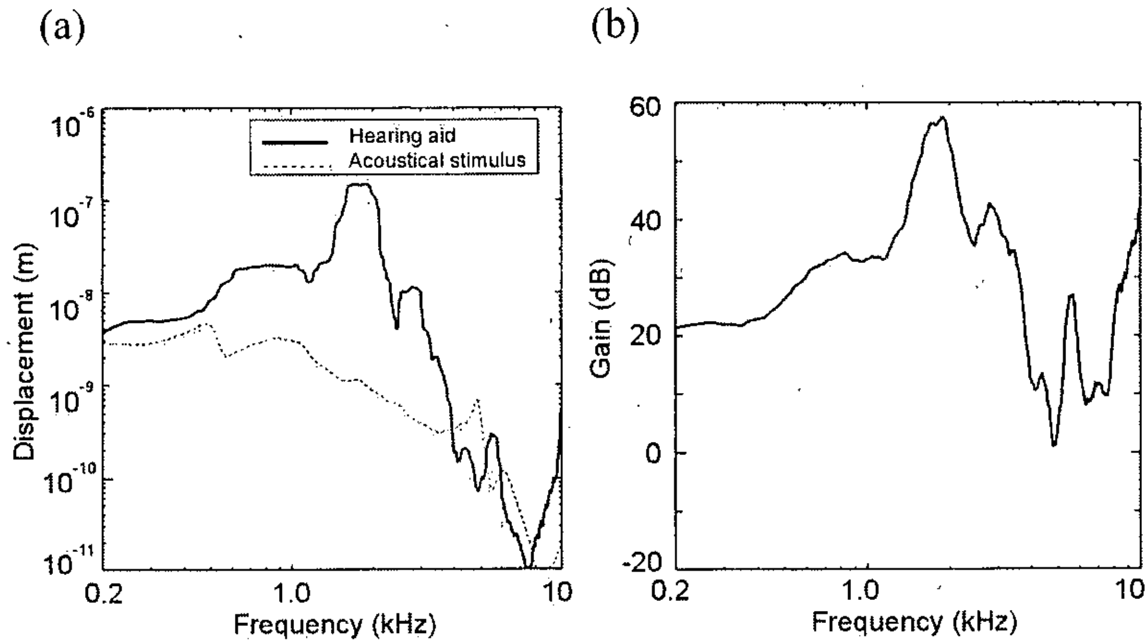

Figure 4.3. Effect of the shape of the magnet on the excitation force generated by the hearing aid. (a) Frequency responses of the displacement at the stapes footplate. (b) Frequency responses of the acoustical gain calculated on the basis of results in Fig. 8(a). Almost entire frequency range, acoustical gain was more than 20 dB SPL. The maximum gain was 57 dB at 2 kHz and this value was about 15 dB larger than that obtained from small size of magnet. This result indicates that when the larger size of the magnet was used, the hearing aid can generate larger excitation force.

Chapter 5. Discussion

Generally, hearing aids must amplify the acoustical input signal so as to acquire a sufficient acoustical gain, which is needed for the hearing aid wearer. The adequate acoustical gain of the hearing aid is determined on the basis of the most comfortable level for the hearing aid wearer and that in dB is given by

$$P_{HL} / 2,$$

where P_{HL} is the hearing level, namely, the degree of deafness compared with the level of hearing of normal subjects [1]. For example, an adequate acoustical gain of a patient with a hearing level of 80 dB HL is 40 dB. Such patients can understand only loud voices at close proximity to the ear. The sound pressure level of the usual speech range is approximately 60 dB SPL. Therefore, it is necessary for a patient with a hearing level of 80 dB HL to wear a hearing aid which outputs a sound pressure of more than 100 dB SPL.

In the case of the experiments using the artificial middle ear, it generates the equivalent sound pressure of 100 dB SPL above 2 kHz as shown in Fig. 4.1. This result indicates that the hearing aid developed in this study can be used to treat patients with a hearing loss up to about 80 dB HL above 2 kHz.

However, experiments using human temporal bones showed different results compared with those obtained from the artificial middle ear above the frequencies, which the maximum acoustical gain was obtained. In this frequency range, the displacement excited by the hearing aid decreased dramatically. One cause of this result is considered that the mass loading of the Vaseline decreased the efficiency of the hearing aid. In the experiment using human temporal bones, more than 10 mg of the vaseline, which is approximately half as the mass of the vibrator coil (18.3 mg), was used for the tightly attachment of the vibrator coil to the tympanic membrane. Therefore, the mass of the vaseline might affect the efficiency of the hearing aid especially at high frequencies.

The other reason is considered to be the difference of the vibration modes of the stapes footplate caused by the hearing aid and the acoustical stimulation. Hato et al. reported that the footplate motion is a combination of piston-like motion and the rotational motion and the stapes-footplate motion is complicated especially at high frequencies [8]. In addition, the footplate motions were obtained from only one point in this experiment. Therefore, the vibrator coil, which is attached to the tympanic membrane, changed the vibration mode and might affect efficiency of the hearing aid especially at high frequencies.

In experiments using the human temporal bones, the acoustical gain was about 20 dB below 0.5 kHz. The reason for the low gain of the hearing aid in the low frequency range is considered that electromotive force generated at the induction coil decreased with a decrease in frequency. In fact, the electromotive force generated at the induction coil below 0.5 kHz was less than one-fifth of that at 10 kHz. To obtain high gain in this frequency range, improvements of the coils are needed.

Chapter 6. Conclusions

To make a non-implantable hearing aid, a prototype of the hearing aid using coils to vibrate the ossicles via the tympanic membrane was constructed. To determine fundamental properties of the hearing aid, excitation force and acoustical gain were evaluated using the artificial middle ear and the human temporal bones, respectively. The experiments showed that the hearing aid was able to generate the maximum excitation force, which is equivalent to a sound pressure of 100 dB SPL at high frequencies.

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7.研究発表

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2) Shinji HAMANISHI, Takuji KOIKE, Toshimitsu KOBAYASHI and Hiroshi WADA

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Efficiency of a New Electromagnetic Hearing Aid: Evaluated by Measurement of the Stapes-Footplate Motion Using Human Temporal Bones

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