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Characterization of the Attenuation Properties in Motorcycle Helmets

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Summary

The general perception of motorists is that motorcycle helmets not only protect riders against head injuries but also isolate them from the outside noise. However, the acoustic insulation of the helmet is not necessarily as effective as it is perceived. To objectively evaluate the acoustic insulation of the helmet, the insertion loss of a sample of five helmets of full face types from different manufacturers was measured in an semi-anechoic chamber. In the whole processa dummy with microphones in the ear (HATS) was used. The measurement was made according to ISO 4869-3:2007, and it studies three directions of sound arrival (front, lateral and rear). The results obtained indicate that the values of insertion loss are negative in the frequency range of 16 to 250-315 Hz. Furthermore, according to the test, in the range of 250 and 800 Hz there is little insulation, and from 800 Hz insulation increases at a rate of 12 dB/octave or 6 dB/Octave. It has been shown that the occurrence of negative values of insertion loss between the 16 and 250–315 Hz is not attributable to the diffraction of the helmet. Nevertheless, the explanation of this phenomenon may be related to the geometry inside the helmet. The variety of helmets used in this study allows us to extrapolate this result to any helmet of this type. The independence of the insertion loss in relation to the state of the vents (open or closed) has also been demonstrated.

PACS no. 43.58.-e

1. Introduction

Noise level inside a motorcycle helmet has long been recognized as a risk factor for hearing loss, especially for those that earn their living driving a motorcycle. Numerous studies have been performed since the 1980s on the noise perceived by the rider, [1, 2, 3]. In them, noise levels above the 100 dBA were measured at the entrance to the ear canal of the rider.

Much attention has been paid to the noise level generated in movement and very little to the isolation of the helmet. The different existing standards (DOT, ANSI, ECE...) have developed testing methods for the mechanical safety of the helmet. Conversely, there is no procedure for testing the acoustic characterization of the helmet.

There is only one previous study in this sense [4], which determines the amount of attenuation that three models (NOLAN) provide compared to the sound coming from the outside. For that purpose, the method of subjective measurement defined in the standard ISO 4869-1:1990 [5] was used. This method consists of carrying the measures out in a room by placing a miniature microphone at the entrance to the ear canal. The results obtained indicate that there is no attenuation for frequencies below 250 Hz. Between 250 and 500 Hz the attenuation is about 3 dB, whereas between 500 Hz and 8000 Hz the attenuation grows linearly at a rate of 8–9 dB/octave up to 30 dB at 8000 Hz.

This study considers the isolation of the helmet using an semi-anechoic chamber and a Head And Torso Simulator (HATS). Measurements were taken following the procedure described in ISO 4869-3:2007 [6]. The equipment used as well as the results obtained are discussed in this paper.

2. Methodology

Currently, there are a large number of users of helmets. However, there is no procedure for measuring the inser-

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tion loss. Therefore, in the absence of a standard test for the specific acoustic attenuation of motorcycle helmets, the standard of measure of hearing protectors in EN 352-1:2002 [7] has been used. Considering noise attenuation, this standard refers to the standard EN 13819-2:2002 [8], which refers to the ISO 4869-3:2007 [6] when considering test procedures. Of the latter, Part 3 has been selected ”Measurement of insertion loss of ear-muff type meanwhile using an acoustic test fixture", since instead of using people to test the earphones, it utilizes a device expressly designed to test them. The advantage of using this type of device is the repeatability of the results, which are not affected by the physiological characteristics of the listener or the placement of the microphone in the ear. The measures have been carried out using a Head And Torso Simulator (HATS) model 4100 from Brüel & Kjær. Although this device is not exactly the one indicated in the legislation, it allows the user to perform the measurement procedure indicated therein without substantial modifications.

The tests were performed in a semi-anechoic chamber at the University of Vigo, which meets the requirements described in section 5.2.3 - flat progressive waves of the standard ISO 4869-3:2007 [6]. According to this standard, a situation of a free field is required, i.e. absence of surfaces that might reflect sound. In order to minimize the effect of the reflection on the floor of the chamber, the area between the source and the HATS was covered with absorbent wedges.

