Effects of Measurement System on Transfer Function of Gas Mask Speech Membrane

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Abstract – **Speech membrane is one of important elements of some masks such as gas or oxygen mask. This membrane can be characterized from acoustical point of view by certain parameters and quantities such as cut-off frequencies, distortions and transfer function. Regarding the measurement of the membrane transfer function, the results should be free of effects of the measurement system itself, which might be a challenging task. These effects are topic of the present research. Focus here is on influence of a device coupling the sound source and tested speech membrane as well as of position of microphone in reference to the sound source. For that purpose, five different couplers and four microphone distances are applied.**

Keywords – **Gas mask, Speech membrane, Transfer function, Measurement system**.

I. Introduction

There are situations where wearing a mask of specific type is of crucial importance. These include flying in a high-performance aircraft, military actions or activities of firefighters. By placing a mask on a person's face, the conditions for speech generation and emission are changed in comparison with a situation without the mask (no mask situation) [1,2]. The impedance loading the vocal tract is changed since the cavity between the mask and person's face is formed, and there is a specific force imposed on jaw by the mask affecting the speech generation [3-5]. When the vocal track of a speaker is closed with a mask chamber, it seems feasible to introduce the mask as a part of the speech chain.

The mentioned mask effects influence the procedure of speech generation, but also properties of the produced speech, which differentiates from the no mask case. This is why it is reasonable to asses the impact of the mask, and in some cases even to compensate for some adverse effects, as done in some studies, see, for example [1].

Regarding transfer of speech from a mask interior to surrounding environment, some masks have more or less complex device with a main task to enable as efficient as possible speech transfer, and to provide enough efficient protection from fluids (gases) existing in a mask surrounding. This device can be based on a special membrane or diaphragm called speech or speaking membrane. Acoustic behaviour of such a membrane can be described using the quantities such as frequency bandwidth (cut-off frequencies), distortion characteristics and transfer function.

In measurement of the speech membrane transfer function, it is of importance how to couple the membrane to the sound source and microphone, and minimize as much as possible the effects of the measurement system. This is analyzed here using five different couplers placed on an artificial mouth used as a sound source. Coupling of the membrane to the microphone is realized through a free space, where microphone is placed at different distances from orifice of the artificial mouth.

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II. Speech Membrane Effects

In literature, there are studies dealing with change of the speech spectrum, formant frequencies and other parameters of speech caused by different masks, see, for example [4,6,7]. However, literature presenting and analyzing speech membrane is rather rare. There some patents dealing with this topic, e.g., [6,8,9], and the transfer function from inside to outside of the mask is given in [1].

A cavity enclosed by a mask placed on a talker's face has resonances in the speech pass-band. The first resonant frequencies occur in the frequency range where the enclosed interior dimensions have the same order of magnitude with the sound wavelength [4]. The second important effect of a mask comes from a force due to a tight fit of the mask preventing normal jaw motion. These effects result in changes of long-time spectrum of continual speech mostly in frequency range over 800 Hz [4]. There are also some other factors affecting the speech spectrum in the mask situation.

In order to improve the speech transfer through a mask, different systems or elements (sometimes called voice emitting port, see Fig. 1) can be used. One of possible solutions is to use the speech membrane/diaphragm typically made of thin sheet material (or multiple sheets), such as cellulose film or plastic (polyvinylidene chloride) [8]. Protective filters made of metal or plastic (peripherally perforated) are commonly used to protect the speech membrane against mechanical damage. When the speech is transmitted through such a membrane (port), the transmission is called direct one, while transmission through an electro-acoustic system using a microphone is called indirect one [6].

It is questionable how to test and assess the speech membrane from an acoustical point of view. If a parallel between the speech membrane and any other membrane is drawn, then the speech membrane could be tested in the same way as other membranes. In most of such cases, this would mean that the speech membrane is measured in an impedance or transmission loss tube, see for example [10]. Another possibility is to use a specific measurement system containing an artificial mouth as a sound source to which the tested membrane is coupled. Such a system can be used for measurements of frequency bandwidth, distortions and transfer function.

Fig. 1. Gas mask with indicated voice emitting port

III. Measurement System and Procedure

Transfer functions between the sound source (the artificial mouth B&K 4216) and measurement microphone (B&K type 4144) located at certain distances (heights) above the source were measured. The microphone surface was positioned exactly 5 cm, 8 cm, 9 cm and 12 cm above the orifice of the artificial mouth. The gas mask speech membrane was placed in between the source and microphone, and it was coupled to the artificial mouth through a device - element here called coupler. The measurement system was installed in a small anechoic chamber of approximate dimensions 1.2×0.4×0.8 m, see Fig. 2. The excitation signal was an exponential swept sine of length of 5 s. Every measurement was repeated five times under the same conditions.

