# Electromagnetic-Structure-Acoustic Coupled Analysis Method of GMM Transducer Speaker

Byungjin Yoo, Katsuhiro Hirata and Atsurou Oonish
Department of Adaptive Machine Systems, Graduate School of Engineering, Osaka University, Osaka, 565-0871, Japan

## Introduction

The sound field creation of flat panel speaker driven by GMM transducer relies on the vibration of flat panel caused by magnetostrictive phenomenon of GMM when a magnetic field is applied. In this case, to predict the sound pressure level (SPL) at audio frequency range, it is necessary to take into account not only magnetostriction of GMM but also eddy current effect, vibration characteristics of actuator and flat panel.

In this paper, we propose electromagnetic-structural-acoustical coupled analysis method using finite element method (FEM) to predict the sound pressure level of the flat panel speaker at audio frequency. Moreover, the validity of the method is verified through the comparison with the experiment of a prototype.

## Analysis Method

### Magnetic Field Analysis

The fundamental equation of the magnetic field can be indicated in frequency domain as follows:

$$\begin{cases} \mathrm{rot}\left(\nu\,\mathrm{rot}\,\dot{A}\right) = \dot{J}_0 + \dot{J}_e = \dot{J}_0 - \sigma\left(j\omega\dot{A} + \mathrm{grad}\dot{\phi}\right) \\ \mathrm{div}\dot{J}_e = 0 \end{cases} \quad (1)$$

- $\nu$ : The magnetic reluctivity
- $\dot{J}_0$ : The exciting current density
- $\dot{J}_e$ : The eddy current density
- $\dot{A}$ : The magnetic vector potential
- $\omega$ : The angular frequency
- $\sigma$ : The electric conductivity
- $\dot{\phi}$ : The electric scalar potential

### Mechanical Analysis

For the modeling of magnetostrictive material, the equation of motion can be expressed as follow:

$$\nabla\cdot\left(\boldsymbol{T}_{mech} + \boldsymbol{T}_M\right) + \boldsymbol{b}_{mech} = \rho\frac{d^2\boldsymbol{u}}{dt^2} \quad (2)$$

- $\boldsymbol{T}_{mech}$ : The stress tensor induced by deformation
- $\boldsymbol{T}_M$ : The Maxwell stress tensor
- $\boldsymbol{b}_{mech}$ : The mechanical body force
- $\boldsymbol{\rho}$ : The mass density
- $\boldsymbol{u}$ : The displacement vector

### The Maxwell Stress Tensor

In this case, the Maxwell stress tensor can be described as follow:

$$\boldsymbol{T}_M = \boldsymbol{H}\otimes\boldsymbol{B} - \frac{\mu_0}{2}(\boldsymbol{H}\cdot\boldsymbol{H})\boldsymbol{I} \quad (3)$$

- $\boldsymbol{H}$ : The Magnetic field
- $\boldsymbol{B}$ : The magnetic flux density
- $\mu_0$ : The permeability of vacuum
- $\boldsymbol{I}$ : The unit matrix

### Constitutive Equations of GMM

The constitutive equations of magnetostrictive material are expressed in (4) and (5) in the *d*-type form.

$$\boldsymbol{S} = \boldsymbol{s}^H\boldsymbol{T}_{mech} + \boldsymbol{d}^t\boldsymbol{H} \quad (4)$$

$$\boldsymbol{B} = \boldsymbol{d}\boldsymbol{T}_{mech} + \boldsymbol{\mu}^T\boldsymbol{H} \quad (5)$$

Where, $\boldsymbol{S}$ is the strain tensor, $\boldsymbol{s}^H$ is the compliance matrix, $\boldsymbol{d}^t$ is magneto-mechanical coupling constant, $\mu^T$ is the permeability of material and the superscript *t* indicates the transpose of the matrix and the superscript *H, T* mean that the value inside the matrix reflect conditions under constant.

### Acoustic Analysis

In this analysis, the Eulerian approach is used to analysis the structure-acoustic coupled system that the governing equation can be written as a wave equation in terms of pressure. In this case, the governing equation of the acoustic field can be indicated using Helmholtz equation in frequency domain as

$$\nabla\cdot\left(-\frac{1}{\rho_0}\nabla\boldsymbol{P}\right) - \frac{\omega^2\boldsymbol{P}}{\rho_0 c^2} = 0 \quad (6)$$

where $\rho_0$ is the fluid density, $P$ is the pressure, $c$ is the speed of sound. In dealing with structure-acoustic coupled system, in which the vibration of structure generates the sound, the pressure can be calculated by using normal acceleration of structure vibration. In this analysis, the normal acceleration of vibration of flat panel induced by GMM transducer, can be given as

$$\boldsymbol{a}_n = \overline{n}\cdot\left(-\frac{1}{\rho_0}\nabla\boldsymbol{P}\right) \quad (7)$$

where $\boldsymbol{a}_n$ is the normal acceleration, and $\overline{n}$ is the normal vector of boundary surface.

