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Invited Paper

Study of the Cone on the Acoustic Characteristics of a Cone Loudspeaker

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Abstract. Loudspeakers are designed for reproducing the original sound field as faithfully as possible. In order to faithfully reproduce sound, it is important to understand the relationships among the physical characteristics of the loudspeaker. Vibration analysis of loudspeakers has been extensively researched over the years, but we believe that it has been insufficiently focused on the cone, which are important elements in loudspeaker design. This paper focuses on the cone which is important elements in the design of cone loudspeakers, and evaluates their effects on the acoustic characteristics of the loudspeaker. First, sound pressure frequency properties of a loudspeaker were measured in order to determine the characteristics of the cone loudspeaker. Next, a coupled analysis of vibration and acoustics that accounts was performed to verify the accuracy of the analysis. Finally, in order to design a loudspeaker with the desired acoustic characteristics, the response surface methodology was applied to obtain optimal cone and edge material properties.

1. Introduction

One of the physical characteristics required for an ideal loudspeaker, assuming a constant input voltage, is a flat sound pressure in the frequency domain.

In pursuit of this goal, researchers have long studied on vibration analysis of the loudspeaker. Nimura et al. [1] carried out a theoretical analysis of the vibration of the cone, and used a graphical method to calculate the eigenvalues of the vibration of a conical loudspeaker cone. Frankort [2] , also seeking solutions for the membrane vibrations of conical loudspeaker cones, formulated a differential equation that accounts for bending vibration, and made detailed calculations of the sound pressure frequency response, vibration patterns, and driving-point admittance. However, Frankort's analysis did not account for the effects of the edge and center cap, which play important roles in cone loudspeakers. Subsequently, the Finite Element Method (FEM) has been used for vibration analysis of the cone [3]-[4]. Kyouno et al. analyzed the sound radiation from loudspeakers, accounting for coupling of the electrical, mechanical, and acoustic systems [5].

In these vibration analyses of cone loudspeakers, the cone maintains a piston motion in the low-frequency region. The biggest difficult point of these analyses is the split vibration of the vibration plate in the middle- and high-frequency regions. Control over the cone is very important in the design of a loudspeaker. However, there has been insufficient study of this topic in research up to now.

This paper examines cone loudspeakers, focusing intensively on the effects of the cone, which have a significant impact on the sound pressure frequency response. First, we perform an experimental study of the characteristics of a cone loudspeaker to determine its sound pressure frequency response. Next, we perform a vibration–acoustic analysis of the cone loudspeaker used acoustic analysis software. Finally, we calculate the optimal cone shape, Young's modulus and density of the cone and edge, and examine in detail their impact on the sound pressure frequency response.

2. Experimental and Analysis

The performance of a loudspeaker is largely governed by its cone, which radiates the sound directly. However, in the middle- and high-frequency regions, the shape and material property values of the cone generate split vibrations in axisymmetric and non-axisymmetric modes, exerting a significant influence on the loudspeaker's sound pressure frequency response.

Typical shapes of cones include parabolic cone speaker, straight cone speaker and Parakabuto cone speaker. In this study, three types of cone speakers were created to study the influence of cone shape.

2.1 Cone loudspeaker

As shown in Fig.1, three types of speakers are shown in Fig.1 (a) is a parabolic cone speaker, Fig.1 (b) is a straight cone speaker, Fig.1 (c) is a parakabuto cone speaker.

(a) parabolic cone (b) straight cone (c) parakabuto cone

Fig.1 Three types of cone speakers

2.2 Measurement of sound pressure frequency properties

The performance of a cone loudspeaker is evaluated in terms of its sound pressure frequency properties; therefore, in our investigation, we took actual measurements of these characteristics.

We tested the sound pressure frequency of the loudspeaker by taking measurements in an anechoic room. Figure 2 shows it. The observation point for measurement of the sound pressure in the anechoic room was a position 1 m in front of the loudspeaker, on its central axis.

