Research of Acoustical Impedance of Human Skin

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Abstract

This paper presents the methodology of measuring acoustic impedance of human skin and discusses the results of the tests. Measurement of the acoustic impedance of human skin is a complex issue. The most difficult thing is related to the nature of the object of research. Cooperation of volunteer participating in the experiment is crucial in collecting accurate data. Appropriate measuring conditions must be provided because of the length of time required to conduct measurement. The Kundt tube method has been used as a research technique applied for evaluation of the material impedance.

It was assumed that the results would differ with regard to different points chosen for measurement, located on the body of volunteer as well as with regard to the features of the skin structure of the volunteers participating in this experiment. Results have revealed that for different people similar parameters have been obtained. Moreover, results are alike for various measured points localized on person's body.

Keywords: acoustical impedance, human skin, HRTF

1. Introduction

The measurements of the acoustic impedance of the human skin were conducted in order to obtain the parameter required for numerical human head model. The model can be used for numerical calculation of Head-Related Transfer Function (HRTF) [1]. To calculate HRTF using numeric methods it is necessary to establish certain border conditions. The acoustic impedance appears to be appropriate border condition [2].

The subject of the acoustic impedance of human skin in the literature is related to medical ultrasound diagnostic methods [3]. Typical methodology is to provide one average value for ultrasound frequencies. It cannot be assumed that the impedance is constant in wider range of frequencies. For practical use in ultrasound diagnosis, resulting in one average value describing the impedance is sufficient.

This paper presents the methodology of measurement of the acoustic impedance of human skin in the audible frequencies range. The results of measurements are presented and a short description of difficulties related to conducting the experiment is given.

2. Methodology

The measuring of the acoustic impedance can be done using standing wave ratio method [4] or using transfer-function method [5]. For the acoustic impedance of human skin standing wave ratio method was applied for the range of frequencies between 800 Hz and 6300 Hz and transfer function method was used for the range between 160 Hz and 1600 Hz.

The test was performed with the participation of two people whose skin structures were different. Volunteer A had more extensive fat tissue than volunteer O. Measuring was done on forehead, cheek, abdomen, hand and lower back (loins). The end of the impedance tube was placed on chosen part of the body and the volunteer was asked to press against the tube. The difficulty faced at this stage was that the person was asked to maintain possibly the same degree of pressure on the tube. It should be noted that there is no method to assure constant pressure of the tube's rim on person's skin. No special means improving tightness in the place of junction between tube's rim and person's skin were used.

Uneven pressure on the tube's rim in the various spots is a significant obstacle in conducting the test. While the pressure is changing, the tested spot is changing its location in relation to the tube's rim to some extent. Increasing the pressure results in a shortening of the part of the tube in operation, whereas decreasing the pressure results in an extension of the part of the tube in operation.

For invariable measuring conditions equally invariable pressure is required. Taking into consideration the nature of the object in the test, achieving constant pressure while conducting the experiment is impossible. In the same time when smaller, 30 mm diameter tube is used the uneven pressure on skin results in insignificant variations in the part of the tube in operation. The variations are in the range of ± 1 mm. However, when the bigger 100 mm diameter tube is used, the range of variations also increases up to ±5 mm.

To validate the obtained data the transfer function method has been applied next. Minimal amount of time needed to obtain measurement assures better accuracy in measuring the depth of tester. In addition, the accuracy of measurement is increased by repeating the operation many times and averaging the obtained results.

3. Results

The results of measuring the human skin acoustic impedance are presented. Figure 1 illustrates module of acoustic impedance of human skin for different localizations. Figure 2 shows phase of the acoustic impedance of human skin. It should be noted that even though the test was done on skin in various parts, the results are consistent and oscillate around certain average value. It could be expected that different results would be obtained for the skin on forehead and for the part of abdomen. This expectation is justified with the fact that the thickness and the structure of forehead and abdominal skin vary to big extend. Furthermore, there is a hard structure – skull bone – under the skin on forehead and soft structures – body organs – beneath abdominal skin. The convergence of results is also found in the phase of acoustic impedance of human skin. In this case the range of variations between the obtained values is minimal and does not exceed the value of $\pi/2$.

