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ATTENUATION OF OUTSIDE NOISE BY SHOTBLASTING HELMETS

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Abrasive blasting is a technological process in which forcibly propelling a stream of abrasive material is used to clean or prepare a surface. Among various physical and chemical hazards related to this process a shotblasting operator is exposed to high levels of noise. Regardless of the fact that there are no requirements to measure and report the attenuation of high level of blasting noise, manufacturers often face a question to which extent shotblasting helmets protect the operator from noise. Currently the well developed method for measuring the noise attenuation of shotblasting helmets is neither given in EN 271 standard dealing with the construction of helmets nor in EN 458 series of standards dealing with requirements for hearing protective devices. The purpose of this paper is to present the method of measurements of the noise attenuation provided by the shotblasting helmet.

Keywords: noise attenuation, measurements on subjects, measurements on dummy head and torso, shotblasting helmets.

1. Introduction

Shotblasting using abrasive materials is used in various technological processes in shipyards, constructing industry and foundries to clean surfaces and produce specific finish of a product. The most common application is cleaning of a rust and old paint surfaces in preparation for new paint coatings. Blasting exposes workers to various risks including silicosis resulting from inhaling particles that may be as small as 0.1 micrometer in size. Other risks include physical injury by particles, and exposure to toxic substances, for example, during sandblasting of lead-containing paints. For these reasons the shotblasting operators are required to wear protecting shotblasting helmets equipped by the breathing air supply.

Shotblasting operators are also exposed to very high noise levels, which range from 100 to 130 dB (A) [1–4]. The very high noise level requires that operators must use hearing protectors, typically the earplugs. In some cases, helmets are also equipped by their manufacturers with lightweight earmuffs. Nevertheless, there is an open question whether a helmet can be treated as the personal protective equipment that also offers protection against high-level noise generated in sandblasting process. This information is of interest both for the manufacturers and for the users of helmets.

Existing standards do not establish any method for measuring the attenuation of noise by shotblasting helmets, and they do not require such information from the manufacturer. The EN 271 standard [5] specifies requirements only for noise generated by the air supply system, and requires that this noise level is lower than 80 dB (A). Level of noise generated by the air supply system is much lower than the noise generated during shotblasting and possibly contributes very little to the noise level under a helmet, which the operator is exposed to.

Normally sound attenuation of hearing protective devices such as earmuffs or earplugs should be determined as a difference in level measured at threshold of hearing when the protector is donned or doffed. This subjective measurement is required by the EN 24869-1 standard [6] because only subjective measurement can take into account all possible paths of noise transmission (i.e. air and bone conduction) to the inner ear. In principle, the procedure prescribed in the EN 24869-1 standard could be used for measuring of sound attenuation of shotblasting helmets as well. However, the major obstacle that cannot be easily overcome is the noise of the breathing air supply to the helmet. If air supply is used additional noise makes it virtually impossible to perform measurements at the threshold of hearing. If air supply is not used, the discomfort of breathing under the helmet is so large that it is not possible to wear the device for a duration longer than one or two minutes while participating in threshold measurements. These are the possible reasons why measurements of sound attenuation of helmets are neither recommended nor standardized.

A measurement of insertion loss introduced by shotblasting helmets is the only available alternative for estimating the attenuation of external noise provided by this protective device. The only most extensive work devoted to the insertion loss of shotblasting helmets known to us is that of PATEL and IRVING [3] who measured attenuation of helmets positioned on head and torso simulators (HATS) and human subjects using miniature microphones fixed in the concha. Their results showed that the attenuation introduced by helmets is negligible for frequencies below 500 Hz and gradually increasing to about 20–25 dB at 8000 Hz.

One of the purposes of the present work was to measure attenuation of noise provided by shotblasting helmets equipped and not equipped with additional lightweight earmuffs installed inside the helmet. The basic interest was to check to which extent the use of additional hearing protection by earmuffs is advantageous for the operator taking into account that the earmuffs decrease the comfort of wearing the shotblasting helmet. The measurements were performed on human subjects and on the Kemar manikin.