Regarding the orientation of the HATS towards the source, in paragraph 5.2.3 it is recommended to locate the source facing the carrier device of the headphones as if it were the head of a listener (angle of incidence of the sound of 0°). In our measures two more orientations were included: side incidence, with the source facing the left ear of the HATS (incidence angle of 90°) and rear incidence (180°). The purpose of this was to analyze the behaviour of the helmets depending on the different angles of incidence of the sound.

In regard to the test signal, the standard allows the use of multiple signals. In this study two different noises were utilized: pink noise, which facilitates the study of the attenuation in third octave bands, and white noise, which is more comfortable for the FFT analysis track. Both were generated with a Brüel & Kjær WB1314 noise generator and cast by a 4.25 inch Beyma loudspeaker.

The HATS was placed in the center of the semi-anechoic chamber on a rotating platform formed as a goniometer to measure angles. The loudspeaker was set at the height of the ears of the HATS at a distance of 1 m, with its acoustic axis pointing to the center of the head.

The HATS was stimulated with the signal produced by the noise generator, with pink or white characteristics and filtered between 50 Hz and 10 kHz. The playback level was adjusted to 85 dBA (slow), measured with a sound-level meter located on the HATS. Firstly, pink noise was generated, maintaining the adjustment during each step. After that, the source was switched to white noise and the automatic range of the acquisition equipment implemented (Symphonie 01dB).

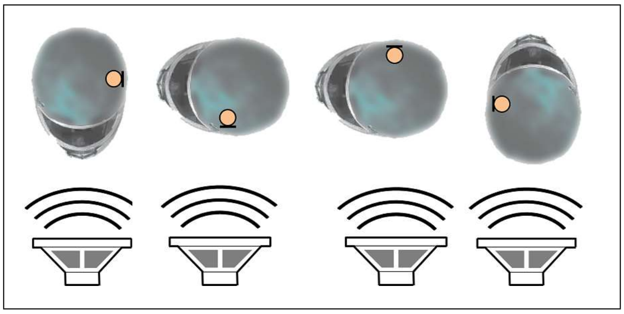

Figure 1. Positioning of the helmets in relation to the sound source from left to right: Front 0°L, Lateral 90°L, Lateral 90°R and Rear 180°L.

The first measurement was carried out with the HATS without helmet. The purpose of this was to acquire the same signal that a listener would receive in each ear without a helmet. The HATS is oriented at 0°, 90° and 180° in relation to the source, see Figure 1. For the front (0°) and rear (180°) orientations, only results for one ear (left, L) are presented in this document, since by symmetry they are virtually identical to the right ear. This is not the case in a lateral orientation (90°), where the results for both ears are presented. In each case, the signal from each microphone was recorded with the source off, with pink noise, and with white noise. Each recording is 30 seconds long.

Then, the HATS was attached to the first helmet to be measured, visor and vents closed, and the three orientations with the two types of noise were recorded. After that, the procedure was carried out with the visor closed and the vents open, and the measurement was repeated with the other four helmets. Finally, the complete sequence was repeated three times so that at the end of the procedure there were three recordings for each tested helmet model. It is important to highlight that the helmet was adjusted before each repetition in order to study the effect on the attenuation of the adjustment of the helmet on the HATS, following the instructions of the standard of measure. Those helmets fitted with noise attenuators were measured with them installed in all cases

Figure 2 corresponds to a measurement with front incidence. It shows: the base of the device upon which the source was mounted, lined with cotton felt to minimize reflections; the circular back of the source resting on a bed of felt; the absorbent wedges located on the ground; and the HATS placed on a turntable.

3. Results

Five helmets of full face types of medium to high quality from brands of great note in the market were used to carry out the tests. The helmets shown in Figures 3 and 4, were all approved by the ECE 22.05 [9] and correspond to Spanish, German and Italian manufacturers. All helmets included a fiberglass housing with kevlar reinforcement in various areas, depending on the manufacturer. All of them

Table I. Insertion loss total, in dB.