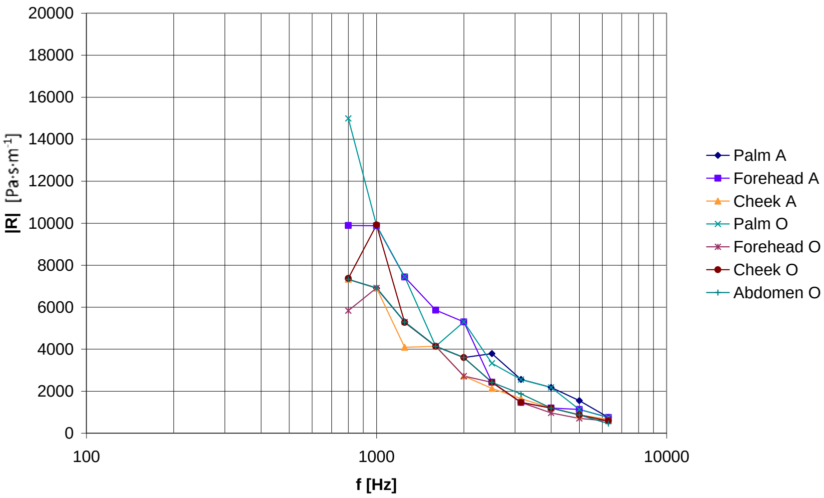

Figure 1. Module of acoustic impedance of human skin measured with standing wave ratio method

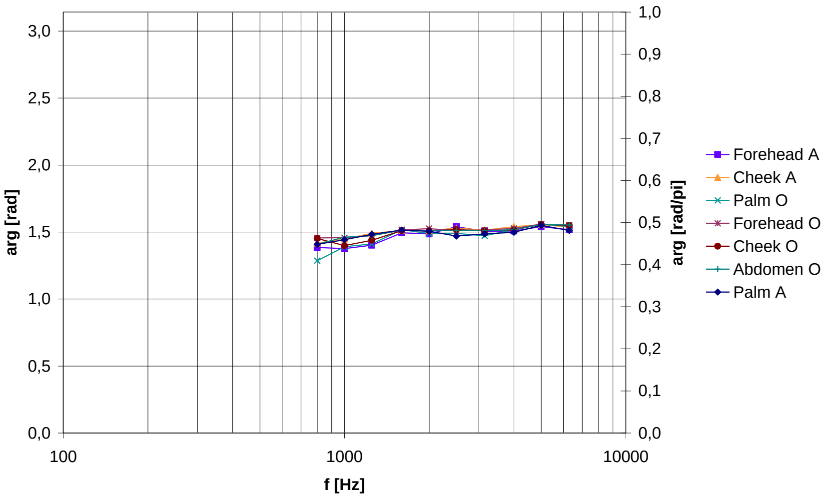

Figure 2. Phase of acoustic impedance of human skin measured with standing wave ratio method

Figures 3 and 4 present the same results averaged for all measured points. What is distinctive is the fact that while the frequency is increasing the variation in obtained values decreases.

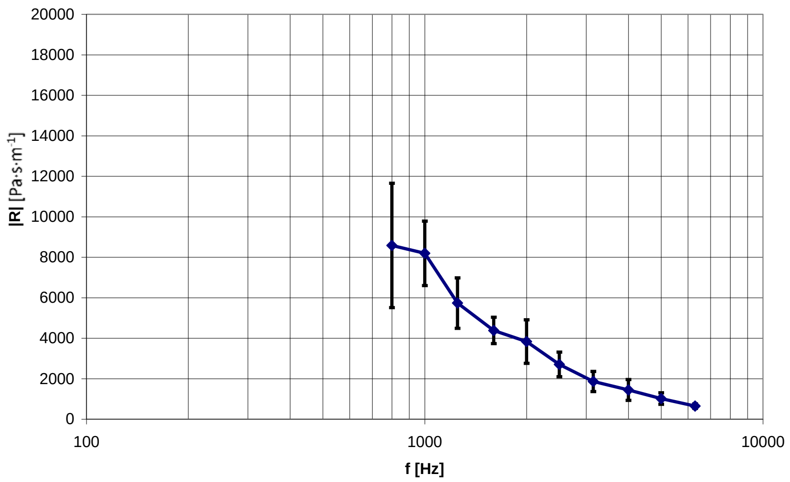

Figure 3. Average value of module of human skin acoustic impedance measured with standing wave ratio method

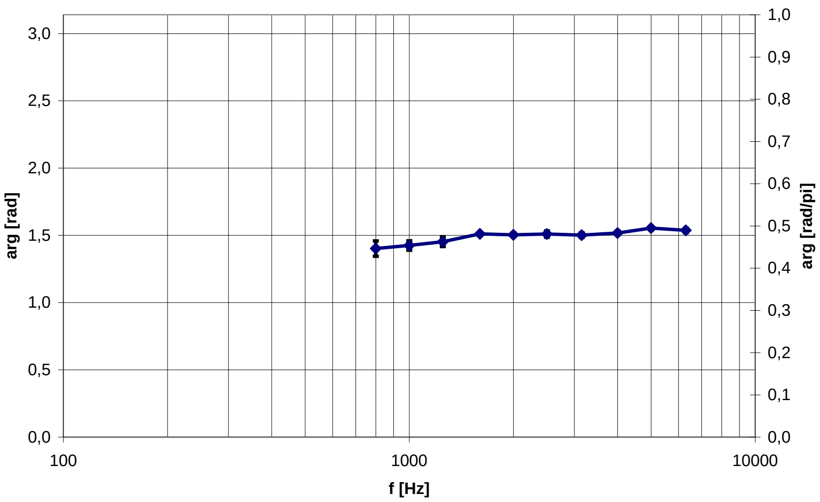

Figure 4. Average value of phase of human skin acoustic impedance measured with standing wave ratio method

