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VIBROACOUSTIC ANALYSIS OF A LOUDSPEAKER CONE

J H Kim (1), J T Kim (1), J O Kim (1) & J K Min (2)

(1) Samsung Advanced Institute of Technology, Korea, (2) Samsung Electro-Mechanics Co, Korea

1. INTRODUCTION

This paper deals with the direct radiator type loudspeaker, which drives a conical diaphragm (referred to as a 'cone' hereafter).

The cross-section of the cone paper of the loudspeaker considered in this paper is not a straight line but a slightly curved one as shown in Fig. 1. Since the shape of the cone is axisymmetric, the two-dimensional analysis of the axisymmetric vibration has already been reported [1,2]. However, three-dimensional analysis is needed to obtain non-symmetric vibration mode as well. A theoretical approach is not easy because the cone paper cross-section is curved and the cylindrical bobbin is elastically supported by a spider. Therefore, three-dimensional vibration of the cone has been obtained by numerical analysis using finite element method. The vibration result has been used to calculate numerically the coupled acoustic response by boundary element method.

2. ANALYSIS MODEL

The loudspeaker cone shown in Fig. 1 has been modeled as finite elements by using MSC/PATRAN. The cone paper and the bobbin have been modelled as shell elements and the edge and the spider have been modelled as spring elements as shown in Fig. 2. The edge could be modelled as shell elements, but the elastic constants for the elements were not available. The maximum length of the shell elements used in the model is 14 mm, which is much less than 1/6 times the smallest wavelength in the frequency range upto 4 kHz. The boundary condition is that the bobbin is radially-fixed and the edge is axially free.

The elastic properties and mass density of the cone paper, the edge and the spider have been measured. Young's modulus E of the cone paper has been obtained as [3]

$$E = (1 - \nu^2) \rho c^2 \quad (1)$$

where ν is Poisson's ratio, ρ is mass density, and c is the quasi-longitudinal wave speed measured in a paper sheet using H. M. Morgan's Dynamic Modulus Tester PPM-5R [4]. The properties of the cone paper used for the analysis are E = 2.26 GPa, ν = 0.3, and ρ = 473 kg/m³.

The spring constants of the edge and the spider have been obtained by measuring the static deflection under stepwise loading as 441 N/m and 297 N/m, respectively. The spring constants have been divided to be distributed around the edge and the bobbin, respectively, as shown in Fig. 2. The elastic constants and mass density of the aluminum bobbin have been cited from the properties of aluminum [3] as E = 71 GPa, ν = 0.33, and ρ = 2,700 kg/m³.

3. VIBRATION ANALYSIS

The mechanical vibration of the cone modeled above has been calculated by using MSC/NASTRAN. The calculated frequencies of the natural mode are listed in Table 1 with the numbers of the nodal diameter N_d and the nodal circle N_c on the cone paper. The calculated mode shapes at 51 Hz and 1.24 kHz are shown in Fig. 3.

The first mode is a rigid-body motion of the cone paper as if it oscillates like a piston. This mode is significant in defining the lower limit of the frequency range. The mode shapes of higher modes include nodal diameters, and show a different trend from the mode shapes of a conical shell [5]. The vibration response of the cone excited by the voice coil has also been calculated, and results at two different frequencies are shown in Fig. 4.

4. ACOUSTIC ANALYSIS

Since the sound radiation from the loudspeaker is generated by the vibration of the cone, the acoustic characteristics of the cone are considered to be coupled with the vibration characteristics of the cone. In this paper, one-way coupled analysis has been adopted, and the vibration response calculated above has been used as input data of acoustic excitation. The calculation has been carried out by boundary element method using SYSNOISE.

The calculated frequency characteristic of the loudspeaker is shown in Fig. 5. and the calculated directivity at 500 Hz is shown in Fig. 6. These results have been compared with experimental ones and appear to be reasonable.

5. CONCLUSION

The mechanical vibration of a loudspeaker cone has been calculated by the finite-element method. The analysis model has provided an estimation tool for the lower limit of the frequency range. The frequency characteristics and directivity of the loudspeaker have been calculated based on one-way coupling of the vibration and acoustic behavior of the cone by using the calculated vibration response.