		Vents closed				Vents opened			
Helmet	Repetition	0°L	90°L	90°R	180°L	0°L	90°L	90°R	180°L
AGV	1	8,4	13,2	-0,3	7,3	8,2	13,2	-0,4	7,3
	2	8,9	13,2	-0,4	7,2	8,8	13,2	-0,4	7,2
	3	8,8	13,0	-0,4	6,8	8,7	13,0	-0,5	7,0
ARAI	1	6,6	13,9	-0,7	8,5	6,2	13,3	-1,5	8,5
	2	8,0	14,3	0,5	9,1	6,9	13,7	-0,5	8,6
	3	8,3	14,5	0,5	9,2	7,2	13,9	-0,5	8,9
NZI	1	10,5	13,7	1,1	8,4	9,8	13,3	0,6	8,3
	2	10,4	14,0	1,1	8,8	9,6	13,7	0,8	8,8
	3	10,6	14,2	0,7	8,9	10,0	13,9	0,3	8,6
SCHUBERTH	1	11,4	16,3	2,5	8,5	11,1	16,3	2,4	8,4
	2	11,3	15,9	2,4	7,3	11,2	15,7	2,3	7,3
	3	10,5	15,4	1,9	7,9	10,4	15,5	2,0	7,9
MT	1	8,2	14,0	1,7	8,8	8,0	14,0	1,4	8,7
	2	8,2	13,7	1,9	8,5	8,2	13,8	1,5	8,2
	3	8,4	13,5	1,4	7,8	8,2	13,5	1,1	7,7

Figure 2. Experimental Assembly, incidence 0°.

were equipped with ventilation outlets, retractable visors and are lined with polystyrene for the comfortable movement of the head inside the helmet. Furthermore, they all had adjustable safety straps to ensure that the movements of the helmet always followed the head of the rider.

The insertion loss was measured in third octave frequency bands, between 63 Hz and 8000 Hz, as recommended by the testing standard. The behaviour in frequency of the different helmets is very similar. Therefore, the total values for insertion loss were used for a first study. This was due to the large number of results to handle and the resemblance to the behaviour in frequency of the different helmets (shown below in detail).

Table I shows the losses in terms of total insertion, in dB, for each helmet, as well as the measurement conditions and repetition.

The typical combined uncertainty is determined in accordance with Annex B of the ISO 4869-3:2007 [6]. The uncertainty of the insertion loss is 1.3 dB, based on the experience gained in several testing laboratories around the world. The expanded uncertainty is estimated at 2.6 dB for a coverage factor k=2. This means that the actual value of the insertion loss is, with a probability of 95%, a range of ±2.6 dB around the outcome of the laboratory testing. Table II shows the maximum deviation between repetitions of insertion loss, in dB. This data is calculated as the greatest difference found in the test results based on the three times each helmet was tested.

4. Discussion

The maximum deviation is 1.7 dB and corresponds to the ARAI helmet, front incidence. This value is below the 2.6 dB of expanded uncertainty, which means that the differences between the results of the repetitions are within the expected range given the characteristics of the test. It is therefore reasonable to average the results of the three repetitions to obtain a representative value for each test condition and helmet. Table III shows the averages between repetitions.

All the helmets were tested taking into account the status (open/closed) of the vents; the results are shown in Table III. There is very little difference between the attenuation of the helmets with the vents open and closed, as shown in Table IV. It also can be seen that the attenuation of the helmets is slightly higher in almost all cases when the vents are closed, but the difference between the two conditions is very small. The biggest difference in the averaged values corresponds to the ARAI helmet and is $-0,9$ dB, well below the expanded uncertainty. If, instead of studying the difference between the average values, the maximum deviation of all occurrences is calculated, it amounts to 2.1 dB (this value was 1.7 when the ventilation conditions were considered separately).