The results of the sound pressure frequency characteristics of three tapes of cone speakers are shown in Fig.3. From the measurement results of the sound pressure frequency characteristics of the cone, the sound pressure frequency characteristics of the three types of cone speakers were confirmed.

2.3 Verification of the accuracy of our analysis of sound pressure frequency properties

Figure 4 compares the results of our calculation of the sound pressure frequency response in the direction of the axis of the loudspeaker to the actual measurement results from the sweep signal excitation. The solid line represents the measurement results, and the dashed line represents the results.

The changes and characteristics of the sound pressure frequency response from our analysis results are consistent with the traditional view in the literature that more accurate characteristics can be obtained by analyses [6].

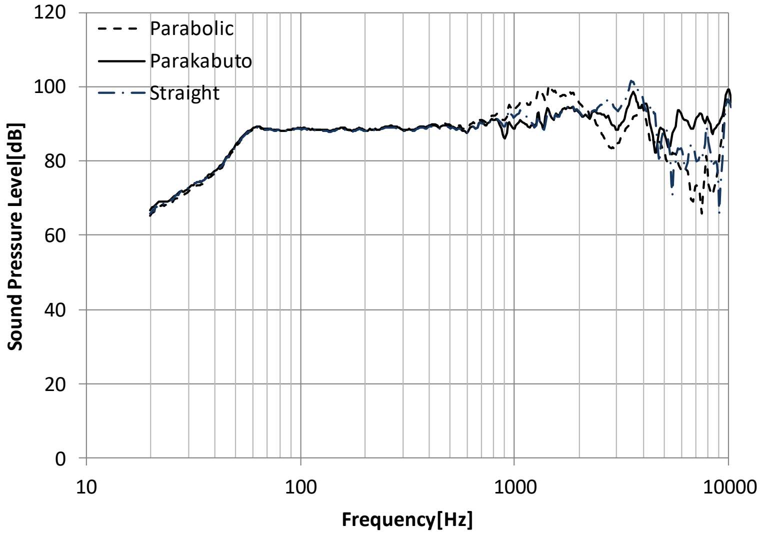
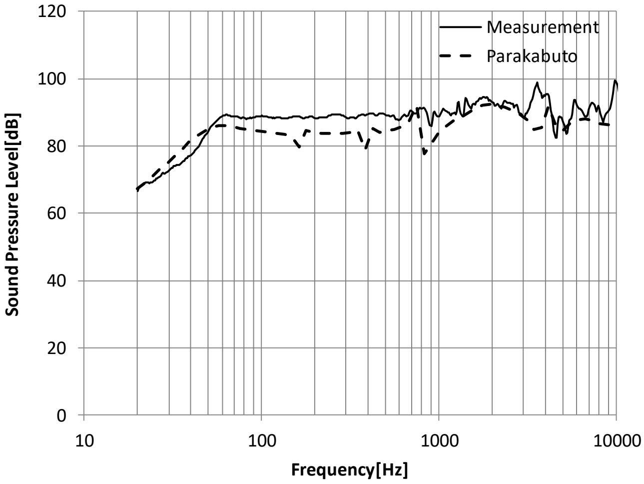
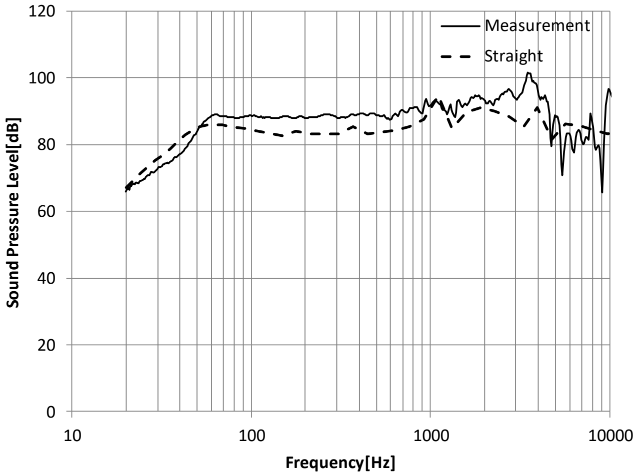