## Analyzed Model and Condition

### Analyzed Model

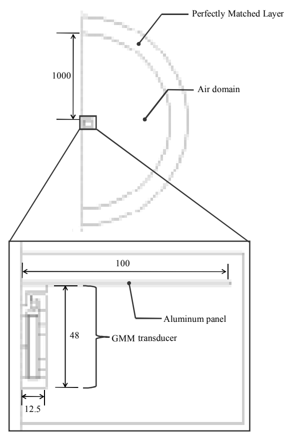


Fig. 1 2D axial symmetric analyzed model

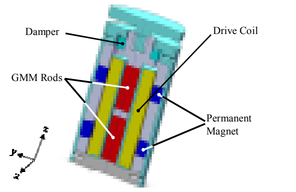


Fig. 2 Structure of GMM transducer

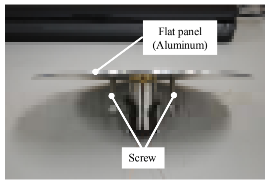


Fig. 3 Prototype GMM speaker

### Analysis Condition

A new approach is proposed to take into account the effect of biased condition on GMM rod by permanent magnet mounted in GMM transducer. In this method, we modified original ***H-λ*** and ***B-H*** curves to be shifted bias magnetic field (45kA/m) to 0A/m.

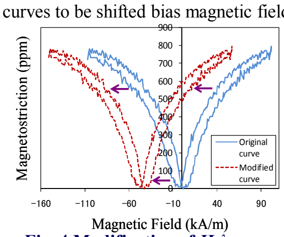


Fig. 4 Modification of *H-λ* curve

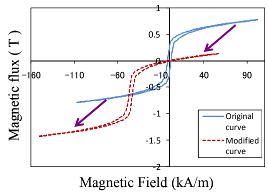
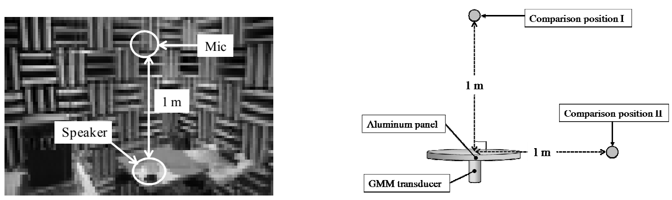


Fig. 5 Modification of *B-H* curve

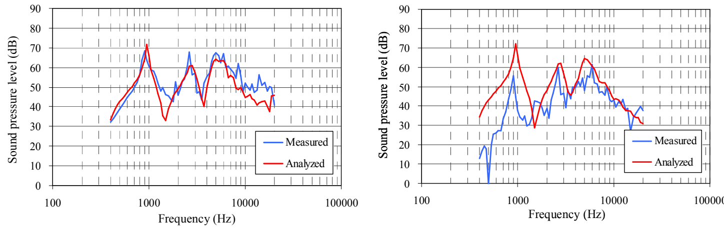
## Analyzed Result

Fig.6 shows the SPL measurement of speaker driven by GMM transducer. Fig. 7 shows the SPL comparison between analyzed and measured results. As can be seen, all of the analyzed results shows good agreement with the measured ones. The reason of errors between analyzed and measured result at comparison position II under 1 kHz is because the screw constraint condition could not be modeled at 2-D symmetric analysis model, the amplitude decrease of vibration at resonance of the flat panel was not considered in analysis.



(a) (b)

Fig. 6 (a) SPL measurement. (b) SPL measurement point.



(a) (b)

Fig. 7 SPL comparison between analyzed and measured results (Input 1Vpkpk)
(a) comparison position I. (b) comparison position II.

## Conclusion

- **The electromagnetic-structure-acoustic field coupled analysis method was proposed to predict the SPL of flat panel speaker driven by GMM transducer.**
- **The method that in order to compute the magentostrictive phenomenon of GMM under biased condition by means of frequency domain magnetic field analysis was proposed.**
- **In conclusion, the proposed coupled analysis method is simple, reliable and fast in computation.**