Five different couplers were used, see Fig. 3(a). Three of them (couplers 1, 2 and 3) are made of clay with interior shape of a conical waveguide. The coupler entrance (lower) port is of approximately the same area as the opening of the artificial mouth. The outer (upper) port is of approximately the same area as those of the tested speech membrane. The bottom surface of these couplers fits closely the top inclined surface of the artificial mouth. The heights (waveguide lengths) of the clay couplers are 0.6 cm, 1 cm and 1.9 cm. The fourth coupler is a metal ring with circular opening of height of approximately 1.1 cm. The fifth coupler represents a ring of isolating tape with a holder. The height of this coupler is about 1.8 cm. Fitting of the speech membrane to the coupler is improved by using a rubber ring placed on the coupler. Transfer function of two speech membranes was measured, the membrane 1 and 2, shown in Fig. 3(b).

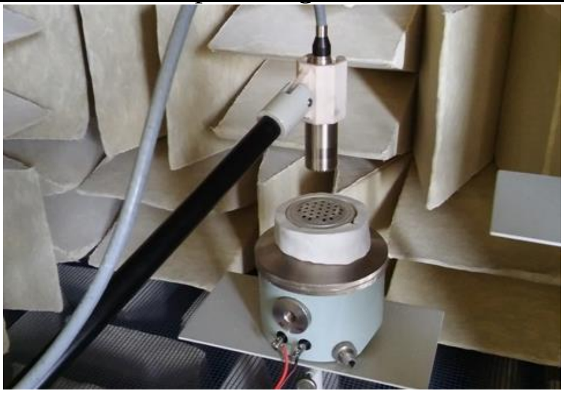

Fig. 2. Measurement of transfer function of speech membrane in a small anechoic chamber using the coupler 2

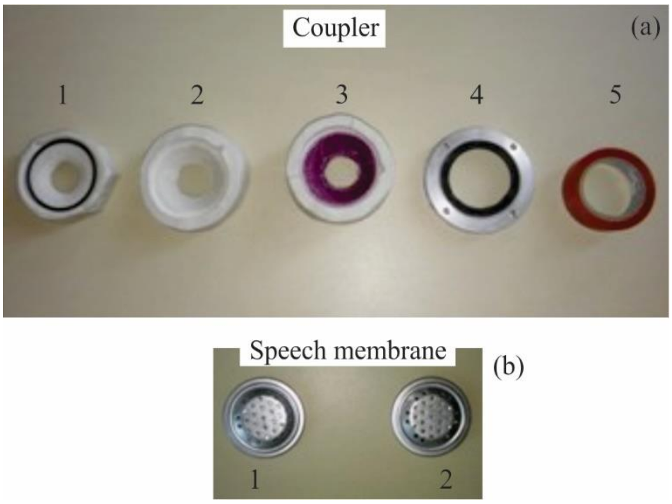

Fig. 3. (a) Five couplers for coupling the speech membrane to the artificial mouth; (b) two used speech membranes

IV. Results

The smallest value of signal to noise ratio is above 25 dB, while its largest value is close to 80 dB showing that the measurements are reliable from that point of view. The transfer functions of the artificial mouth measured without any coupler and speech membrane are shown in Fig. 4. The functions for different distances of the measurement microphone from the artificial mouth are almost parallel. Two prominent peaks at about 1.5 kHz and slightly above 5 kHz as well as a dip at about 4 kHz can be seen in the presented transfer functions. The mouth response decreases below 300 Hz.

By placing a coupler on the artificial mouth, the response of the mouth is changed, see Fig. 5. The couplers cause a certain increase of transfer function amplitude in a large part of the analyzed frequency range. At frequencies up to the first peak at about 1.5 kHz, the presented transfer functions are almost parallel. Above that frequency, there are some specific behaviors associated to every particular coupler. The two peaks seen in the functions measured without couplers are also prominent in the functions measured with the couplers.