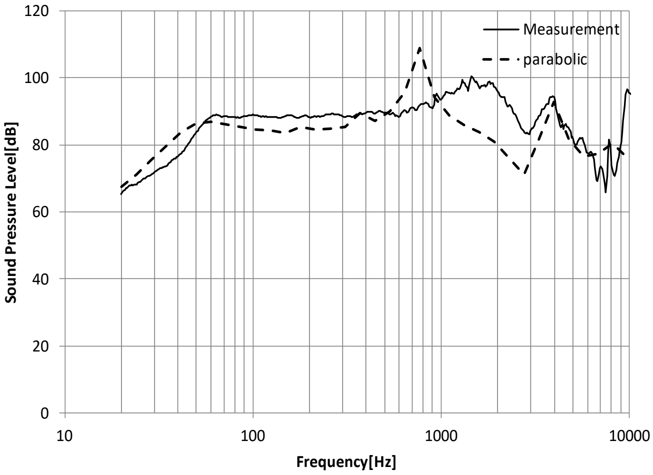
Fig.2 Anechoic room　　Fig.3 Measurement result of sound pressure frequency characteristics



(a) Parakabuto cone loudspeaker



(b) Straight cone loudspeaker



(c) Parabolic cone loudspeaker

Fig.4 Comparison of measurement result and analyses result

3. Discussion

In the previous sections of this paper, we verified the accuracy of the coupled analysis of vibration and acoustics of the loudspeaker. Extending this line of research, a significant remaining challenge is to design the appropriate cone characteristics to obtain the desired acoustic characteristics in the loudspeaker.

To address this challenge, in this section, we consider how to optimize the cone, expressing the problem mathematically as follows.

$$\text{Find} \quad x = [S_c, \quad E_c, \quad \rho_c \;]^T$$

$$\text{Min} \quad W = f(x) = \sqrt{\sum_{i=1}^{n} {d_i}^2} \qquad (i = 1, 2, \cdots, n)$$

$$\text{S.t.} \quad \begin{aligned} & -0.01 \le S_c \le 0.01[kg/m^3] \\ & 7.3 \times 10^8 [N/m^2] \le E_c \le 70 \times 10^8 [N/m^2] \\ & 100[kg/m^3] \le \rho_c \le 1200[kg/m^3] \end{aligned} \qquad (1)$$

Here, S_c is the shape of the cone, ρ_c is the density of the cone, E_c is the Young's modulus of the cone, and $W = f(x)$ is the objective function of optimization. In Figure 5, the solid line represents the target characteristic value, and $d_i \; (i = 1, 2, \cdots, n)$ represents the distance from the displacement characteristic to the target characteristic value at each frequency from 60 Hz to 10 kHz.

Although paper-based materials, metal materials, and other materials have been used to construct the sound-radiating cones in loudspeakers, paper-based materials are used most often. For that reason, the constraints imposed on the ranges of the cone's density and Young's modulus in (1) were set in the ranges for paper-based materials.

We used the response surface methodology to optimize the physical properties of the cone by carrying out the following calculation steps. First, we generated sample data in order to create the response surface for the optimization. Next, using the sample data, we carried out vibration analysis of the loudspeaker by changing the physical properties of each of its parts and, based on the results of the analysis, extracted the objective function values for the optimization calculation. Finally, we established a one-to-one correspondence between sample data and the characteristic values, created an interpolation approximation formula by the response surface method, and then used the approximation formula to find the optimum solution by performing the optimization calculation [7][8] .

Figure 6 shows the results of the vibration analysis using the optimal solution that was obtained. The black solid line represents the analysis result for the optimal solution and the red solid line represents the target characteristic values. The dashed line represents analysis results for the original loudspeaker. The results obtained for the optimal solution closely match the target characteristic values.