Taking into account that this value remains below the expanded uncertainty, it seems reasonable to average the

Table II. Maximum deviation between repetitions of the total insertion loss in dB.

	Vents closed				Vents opened			
Helmet	0°L	90°L	90°R	180°L	0°L	90°L	90°R	180°L
AGV	0,5	0,2	0,1	0,5	0,6	0,2	0,1	0,3
ARAI	1,7	0,6	1,2	0,7	1,0	0,6	1,0	0,4
NZI	0,2	0,5	0,4	0,5	0,4	0,6	0,5	0,5
SCHUBERT	0,9	0,9	0,6	1,2	0,8	0,8	0,4	1,1
MT	0,2	0,5	0,5	1,0	0,2	0,5	0,4	1,0

Table III. Insertion loss total averaged between repetitions, in dB.

	Vents closed				Vents opened			
Helmet	0°L	90°L	90°R	180°L	0°L	90°L	90°R	180°L
AGV	8,7	13,1	-0,4	7,1	8,6	13,1	-0,4	7,2
ARAI	7,6	14,2	0,1	8,9	6,8	13,6	-0,8	8,7
NZI	10,5	14,0	1,0	8,7	9,8	13,6	0,6	8,6
SCHUBERT	11,1	15,9	2,3	7,9	10,9	15,8	2,2	7,9
MT	8,3	13,7	1,7	8,4	8,1	13,8	1,3	8,2

Figure 3. Helmets studied. From left to right: AGV T6i Tech, Arai RX7 Corsair, MT Revenge.

Figure 4. Helmets studied from left to right: NZI Spider III, Schuberth R1.

two ventilation conditions to obtain the mean attenuation of each helmet for each orientation.

Table V and Figure 5 summarize the attenuation averages of each helmet in terms of total insertion losses (dB), after averaging the three repetitions for each helmet and the two ventilation conditions.

The measurement uncertainty of the results in Table V can be estimated from its repeatability, calculated as the sample standard deviation of the averaged values for each result. This repeatability is, in the worst case, 0.74 (ARAI helmet, orientation 0°L), well below the estimated uncertainty of the test sets according to the ISO 4869-3:2007.

Table IV. Difference between conditions of ventilation of the total insertion loss in dB.

Helmet	0°L	90°L	90°R	180°L
AGV	0,1	0,0	0,1	-0,1
ARAI	0,9	0,6	0,9	0,3
NZI	0,7	0,3	0,4	0,1
SCHUBERT	0,2	0,0	0,0	0,0
MT	0,1	0,0	0,3	0,2

Table V. Average value of the total insertion loss in dB.

Helmet	0°L	90°L	90°R	180°L
AGV	8,6	13,1	-0,4	7,1
ARAI	7,2	13,9	-0,4	8,8
NZI	10,2	13,8	0,8	8,6
SCHUBERT	11,0	15,9	2,3	7,9
MT	8,2	13,8	1,5	8,3

The insertion loss in third-octave bands for each direction of sound incidence are shown in Figures 6 to 8. The curve corresponding to each helmet is obtained by averaging the insertion loss (level with helmet minus level without helmet in the third-octave band) for the three replicates

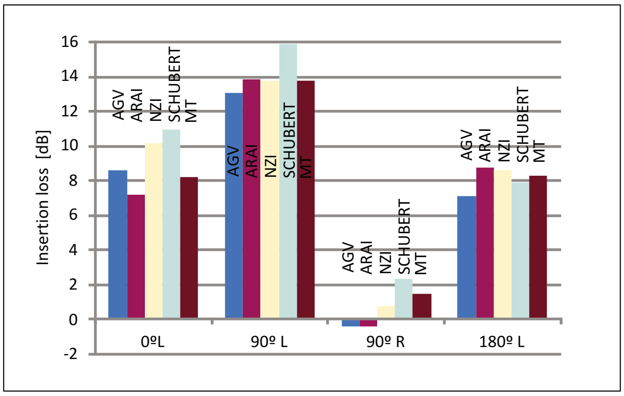

Figure 5. Average value of the total insertion loss in dB.