Basic estimate of insertion loss by shotblasting helmets involves measurement of sound pressure level (SPL) using probe microphone at the entrance of the ear canal in two conditions: when helmet is donned and when it is doffed. This measurement does not represent, however, the requirement imposed by the standards for the measurement of noise exposure at a workplace. According to Polish standard [7] as well as many international and national standards and regulations [8, 9] the level of noise is measured in unobstructed sound field that means using a microphone at the worker's head position with the person absent. Due to this requirement the insertion loss measured at the entrance of the ear canal cannot be used to calculate the equivalent noise exposure at work of a shotblasting operator using the helmet. Second aim of this work was then to measure the noise attenuation introduced by shotblasting helmets, which was referenced to the level measured in the sound field undisturbed by the presence of a subject, that is including the transfer function from diffused field conditions to the ear canal entrance of unocluded ear.

2. Shotblasting helmets

The noise attenuation of four shotblasting helmets was measured. The helmets were produced by one manufacturer. They were new and therefore in good condition. All helmets were of heavy-duty plastic construction and were equipped with reinforced nylon cape. One helmet was equipped with panoramic acetate window (Fig. 1), and three other helmets had flat square glass windows protected by a steel grid at the outside (Fig. 2). Two of the square window helmets were covered with latex on the outer surface. One of these helmets was equipped with lightweight earmuffs. The fourth helmet was equipped with same type of earmuffs but was not covered with latex. All helmets were filled with sound absorbing material inside.

Fig. 1. Shotblasting helmet with panoramic acetate window.

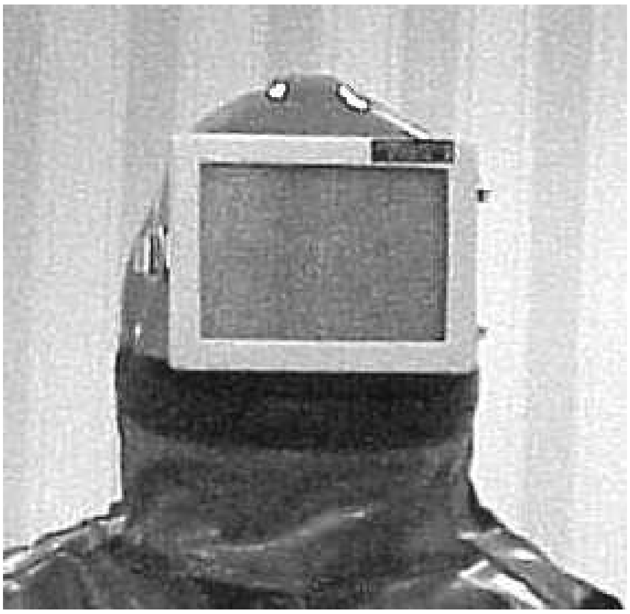

Fig. 2. Shotblasting helmet with square glass window.

3. Measurement site and procedure

Measurements were performed in a test room originally designed for determining sound attenuation of hearing protectors (Fig. 3). The diffused sound in the area of a subject's head position was produced by the four JBL 4802 loudspeakers powered by the two QUAD 520f power amplifiers. The test room and the diffused sound field fulfilled the requirements of the EN 24869-1 standard [6]. Pink noise was generated using Norsonic type 828 system controlled by a PC computer through IEC 625 (IEEE 488) interface. The wide band level of pink noise (frequency range 50 Hz – 10 kHz) was set to 97 dB.

Subject was seated in the middle of a test room. The average height of the entrance of the ear canal was 119 centimetres over the floor. When the Kemar manikin (Fig. 4) was used for the measurements it was placed at the same position as the subjects.

The noise level was recorded using Brüel & Kjaer type 4170 probe microphone. The probe microphone was placed at the entrance of the ear canal as shown in Fig. 5. It was attached to the subject or Kemar manikin using a medical tape to avoid any movements when the helmet was donned or doffed. Recorded signal was delivered to the Brüel & Kjaer type 2144 spectrum analyser to perform analysis in third-octave bands. The measurement system was calibrated using the Brüel & Kjaer type 4230 pistonphone. The calibration was performed before and after each measurement session and every time when the probe microphone was removed from its position at the entrance of the ear canal.