References

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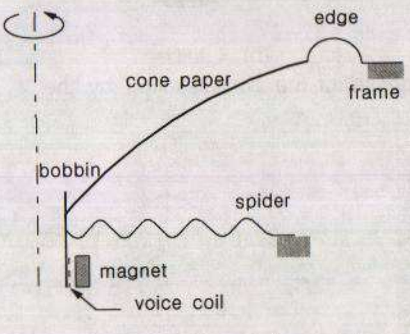


Fig. 1. Cross-sectional view of the loudspeaker cone.

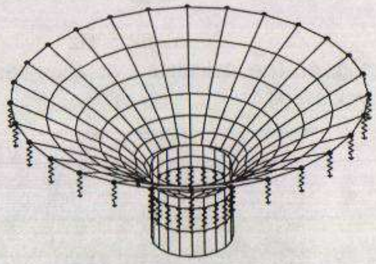
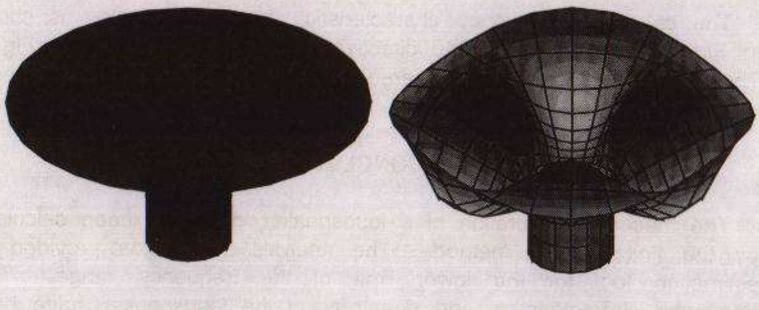


Fig. 2. Finite-element model of the loudspeaker cone with spring-element edge.

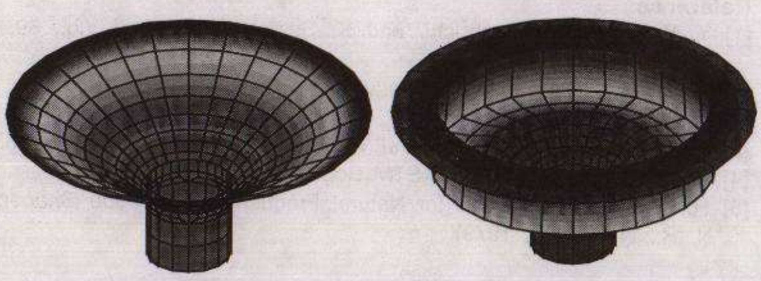
Table 1. Natural frequencies of the cone calculated by the finite element method and measured by sine-sweep test.

Frequency(Hz)	51	1245	1251	1304	1501	1790	2131
(N_d, N_c)	(0,1)	(3,1)	(4,1)	(5,1)	(6,1)	(7,1)	(8,1)



(a) 51 Hz (b) 1.24 kHz

Fig. 3. Mode shapes of the cone obtained by the finite element method.



(a) 62.5 Hz (b) 4 kHz

Fig. 4. The calculated vibration response of the cone excited by the voice coil.

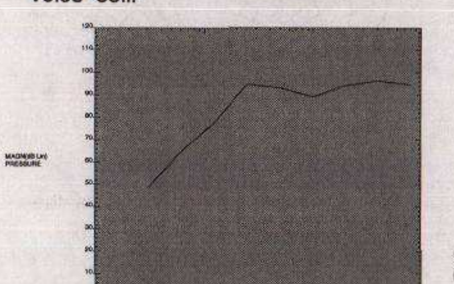


Fig. 5. The frequency characteristics of the loudspeaker at 1m distance.

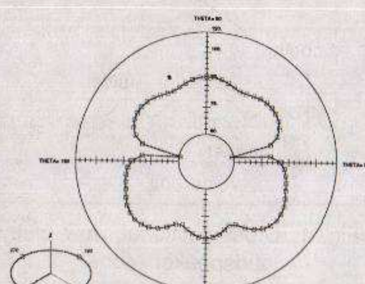


Fig. 6 The directivity of the loudspeaker at 500 Hz.