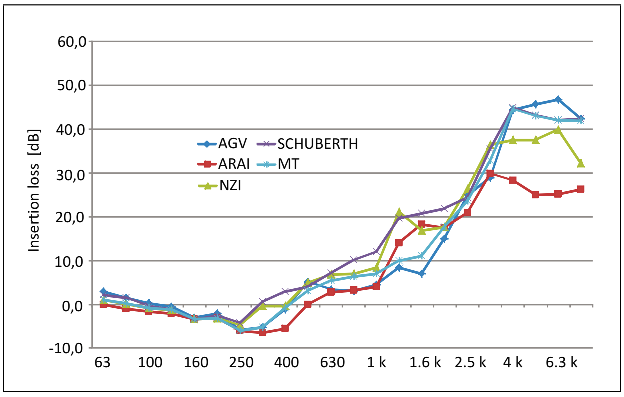

Figure 6. Insertion Loss in third-octave, vents closed, for the sonorous incidence 0°L.

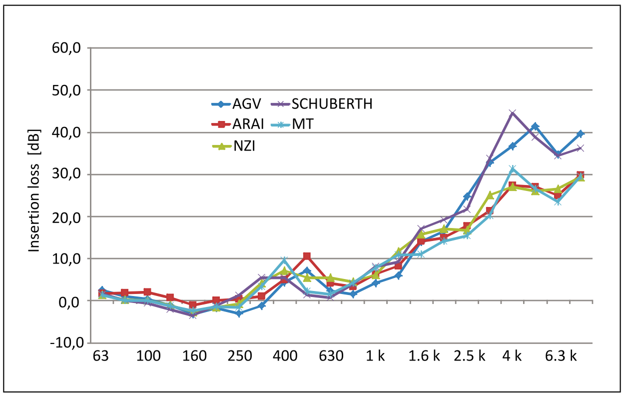

Figure 7. Insertion Loss in third-octave, vents closed, for the sonorous incidence 180°L.

of each measurement with vents closed. The results obtained with open vents are, in accordance with the global values, very similar to those presented in Table I, and are therefore not presented here.

It is apparent that for all the directions of sound arrival the attenuation is very small or even negative for frequencies below 800 Hz. Taking this into account, we can observe that absorption levels rise with frequency at approximately 12 dB/octave, except in the 90°R position (source in the opposite position to the ear), in which the growth is only about 6 dB/octave.

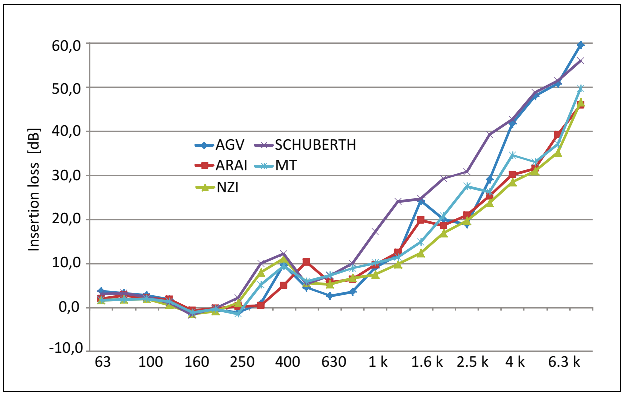

Figure 8. Insertion Loss in third-octave, vents closed, for the sonorous incidence 90°L.

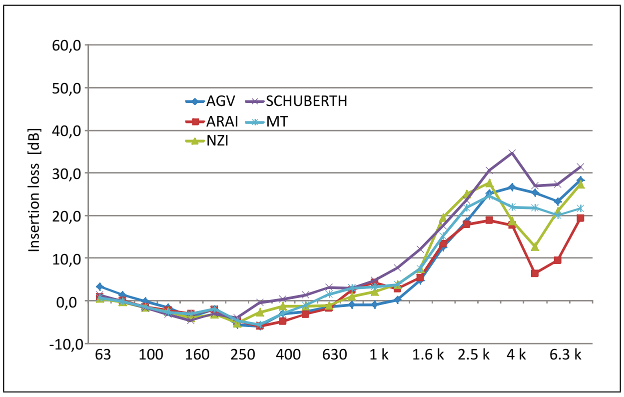

Figure 9. Insertion Loss in third-octave, vents closed, for the sonorous incidence 90°R.