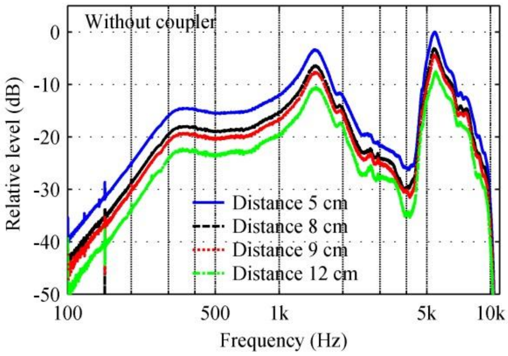

Fig. 4. Transfer functions of the artificial mouth without coupler and membrane measured at different microphone distances

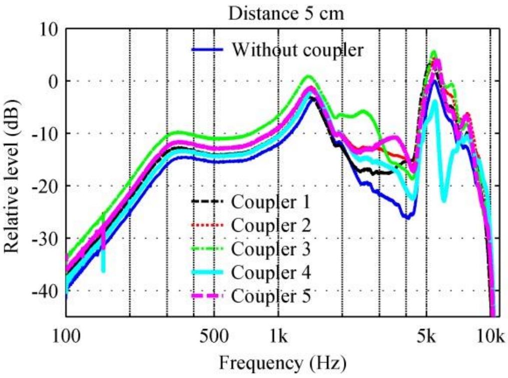

Fig. 5. Transfer functions measured without coupler and with all 5 couplers without membrane for microphone distance of 5 cm

Similar as in the case of transfer functions of the artificial mouth, change of the microphone distance in the measurements with the couplers placed on the mouth leads to almost parallel transfer functions, as shown in Fig. 6 for the coupler 1. Here, closer the microphone to the artificial mouth, higher the level of the transfer function. The situation is similar for other couplers.

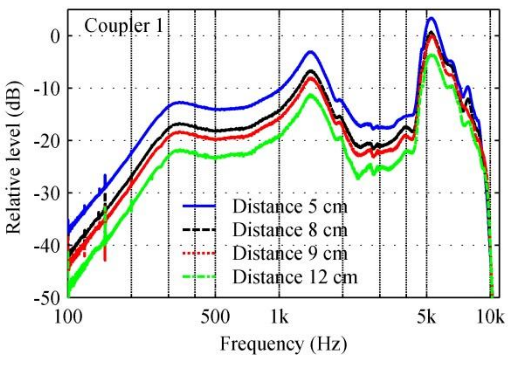

Fig. 6. Transfer functions measured with coupler 1 and without speech membrane for different microphone distances

The function obtained by subtracting the transfer function measured without a coupler from the transfer function measured with the coupler is here called transfer function of the coupler. Such transfer functions for the coupler 1 and different microphone distances are presented in Fig. 7. The functions are very similar to each other. The main trends are the same, and there are only slight deviations among the curves. The main contribution of this coupler is seen in the frequency range above 2 kHz. There is a prominent peak at about 4 kHz. The characteristics of other couplers are in accordance with the results given in Fig. 5.

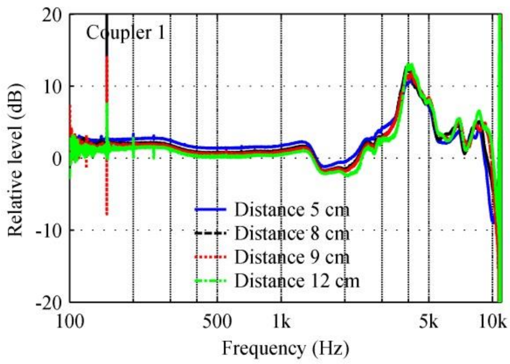

Fig. 7. Transfer functions of the coupler 1 obtained as a difference of the transfer functions measured with and without coupler for different microphone distances

When the speech membrane is placed on the coupler, it causes certain changes of the transfer functions (see Fig. 8) measured without the membrane, shown in Fig. 6. The peak at about 1.5 kHz is less prominent, and there is an additional peak between 3 kHz and 4 kHz. The transfer functions decreases with frequency decrease below 500 Hz, having a peak at about 200 Hz. These changes caused by the speech membrane are easier to be observed in the functions obtained as a difference between the transfer functions measured with and without the membrane, called here transfer functions of the membrane. They are shown in Fig. 9. It is interesting to note that the smallest influence of the membrane itself exists in the frequency range between 500 Hz and 1.5 kHz.