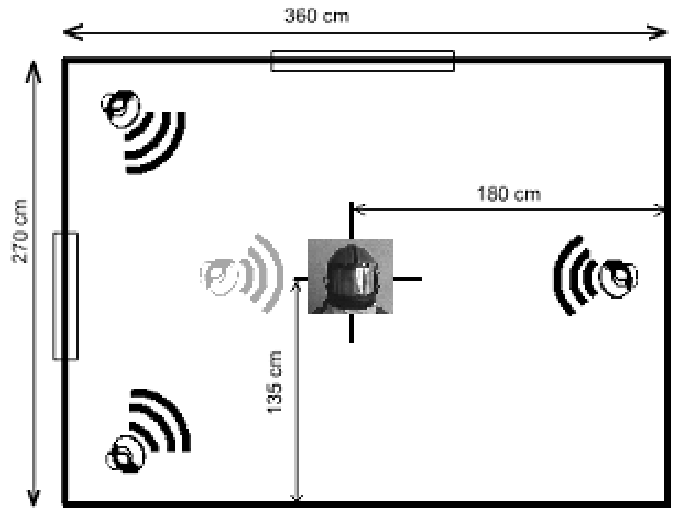

Fig. 3. Arrangement of equipment in a test room.

Fig. 4. Kemar manikin.

Fig. 5. Position of the Brüel & Kjaer type 4170 probe microphone at the entrance to the ear canal.

The measurement session comprised the following steps. First, levels in third-octave bands were measured in the diffused sound field with subject absent. The probe microphone was placed at the position corresponding to the mid-point of a line connecting the ear canal entrances. Then, the subject was seated and the probe microphone was located at the entrance to the right ear canal. The measurements in third octave bands were conducted for the ear not covered with helmet. In the third step, the levels were determined at the right ear for each of the helmets tested. Finally, measurements at the open ear as well as in the sound field with subject absent were repeated. After measurements were completed for the right ear, the measurement procedure was conducted for the left ear in the similar manner. When Kemar manikin was used, the measurement procedure was identical except that the manikin was placed at a position of a subject.

For each condition equivalent levels were determined using linear time averaging of Brüel & Kjaer type 2144 spectrum analyser over a period of 10 seconds. Measurements were repeated five times for each condition. To avoid additional noise, the breathing air supply of helmets was not used. Therefore subjects were given sufficient rest between measurements. Short averaging time and the measurement procedure allowed for avoiding exposing subject to over normative dose of noise.

The insertion loss T_e was calculated as a difference between third-octave levels measured at the entrance of uncovered ear and levels measured under the helmet. The attenuation T_f referring to the level in the diffused field was calculated as a difference between levels measures at the reference point with subject absent and levels measured under the helmet.

4. Insertion loss measurements

The insertion loss T_e of a helmet defined as the difference in signal levels in third-octave bands measured with helmets doffed and donned is displayed in Fig. 6. Lower panel in Fig. 6 shows the difference in attenuation measured on Kemar and on subjects. Regardless of the details of helmets' construction, the two helmets equipped with earmuffs and the two helmets not equipped with earmuffs show similar insertion loss. For frequencies below 250 Hz, there is essentially no attenuation of the outer noise level. For helmets not equipped with earmuffs, the attenuation gradually increases to about 30 dB in frequency range from 500 Hz to 8 kHz. In frequency range 250–500 Hz the attenuation is about 10 dB. For helmets equipped with earmuffs, the insertion loss gradually