The optimal solution exhibits flatter characteristics compared to the original cone vibration displacement characteristics, which exhibited peaks at 3.5 kHz. The result of the objective function value d for the optimal solution was d = 48, which represents an improvement of approximately 28% over the original loudspeaker, for which the result was d = 17.

In the optimal solution, the density of the cone was 100 kg/m^3, and the Young's modulus was 50 × 10^8 N/m^2. These properties define a cone that is lighter in weight and vibrates more easily, but whose stiffness enables suppression of split vibration in the non-axisymmetric mode. This suggests that cones should be constructed from light but rigid materials.

By changing the shape, the Young's modulus and density of the cone, we were able to reduce the peaks that occur due to split vibration of the cone in the middle- and high-frequency regions above 1 kHz and achieve flatter frequency characteristics.

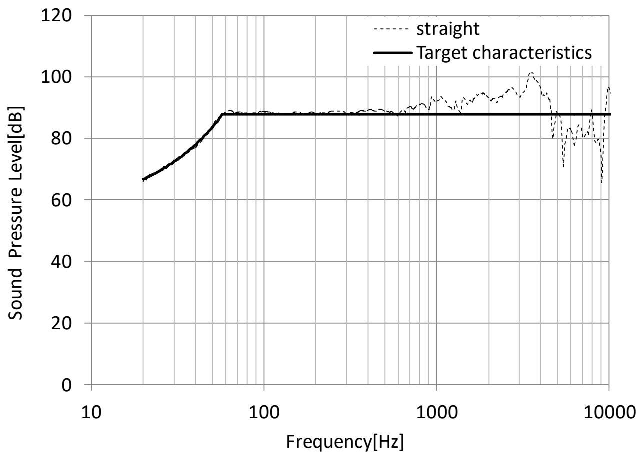


Fig.5 Objective function

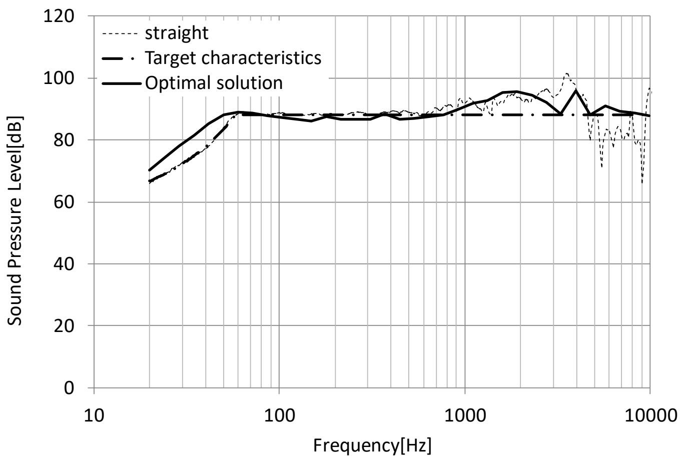


Fig. 6 Analysis result of optimal solution

4. Conclusion

This study focused on the cone which is important elements in the design of cone loudspeakers, and evaluated their effects on the acoustic characteristics of a loudspeaker. We performed a coupled analysis of the vibration and acoustics of a cone loudspeaker, and then sought optimal materials for the cone. The following results were obtained:

(1) We took measurements of sound pressure frequency response of a cone loudspeaker in order to determine its acoustic characteristics.

(2) We performed a coupled analysis of the vibration and acoustics of the loudspeaker, and compared the sound pressure frequency response to the actual measured values. The analysis was able to yield high accuracy.

(3) We used the response surface methodology to optimize the design of the shape, the Young's modulus and density of the cone, and obtained the optimum physical properties of the cone in order to design a loudspeaker with the desired acoustic characteristics. The optimal solution that was obtained reduced the peaks and dips caused by split vibration of the cone and achieved flatter vibration characteristics.

With respect to future challenges, we hope to investigate the analysis of loudspeakers of complex shapes, beyond typical cone loudspeakers. In addition, we would like to alter the shape of the loudspeaker components in ways that will lead to an optimum design to achieve flatter sound pressure frequency properties.

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