Basic Consideration of Analysis Method for Magnetostriction Bone Conduction Speaker

Shimpei Takanami[1], Wataru Kitagawa[1], Takaharu Takeshita[1], Akihiro Masuda[2], and Masahiro Nakashima[2]

[1]Nagoya Institute of Technology, Gokiso, Showa, Nagoya, Aichi, Japan, kitagawa.wataru@nitech.jp
[2]SANKO MOLD Co., LTD, 1-130, Hannoki, Miyoshi, Miyoshi, Aichi, Japan

Bone conduction sound is propagated without through the eardrum. Therefore, a conversation is possible under the sound noise by using bone conduction speaker (BCS). However, the size of BCS becomes larger than conventional earphone because BCS is necessary a large exciting force like let vibrating a side of the head. Giant magnetostrictive materials (GMM) have large magnetostriction and high rigidity. It is expected that BCS is possible to miniaturize to make because it has large displacement by magnetostriction. Recently, many kinds of analysis with finite element method are proposed for the actuators with GMM that has complex characteristics. However, it seems few papers about analysis method for loudness of bone conduction sound that human actually hear. In this paper, the analysis method for loudness of bone conduction sound that magnetostriction BCS outputs in consideration of the mechanical characteristics of human head is proposed. Moreover, usefulness of proposed analysis is considered by comparison with the experiment result of prototype.

Index Terms—**magnetostriction, bone conduction speaker, finite element method, mechanical impedance**

I. Introduction

Bone conduction sound is propagated without through eardrum, so that is different from air conduction sound. Therefore, it is expected that bone conduction speaker (BCS) is used for communication under sound noise such as construction site because BCS user is able to talk with hearing environmental sound [1]. However, the size of BCS become larger because larger in order to exciting force is needed than conventional earphone needed.

This paper is proposed to use Giant Magnetostrictive Materials (GMM) that has several times as large distortion (magnetostriction) as piezoelectric materials [2] for small-sized and high-power BCS. However, adequate intensity of magnetic field must be generated for the large magnetostriction. In addition, the characteristics of GMM is complex. Therefore, magnetic analysis with finite element method is needed in calculating magnetic flux density distribution in GMM. Recently, many papers about analysis of bone conduction devices and magnetostriction actuators are presented, but its evaluation of almost paper are that displacement of vibration component is evaluated as the output. However, its evaluation is needed that the acceleration of bone conduction sound of BCS's output to accuracy. It seems that a few papers about the evaluation of magnetostriction BCS or exciter has suggested [3][4][5]. However, they do not consider the load such as the human head. In this paper, an analysis method is proposed for optimal design of magnetostriction BCS. In addition, the usefulness of proposed analysis method is considered by comparison between result of analysis and experiment using artificial mastoid and prototype model.

II. Magnetostriction Bone Conduction Speaker

GMM has especially large magnetostriction in the direction of magnetic field. The main characteristics of GMM is B-H and S-H curves [6]. They are nonlinear and has a hysteresis, however, GMM is able to be vibrated in their linear area by adequate bias magnetic field. Therefore, GMM is possible to output sinusoidal exciting force. And, they are changed by the pressure to GMM. Magnetostriction BCS considered in this paper is shown in Fig.1. In addition, materials and sizes are shown in Table.1. Although conventional speaker is vibrated by magnetic force between coil and magnet, Magnetostriction BCS is vibrated by what alternating field with coil surrounding GMM has GMM expanded and contracted. Diaphragm of magnetostriction BCS is pressed against the skin on zygomatic process. Therefore, vibration of the diaphragm is propagated to cochlea as bone conduction sound.

III. Analysis Method

JMAG-Designer ver.13.1 made by JSOL is used as electromagnetic analysis calculation tool. The flow chart of proposed analysis method is shown in Fig.2. First, B-H and S-

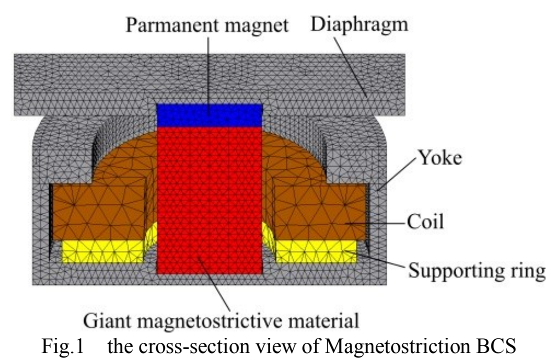

Fig.1 the cross-section view of Magnetostriction BCS

TABLE I
MATERIALS

Part	Material
Diaphragm Yoke	AISI430
Support Ring	AISI304
Giant Magnetostrictive Material	Te-Dy-Fe
Permanent Magnet	Nd-Fe-B (B_r:1.2T)
Coil	Copper
Part	**Sizes**
Diameter of Yoke	13.6mm
Diameter of GMM	4.0mm
Height of BCS	8.5mm