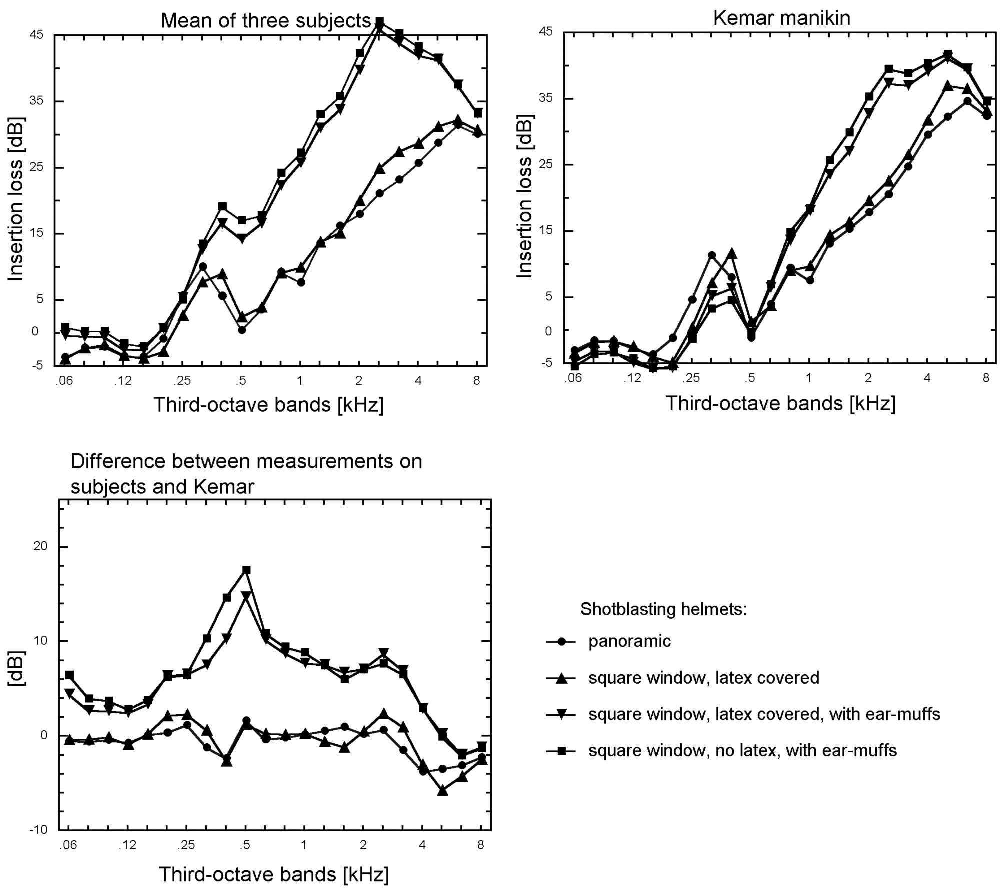

Fig. 6. Insertion loss T_e for the shotblasting helmets tested on subjects and Kemar manikin. The average standard deviation of measurements on subjects for helmets not equipped with earmuffs equals 2.4 dB, and for helmets equipped with earmuffs 3.9 dB. The average standard deviation of measurements on Kemar manikin equals 1.5 dB.

increases to about 45 dB in frequency range from 250 Hz to 2.5 kHz, then it decreases to about 35 dB for 8 kHz frequency band. The decrease of attenuation at 500 Hz is largely diminished as compared to helmets not equipped with earmuffs. This suggests that the dip of attenuation at 500 Hz seen for helmets not equipped with earmuffs may be related to some leakage of sound through the cape. The results show that using the earmuffs improves the attenuation by about 20 dB at a frequency of 1 kHz, and by about 24 dB at 2.5 kHz.

For helmets not equipped with earmuffs, measurements done on Kemar manikin are almost equivalent to the measurements performed on human subjects. In contrast, the insertion loss measured on Kemar is about 10 dB smaller than that measured with subjects for helmets equipped with earmuffs. Moreover, the dip at 500 Hz is more pronounced. This suggests that while measurements on Kemar manikin are quite appropriate for standard type of helmets they are not suitable for helmets equipped with earmuffs, most likely because of the poor fit of the earmuff's cushion to the manikin surface. The second factor is a difficulty of proper controlling of this fit when the manikin is used. In conclusion, measurements performed on subjects should be considered as more reliable than measurements performed with the use of the manikin.

5. Attenuation referred to the sound field

Insertion loss presented so far measured using probe microphone positioned in concha at the entrance of the open ear canal are not suitable for assessment of noise attenuation according to existing rules for determination of noise exposure at work. The level observed inside the shotblasting helmet, actually reaching the operator's ear, can be treated as coming from the source close to the ears. In order to make it possible to assess such an exposure by means of well-established criteria, the exposure at the ear should be converted into a corresponding free-field or diffused-field level. For this reason the helmet's attenuation should be determined using a measurement in the field with the subject absent as the reference measurement.

