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Effect of intermediate material at contact surface of bone-conducted sound transducer on propagation characteristics

骨導音トランスデューサの接触面における介在物が伝達特性に与える影響

Satoki Ogiso[‡], Koichi Mizutani[*], Naoto Wakatsuki, Keiichi Zempo and Yuka Maeda (Univ. of Tsukuba)

小木曽里樹 [1†‡], 水谷孝一 [2], 若槻尚斗 [2], 善甫啓一 [2], 前田祐佳 [2] ([1] 筑波大・エンパワーメント情報学プログラム, [2] 筑波大・シス情系)

1. Background

Bone-conducted sound is one of the sounds which propagate through skin or bone in the head, while usual airborne sound, or air-conducted sound, propagates from the outer ear to the inner ear. The bone-conducted sound has originally been utilized in clinical applications. They have been playing important role in clinical diagnosis or hearing aid, and now spreading to the consumer headphones, including augmented reality[1)]. From these developments, the influence of contact condition of bone-conducted sound transducer on sound characteristics have been reported[2)]. Usually, the transducers are placed on the forehead or mastoid, where the skin is relatively thin and usually there is no hair.

However, recent bone-conducted sound headphone including ones used in our previous researches are placed just in front of the ear for convenient and confortable use[3-4)]. In most cases, there are hairs and that effect cannot be ignored. In this condition, estimation of the propagation characteristic difference caused by intermediate material, namely hair in this case, between the transducer and the skin is important to compensate the effect of that material on the propagation characteristics[5)]. If we could estimate the difference instantly, it would be valuable not only for this type of transducers, but also for other fields including traditional bone-conducted sound transducers and any others using contact transducers. The intermediate material affects the transmittion of the sound from the transducer, and that can be seen as a change of mechanical impedance. On the other hand, the mechanical impedance of the transducer is observed via the electrical impedance of the input terminal.

In this research, the effect of intermediate material on the electrical impedance of bone-conducted sound transducer is examined. Human hair was employed as intermediate material.

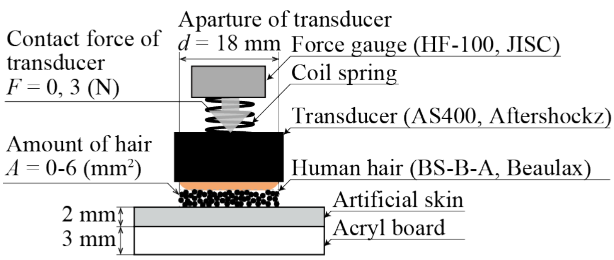

Fig. 1 Setup of experiment.

2. Condition of experiment

In the experiment, the electrical impedance of the bone-conducted transducer was measured for various conditions, which vary the amount of hair and the contact force of the transducer. The experimental setup is shown in **Fig. 1**. Human hair (BS-B-A, Beaulax) was employed as intermediate material. The amount of the intermediate material A was classified by the cross-sectional area of intermediate material. A was measured as a height of stuffed hair in a 1 mm slit. In some cases, A would be different from the actual cross-sectional area in between the transducer and the skin, as it only expresses the amount of the material. The measured range of A was from 0 to 6 mm^2 for each 1 mm^2. For each amount of the intermediate material, the electrical impedance was measured for two contact forces F = 0 N and 3 N. For each condition, the electrical impedance was measured for 5 times and averaged result was employed. The electrical impedance was measured from 10 Hz to 60 kHz. The lower limit of this range was chosen to cover the audible range of human, and higher limit of this range was chosen to cover the perception of bone-conducted ultrasound, which is mainly from 30 to 40 kHz. For measurement of electrical impedance of the transducer, a network analyzer (E5061B, Agilent) was used. A force gauge (HF-100, Japan Instrumentation System Co. Ltd. (JISC)) was connected with the transducer (AS400, Aftershockz) via a spring in order to measure the contact force F. The force gauge was placed on a servo stand (JSV-H1000, JISC) to make the contact force constant. The transducer was contacted with a

*mizutani@iit.tsukuba.ac.jp

board that substitutes the human skin and bone. The board consists of soft gel of 3 mm thickness representing human skin and of acrylic board representing human bone of 2 mm thickness.

3. Results and discussions

Figure 2 shows the change of impedance depending on the amount of intermediate material. Each line in these figures represents a different amount of hair. Figure 2 (a) and (b) show the result when the contact force of the transducer is 0 N, and Fig. 2 (c) and (d) show the result when the contact force of the transducer is 3 N.

