coil produces a counter electromotive force. To calculate the values of factors BL and Z_b, the resultant driving force on the coil can be obtained. Then the result can be plugged directly into the acoustic-structure coupling calculation of the horn-type loudspeaker performance. The first coupling solves the electromagnetic part of the problem. The second coupling is a full model, including the relevant multiple physics interactions from the drive voltage to the calculated sound pressure level (6).

4. RESUITS

4.1 The Variation of Sound Pressure Level

According to the analysis of acoustic-structure interaction, the distribution of sound pressure levels inside and outside the sound source at different frequencies is calculated, as shown in Fig. 3.



(a) (b)

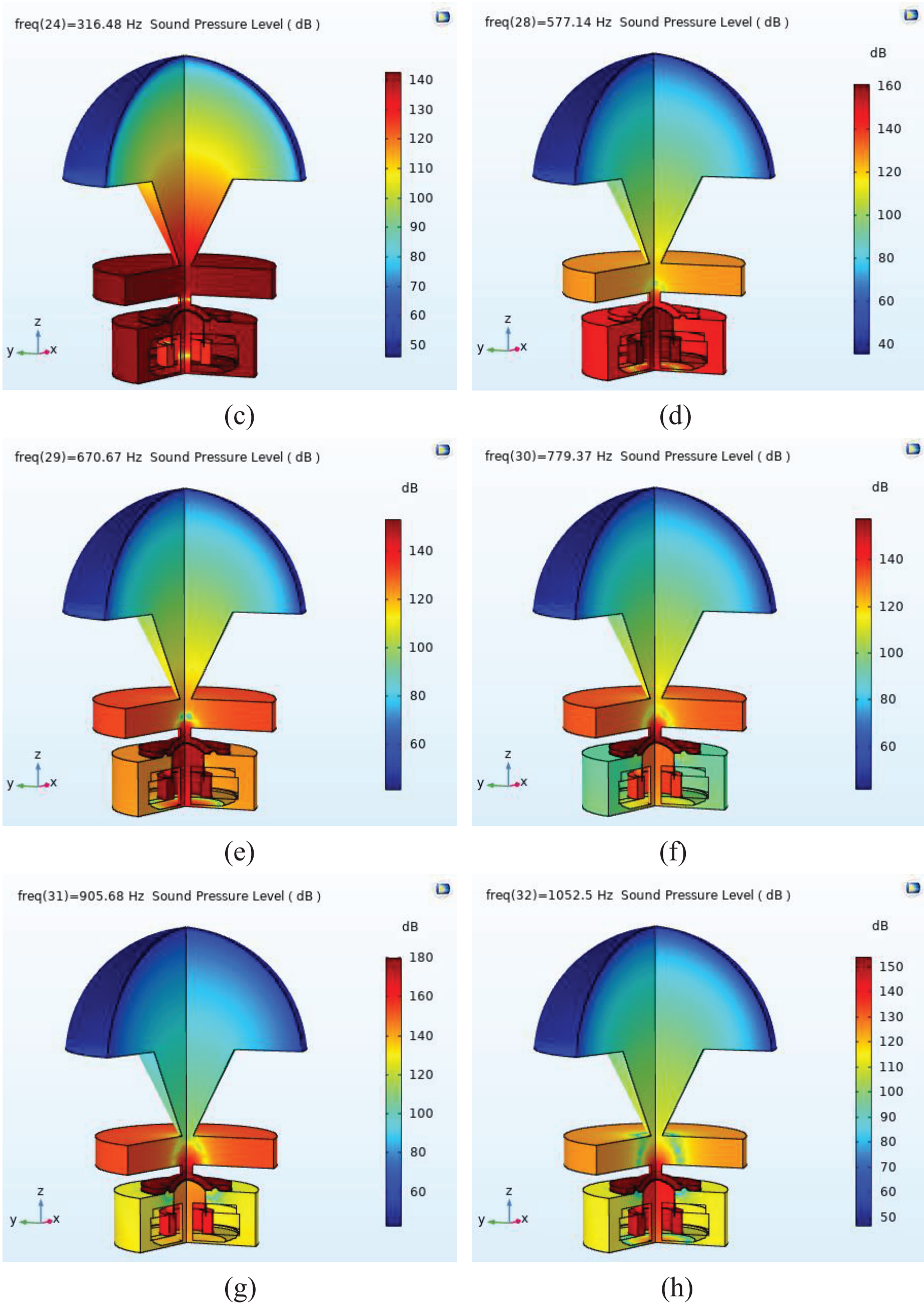
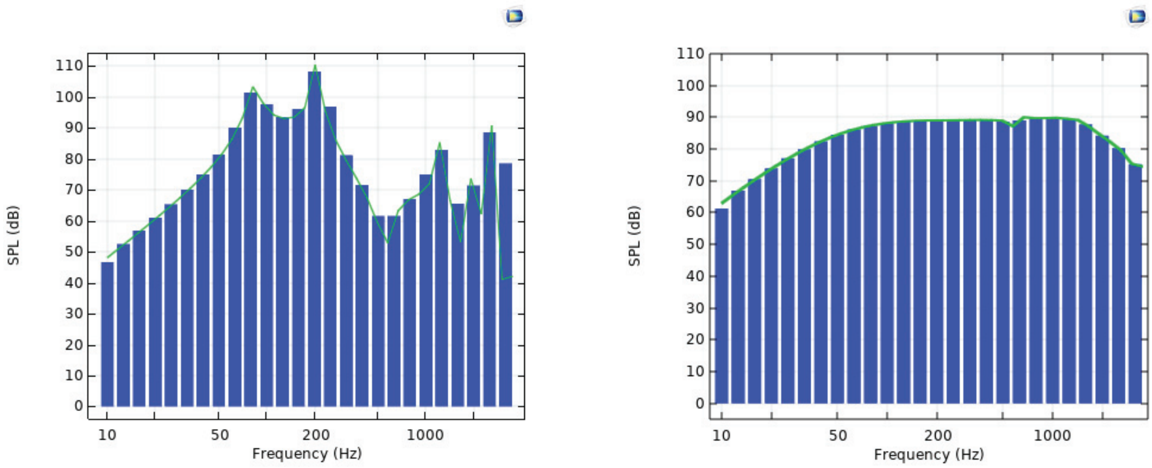