The helmet attenuation T_f referenced to the mid-point of a line connecting the ear canal entrances is displayed in Fig. 7. As for the measurements of insertion loss, details of helmets' construction do not cause significant difference in helmets attenuation. The two helmets equipped with earmuffs show 10 to 25 dB larger attenuation than the two helmets not equipped with earmuffs. For frequencies below 250 Hz there is no significant attenuation of the outer noise level. When the earmuffs are not installed in the helmet, the attenuation increases to about 30 dB in frequency range 500 Hz to 8 kHz. For helmets equipped with earmuffs, the increase in attenuation is smaller than previously observed increase in insertion loss and reaches about 40 dB at the frequency of 2.5 kHz.

Comparison of helmets' insertion loss and the attenuation referred to the reference point in the sound field makes it possible to determine the transfer function $T_e - T_f$ between the measurement point in the sound field with the subject absent and the av-

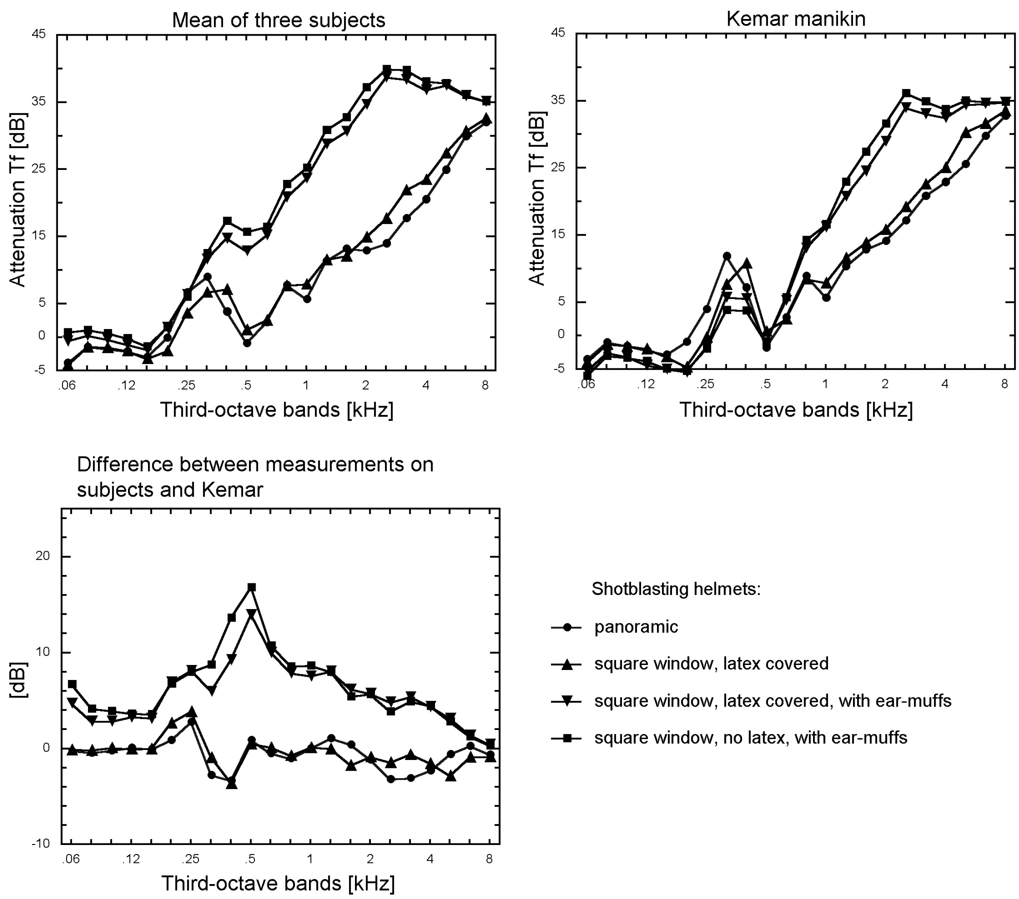

Fig. 7. Attenuation T_f of the shotblasting helmets referred to the point in diffused sound field defined at the position corresponding to the mid-point of a line connecting the ear canal entrances with subjects and helmets absent. Results for subjects and Kemar manikin. The average standard deviation of measurements on subjects for helmets not equipped with earmuffs equals 2.2 dB, and for helmets equipped with earmuffs 3.6 dB. The average standard deviation of measurements on Kemar manikin equals 1.4 dB.