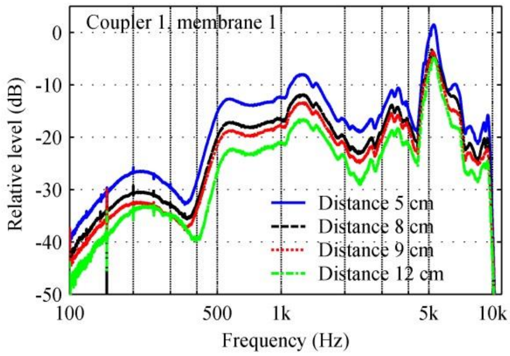

Fig. 8. Transfer functions measured with coupler 1 and membrane 1 for different microphone distances

For the used measurement setup, the effects of changing the microphone distance on the transfer functions of the membranes seem to be rather small up to about 10 kHz. Thus, the functions of the membrane 1 for different microphone distances coincide very well with each other, as shown in Fig.

10. There is a slight difference at lower frequencies (below several hundreds of Hz), and this difference might be a consequence of not completely stable leakage between the coupler and artificial mouth as well as between the speech membrane and the coupler. The situation is similar for another speech membrane used here – the membrane 2, see Fig. 11. This membrane has also some specific features, and the most important difference in comparison with the membrane 1 is ringing manifested by fluctuations of the transfer functions.

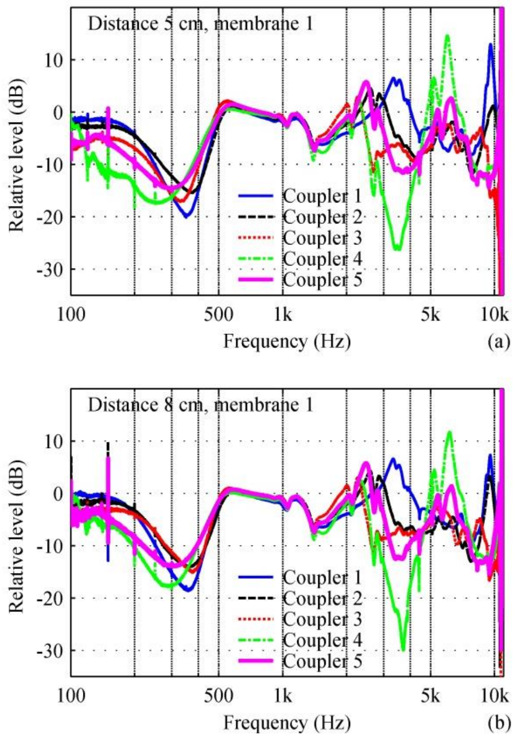

Fig. 9. Differences between transfer functions measured with particular coupler with membrane 1 and without the membrane for microphone distance of (a) 5 cm and (b) 8 cm

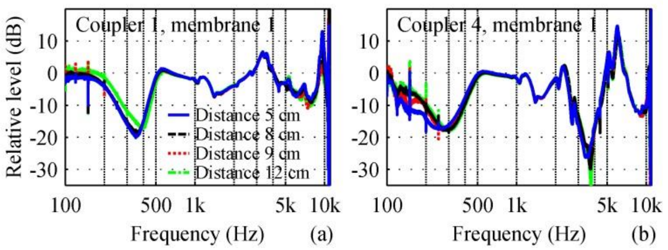

Fig. 10. Differences between transfer functions measured with coupler (a) 1 and (b) coupler 4 with membrane 1 and without the membrane for different microphone distances

V. Conclusion

A specific system for measurements of some acoustic properties of a gas mask speech membrane is presented here. One of these properties is the membrane transfer function. It is shown that in spite of normalization done through the subtraction of the response (transfer function) of the measurement system and coupler, the obtained transfer function of the membrane still depends on the coupler.

The smallest influence of the coupler is between about several hundreds of Hz (e.g., 500 Hz) to approximately 1.5 kHz. The deviations at lower frequencies might be attributed to the effects of leakage, while the deviations at higher frequencies can be attributed to different resonant properties of the couplers in two conditions – open (without the membrane) and closed (with the membrane). Taking into account the presented results, the preference can be given to the coupler 1 of height of 0.6 cm. For the setup applied here, the effects of distance of the microphone from the sound source are not considered to be of large importance.

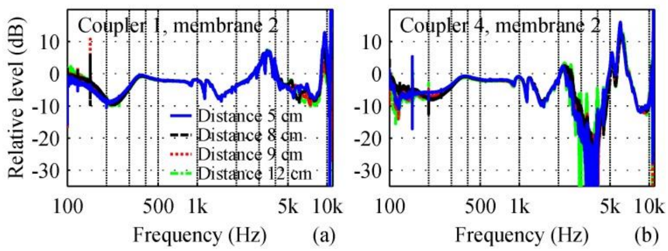

Fig. 11. Differences between transfer functions measured with coupler (a) 1 and (b) coupler 4 with membrane 2 and without the membrane for different microphone distances

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