H curves of GMM is prepared, then *B-S* curve is calculated from them. Next, magnetic flux density distribution at each factor is calculated by non-linear magnetic field analysis based on *B-H* curve. Moreover, magnetostriction is calculated at each factor by referring *B-S* curve, where curves in pressure 0.4MPa are used because GMM is applied 0.4MPa pressure on by pressing the BCS against human body. In addition, maximum pressure generated by vibration of magnetostriction is ignored because it is 0.04MPa. Moreover, it is needed that magnetostriction is changed to the exciting force for inputing to structure analysis. The virtual force that causes magnetostriction at each factor is calculated. It is called magnetostrictive force.

In structure analysis, the same model is used as magnetic field analysis model. The exciting force from the surface of diaphragm is analyzed based on the magnetostrictive force.

Finally, acceleration of bone conduction sound is calculated with the mechanical impedance of the human mastoid. In this paper, the mechanical impedance of the artificial mastoid is used assuming that it is almost same as the mechanical impedance of real mastoid.

IV. Experiment Method

The experiment system is shown in Fig.3. Sweep wave (10Hz ~ 20kHz) as sound signals from function generator is inputted to BCS. Acceleration of bone conduction sound outputted from BCS is changed to voltage by piezoelectric material built in the artificial mastoid. Moreover, the voltage is amplified by charge conditioning amplifier and frequency analysis is performed by FFT analyzer.

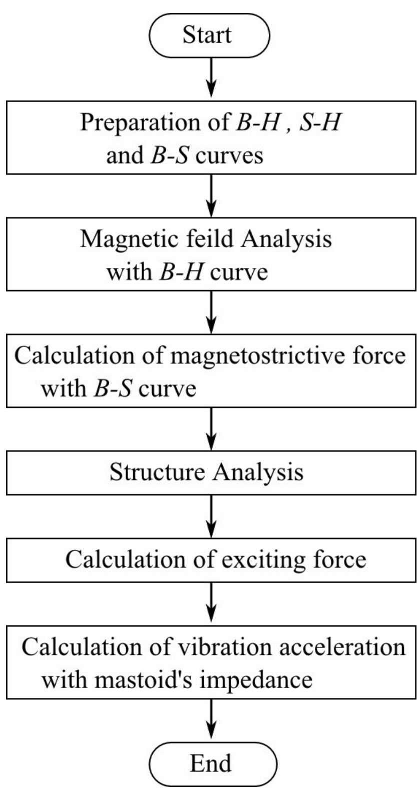

Fig.2 Analysis method

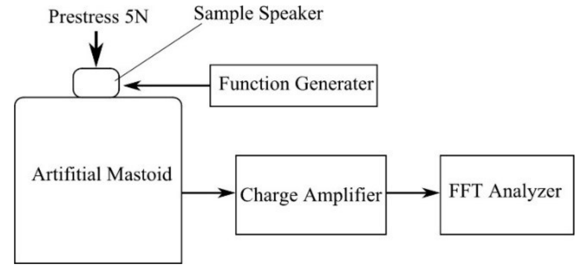

Fig.3 Experiment system

V. Comparison between Experiment and Analysis

The comparison between analysis and experiment result of acceleration-frequency characteristics of bone conduction sound outputted from BCS is shown in Fig.4.

The frequency-acceleration of analysis values approximately agree with experiment values. Especially, reduction at near 5000Hz is caused by anti-resonant frequency of the mechanical impedance of artificial mastoid.

And, the difference between experiment and analysis values is large in low frequency (315Hz~630Hz). Generally, displacement of diaphragm is reduced when Magnetostriction BCS is replaced on the load. However, the exciting force is analyzed without consideration of load, therefore, it is considered that larger exciting force than actual one is obtained as analysis result.

As future work, it is considered that the simple modeling of the human head is needed.

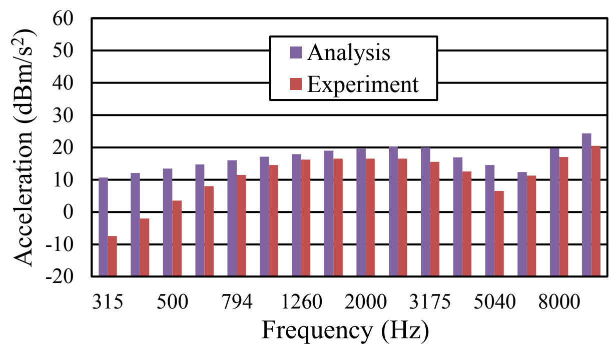

Fig.4 The comparison of acceleration-frequency characteristics between analysis and experiment

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