erage level at the entrance to the ear canal of the subject not wearing the helmet. This transfer function is shown in Fig. 8. As it may be expected the presence of the subject is negligible for frequencies below 250 Hz. In the frequency range from 250 Hz to 1 kHz, there is an increase in the SPL measured at the ear canal by about 2 to 4 dB. The largest influence of the subject's head on the sound field is seen in the frequency range from 1 to 6 kHz, in which the increase in SPL is as large as 6 dB. Because the broadband exposition levels at a workplace are measured using A-weighted levels the presence of a subject significantly increases these values. Calculation of the equivalent level under the shotblasting helmet should be thus done using the attenuation T_f, not the insertion loss T_e.

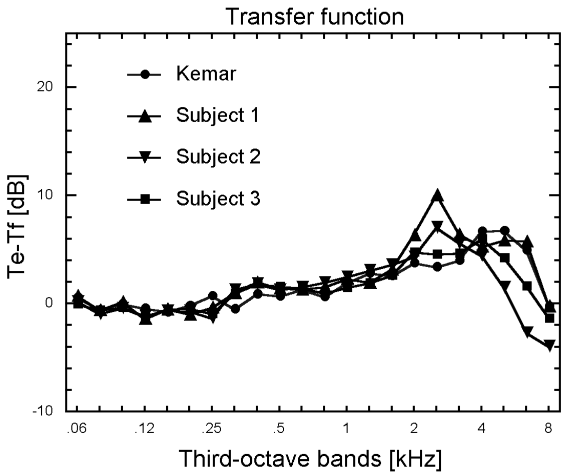

Fig. 8. Transfer function $T_e - T_f$ between the measurement point in the diffused sound field with the subject absent and the average level at the entrances to the ear canals of subjects and Kemar manikin not wearing the helmet. Average standard deviation equals 0.6 dB.

6. Variability between measurements with subjects and Kemar manikin

Some interest may be paid to the variability of measurements made on subjects and Kemar manikin due to the differences of heads' dimensions. The circumference of the subjects' heads participating in the measurements varied from 56 to 59.5 centimetres. The circumference of the manikin's head was the smallest and equalled 55 centimetres. For that reason one may expect some differences in measured attenuation especially for helmets equipped with the earmuffs since there is a very small regulation range of earmuff's spring tension in the helmet due to a limited space available.

The insertion loss T_e and the attenuation T_f measured on the three subjects and Kemar manikin for the square window helmets coated with latex are shown in the upper and lower panels of Fig. 9, respectively. Results for helmets not equipped with the earmuffs are shown in the left panels. Results for helmets equipped with the earmuffs are shown in the right panels. For helmets not equipped with the earmuffs, the differences among measurements on subjects and on Kemar manikin are not larger than 3 dB in the frequency range up to 2 kHz, and not larger than 5 dB in the frequency range from 2 to 8 kHz. For helmets equipped with the earmuffs, the differences between subjects are within 5 dB, but the attenuation obtained for Kemar manikin is about 5 to 10 dB lower. This is most likely the effect of poor fit of the earmuffs' cushions to the hard plastic surface of the manikin. Thus, while the measurements made on the manikin are equivalent to the measurements on subjects for helmets not equipped with the earmuffs, they are not well representing the conditions of normal helmets use for helmets equipped with the earmuffs.