Figure 3 – Sound pressure level at different frequencies: (a) 110.59Hz, (b) 201.67Hz, (c) 316.48Hz, (d) 577.14Hz, (e) 670.67Hz, (f) 779.37Hz, (g) 905.68Hz, and (h) 1052.5Hz

4.2 SPL Response

The sound pressure level is the main and direct reference measurement for designers to predict sound radiation properties of a loudspeaker (1, 5). Comparing the frequency response curves of the high intensity sound source with those of the cone loudspeaker, see Fig. 4, it is found that the high intensity sound source having a Helmholtz resonance structure reaches a high sound pressure level in the range of 50-200 Hz, but gets significantly declined SPL at high frequencies.



(a) (b)

Figure 4 – SPL response of (a) high intensity sound source and (b) cone type loudspeaker.

5. CONCLUSIONS

In this paper, one coupled simulation model for the design of a high-intensity sound source is developed by using COMSOL. Theoretical deduction and finite element simulation conducted to the loudspeakers help to establish the relationship between the electromagnetic field and mechanical vibration and sound field.

The results show that the COMSOL simulation model can clearly reflect the tendency of the acoustic pressure field, and compare the sound pressure level curve between the high intensity sound source and the cone loudspeaker of the same size and the same input voltage.

The parameters used in this model are taken from the COMSOL Acoustic Module User Guide, which can be studied more precisely.

The shortcomings in this paper is that authors do not carefully analyze the structural dimensions of Helmholtz resonator, just highlighting the effect of resonance on the sound pressure level. Hence, the presented simulation model need to refine further.

Many obstacles have been encountered in developing model, which are mainly caused by the form of geometric inaccuracy and uncertainty of material parameters.

ACKNOWLEDGEMENTS

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