Prediction of otoacoustic emission caused by bone conduction actuator using piezo-electric device

圧電デバイスを用いた骨導アクチュエータに起因する外耳道放射音の予測

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1. Introduction

Bone conduction (BC) actuator has been used for some commercial headphones. Typical actuator placement is illustrated in Figure 1(a).

The calibration method for commercial BC headphones to deliver the sound equivalent to generic headphones using air conducted sound is yet to be established while the method for BC hearing aid is standardized for the measurement purposes. Accordingly, we have been investigateing simplified estimation model for BC headphones by combining the models for BC hearing aid [1] and generic headphones [2].

Our recent study [3] indicates that transmission occurred from BC actuator are highly characterized by the mechanical impedance of the actuator. Specifically, electrodynamic actuator tends to perform more sensitive to the change in the stiffness of the attached soft tissues compared to electromagnetic actuator and affect on the emission to the ear canal. The results implies that piezoelectric actuator oparating in audible frequancy range, having relatively close machanical impedance with electrodynamic actuator, may perform sensitive to the properties of the soft tissue. This paper, therefore, investigates the behavior of our model when piezo-electric device is applied as BC actuator, especially on otoacoustic emission.

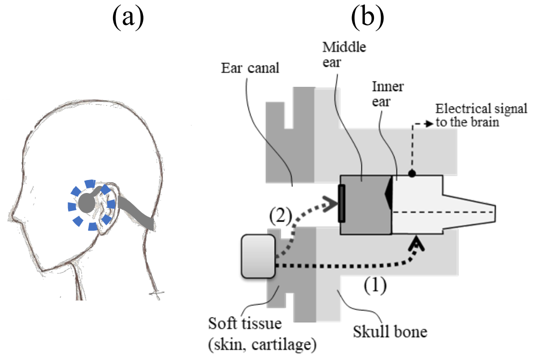

Fig. 1 (a) Typical excitation areas for BC actuators and (b) estimated transmission pathways (1) and (2).

2. Proposed Model for Soft Tissues and the Skull

Figure 2 shows the model for the excitation with the bone conduction headphone actuator, which represents the electrical, mechanical, and acoustic systems in the circuit. The dotted rectangles (1) and (2) correspond to the equivalent circuit for pathways (1) and (2) in Figure 1, and the rectangle on the left describes the equivalent circuit for the actuator, including the electrical input. The connection of circuits (1) and (2) with the actuator is based on the assumption that the forces applied to both pathways originate from the single velocity component at the surface of the actuator.

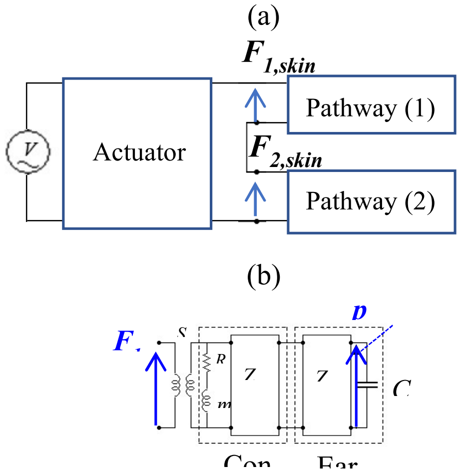

Fig. 2 (a) Simplified lumped parameter model and (b) detailed model applied to pathway (2) in Fig. 1.

3. Piezo-Electric Actuator Model

The actuator using piezo-electric device was modeled as a multi-section beam model both for mimicking the existing BC headsets with pieso-electric device and for simplicity.

Figure 3 shows the model of the piezo-electric actuator for analysis. The mechanical impedance of the actuator was calculated by giving the electrical voltage to the electrodes of the device and assuming the

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resulted force as the sum of the applied force in Fig 2(a).

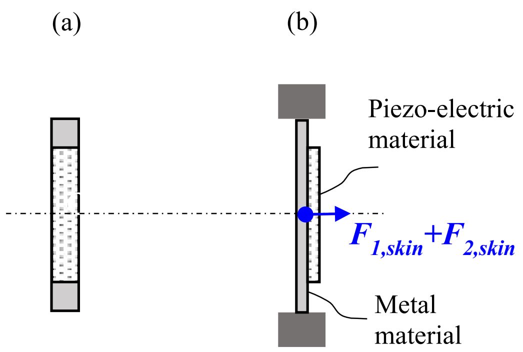

Fig. 3 Construction of the Piezo-electric actuator to analyze and the corresponding force in Fig. 2(b) .

4. Other Actuator Models

Figure 4 describes the models of the two types of actuators: (a) electromagnetic and (b) electrodynamic.

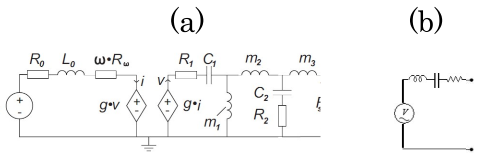

Figure 4: Lumped parameter models for the other types of the actuator. (a) electromagnetic and (b) dynamic.

4. Simulation Results

Figure 5 shows a comparison of the simulation results with different types of actuators, as shown in Figure 3 and 4. Owing to the simplicity of the circuit of the actuator itself and relatively closer absolute parameter values with the components in pathways (1) and (2) directly connected to the actuator, the frequency characteristics of an electrodynamic actuator differ from those of an electromagnetic actuator over the entire frequency range, as reflected int the anti-resonance frequency in the sound pressure characteristics.

The results indicate that the transmission via pathways (2) is characterized by the mechanical impedance of the actuator, and the compensation method may need to include the model of the actuator.

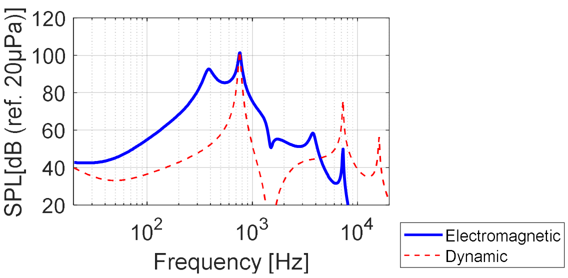

Fig. 5 Sound pressure level in comparison between the types of actuator. .

5. Conclusion

A combined lumped-parameter model based on an existing simulator for human mastoid and ear is proposed for sound delivery with bone conduction headphones by assuming the pathways derived from the recent findings on BC sound transmission. Evaluation towards the difference in the types of the actuator was carried out.

References

1. Fujise, A, Wakatsuki, N., and Mizutani, K. (2021), . Estimation of otoacoustic emission and excitation force of bone conduction actuator by combined lumped parameter model, Inter-Noise 2021,Doi: doi.org/10.3397/IN-2021-2919.
2. IEC, IEC 60318-6: 2007 Electroacoustics - Simulators of human head and ear - Part 6: Mechanical coupler for the measurement on bone vibrators.
3. ITU, ITU-T Recommendation P.57 (2011), Objective measuring apparatus: Artificial Ears.
4. Lundgren, H. (2010), Bone conduction actuators and output variability: lumped-parameter modelling of state variables, Master' s thesis. Chalmers University of Technology.