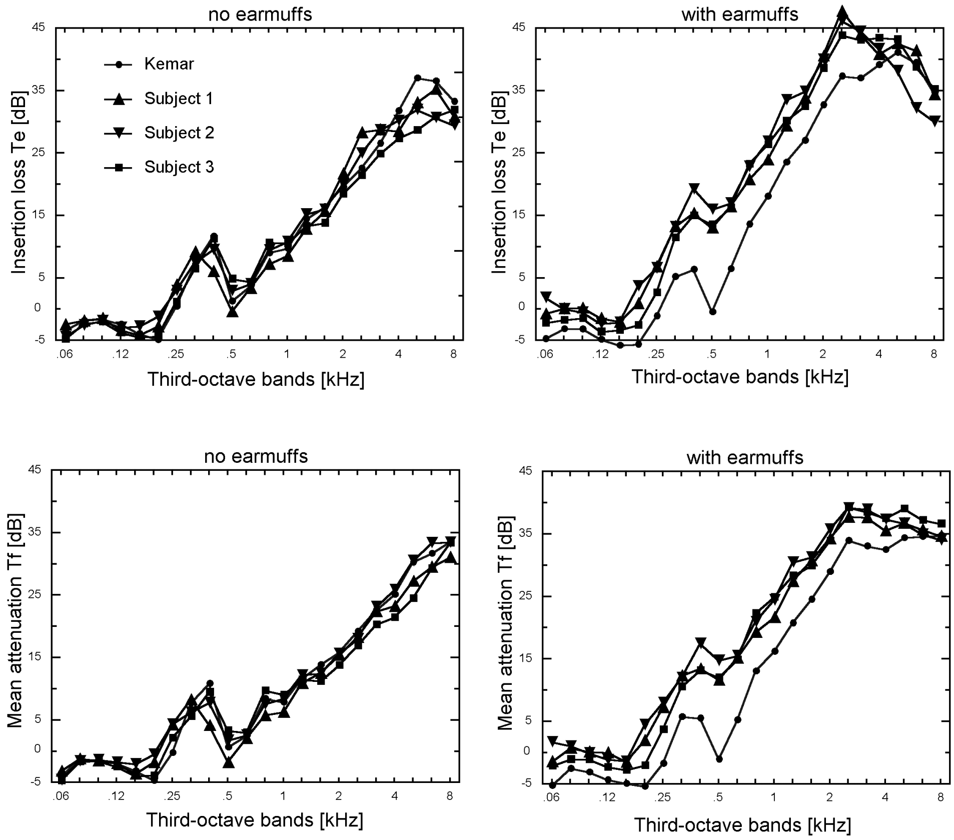

Fig. 9. Insertion loss T_e and attenuation T_f measured on the three subjects and Kemar manikin for square-window helmets, latex covered, with and without earmuffs. The average standard deviation of measurements for helmet not equipped with earmuffs equals 1.3 dB, and for helmet equipped with earmuffs 2.2 dB.

7. Conclusions

External noise attenuation provided by the shotblasting helmets largely depends on the frequency. In low frequency range (up to about 500 Hz), the helmets provide essentially no protection against noise. Lack of attenuation is most likely due to the leakage through the cape [3] and the open bottom part of the helmet, and perhaps due to vibration of the large surface of the helmet. In the frequency range above 500 Hz, the attenuation increases linearly at a rate of 8 dB per octave, to about 30 dB at a frequency of 8 kHz. This attenuation characteristic is similar regardless of differences in details of helmets' design.

Installing the lightweight earmuffs inside the helmets increases the attenuation by about 10 dB in mid frequency range (at 1 kHz), and up to about 25 dB in the high frequency range (at 2.5–4 kHz). Thus using the earmuffs while it decreases the overall comfort of the operator has a positive effect of lowering the A-weighted level of noise that reaches the operator's ear.

For purposes of helmets' labelling, the measurements performed on Kemar manikin might be sufficient provided that helmets are not equipped with the earmuffs. These measurements will tend to underestimate the helmets' attenuation as compared to the measurements on subjects for helmets equipped with the earmuffs.

According to existing regulations for exposition limits at workplaces, the helmets' attenuation should be measured using the measurement point in the sound field as the reference with the helmet and subject absent. This attenuation T_f differs by about 6 dB from the insertion loss T_e in the frequency range of 2 to 8 kHz (see Fig. 8).

When using the data on helmets attenuation as measured in the present study, one should keep in mind that neither the insertion loss T_e nor the helmets attenuation T_f take into account the noise reaching the inner ear through the bone conduction. The bone conduction may be particularly strong due to accumulating sound energy over the hard surface of the helmet and transmitting it to the skull through the helmet's suspension. An additional noise can be also generated due to the particles hitting the helmet's surface.

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