On both results, there are several peaks and the impedance increase with increasing frequency. The increase of the impedance seen in all results can be considered as the inductance of the transducer. Four different peaks can be observed in Fig. 2 (a). Figure 2 (b) shows the detailed view of peaks I and II in Fig. 2 (a). The height and center frequency of peaks I and II highly depend on the amount of intermediate material. As the amount of the intermediate material increase, the height of the peak I and center frequencies of the peaks I and II decreases, while the height of peak II increases. Peaks III and IV do not change with the amount of intermediate material in this condition. From Fig. 2 (c), there are mainly three peaks I, III and IV. The contact force is relatively higher than that of Fig. 2 (a). The peak II seen in the Fig. 2 (a) shrunk into small peaks between peak I and III. In this condition, peaks I, II and IV do not change with the amount of intermediate material. On the other hand, as shown in Fig. 2 (d), the peak III have been influenced by *A*. Cause of these change in the electrical impedance need to be examined.

4. Conclusion

In this research, the effect of intermediate material on the electrical impedance of bone-conducted sound transducer is examined. Human hair was employed as intermediate material. The electrical impedance was measured from 10 Hz to 60 kHz. From the results, the electrical impedances show difference depending on the intermediate material. As future work, the equivalent electrical circuit is needed to estimate the amount of intermediate material and mechanism of change of impedance.

References

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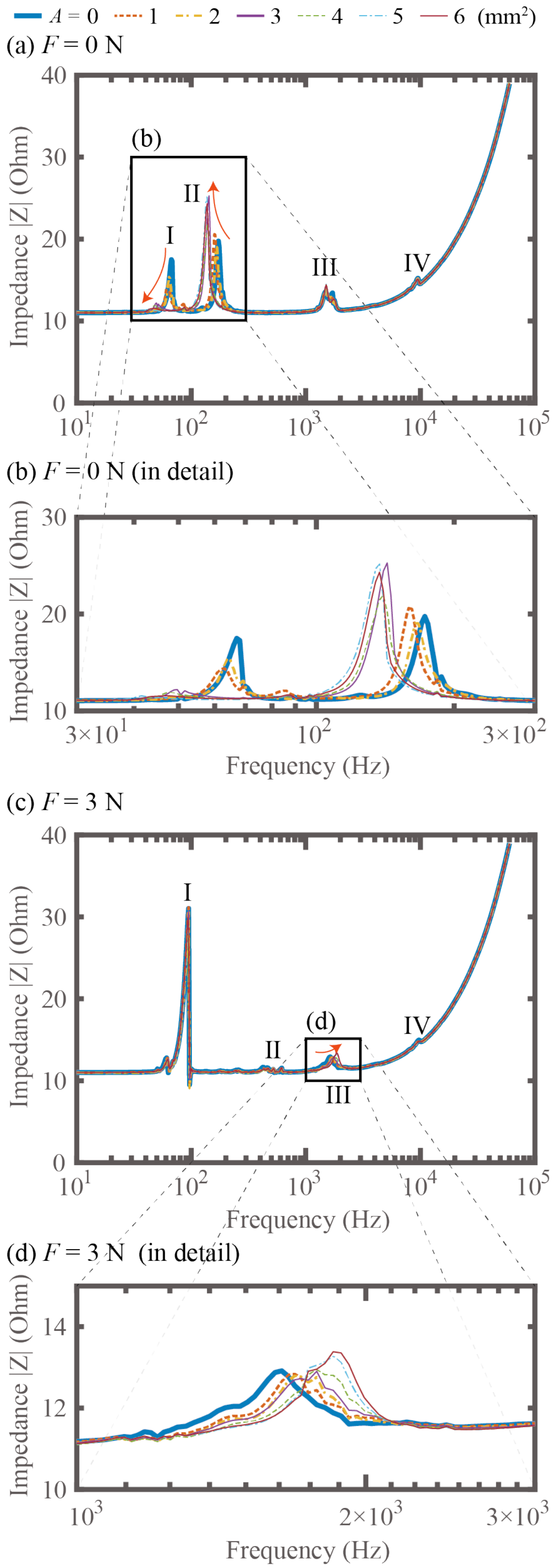

Fig. 2 Change of impedance depending on the amount of intermediate material (hair). (a) Contact force F = 0 N, (b) Contact force F = 0 N, detailed (c) Contact force F = 3 N, (d) Contact force F = 3 N, detailed.