Figures 5 and 6 illustrate the outcome of measuring of human skin acoustic impedance in the ranges of frequencies between 160 Hz and 6300 Hz. The chart presents average value of impedance in all measured points. This type of results presentation is justified in the light of the convergence of results for all measured points. It should be noted that the skin impedance on abdomen and on back were measured using lower frequency range. Due to the big diameter of the tube it could not be applied, for instance, to test skin on hand because the size of hand is smaller than that of the tube.

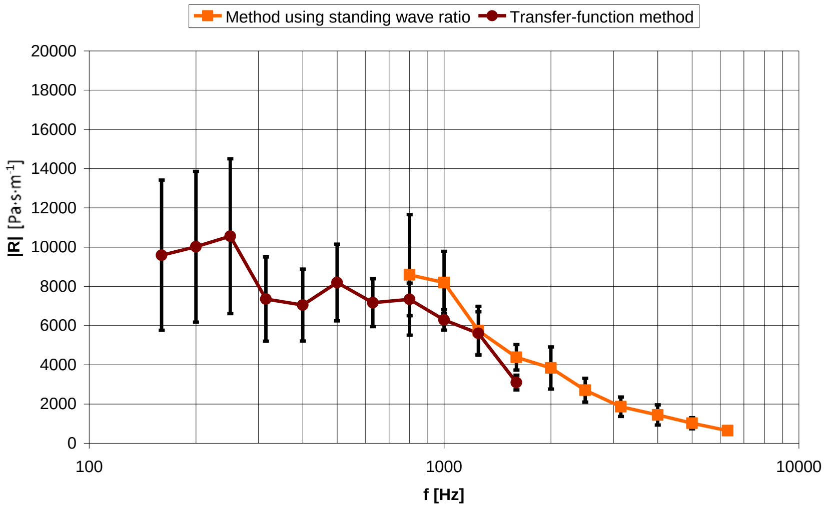

Figure 5. Average value of module of human skin acoustic impedance measured with standing wave ratio method and transfer-function method

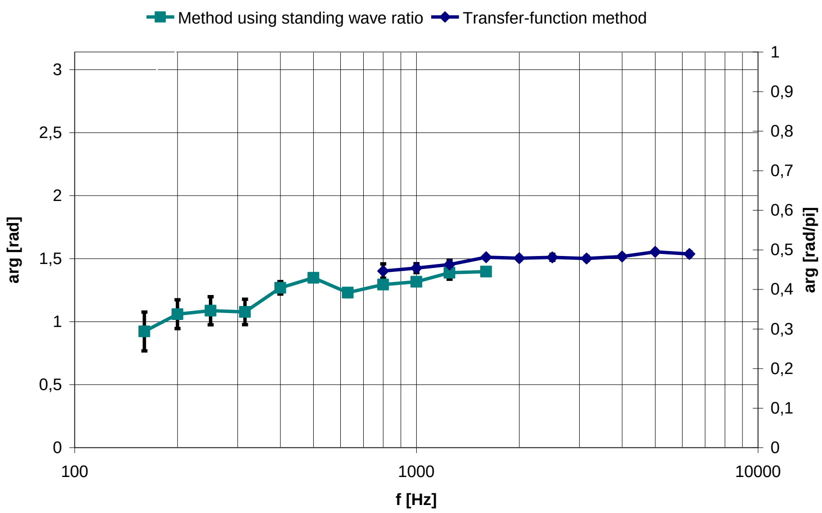

Figure 6. Average value of phase of human skin acoustic impedance measured with standing wave ratio method and transfer-function method

On the base of obtained results it could be concluded that the value of the module of human skin acoustic impedance is decreasing as the frequency increases. Conversely, the value of the phase is increasing, but $\pi/2$ seems to be the maximum value.

In the common measuring range (frequencies between 800 Hz and 1600 Hz) the results are within the range of standard deviation for both methods. This fact exist with regard to both – module and the phase of human skin acoustic impedance.

3. Conclusions

The paper presents the methodology of human skin impedance measurement. On the basis of the conducted tests it can be assumed that the human skin impedance depends on the frequency of the sound and not on the structure of the skin (i.e. the thickness of fat tissue) neither on the structure of the tissues located directly beneath the skin. It can also be assumed that the impedance value is only correlated with the outer layer of tissue.

Although only two person participated in the experiment, author supposed that the result may differ for larger population. Nevertheless, this preliminary results can be used as a boundary condition for numerical calculation.

References

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