It can also be seen in all the curves, except for 90°L (source in front of the ear), that the attenuation curve ceases to grow from 3.15 or 4 kHz, remaining practically stable at higher frequencies or even decreasing in some cases. The greater attenuation at high frequencies can be seen in curve 90°L, and the lowest in 90°R. Therefore, high sound frequencies from a source located next to the rider are heard with much more intensity in the opposite ear. The difference can reach 30 dB in the 1 kHz environment.

It might be thought that the repeated occurrence of negative values of insertion losses at low frequencies is due to the diffraction factors caused by the helmet rather than just the head. To analyze this relationship, the head of the HATS and the helmets tested can be compared to spheres. The dimensions of the head of the HATS are 15 cm (breadth) 19 cm (length), which gives a mean radius of the sphere of 8,5 cm. The mean radius of the helmets is approximately 16 cm. Analyzing the curves of sound diffraction with a sphere, Wiener [10], for these two dimensions, the amplification of the low frequencies that occur in all the helmets, in relation to the sound perceived without them, is not attributable to this diffraction.

To complete this study on frequency, insertion loss via FFT was analyzed. This analysis tool provides the insertion loss for each frequency without affecting the averaged frequency bands. In addition, it allows us to understand if

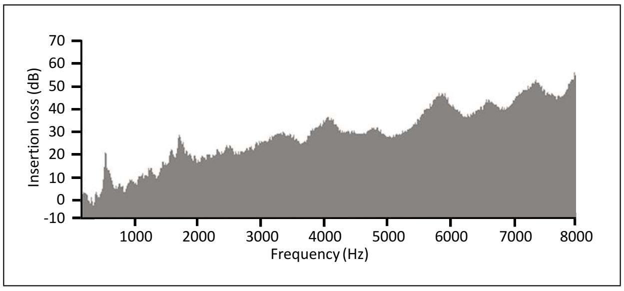

Figure 10. Insertion loss, for the second repetition of the ARAI helmet, vents closed 90°L.

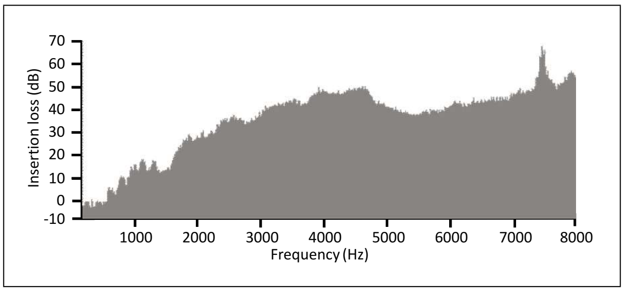

Figure 11. Insertion loss, for the second repetition of the ARAI helmet, vents closed 90°R.

there are nulls or spectral valleys that could be covered up within the representation in third-octave bands. The presence of a null or spectral valley in the insertion loss curve might be due to a bad behaviour of the material at that frequencies. Another explanation might be the resonance of the cavity. Both possibilities would result in an increase in the level of noise inside the helmet within that range of frequencies.

As a representative example of all the results, Figures 10 and 11 show the behaviour of one of the measures of the ARAI helmet with lateral incidence. Several isolated peaks can be observed (for example 400Hz and 1800 Hz in L, 7500 Hz in R), which correspond to frequencies that are more attenuated than those neighbouring. Nevertheless, there are no null or deep valleys, which guarantees the absence of tonal noise.

5. Conclusions

The attenuation provided by the five helmets is poor and very similar among them. It is also very small in all orientations, and even negative below 800 Hz. From this frequency, it grows with a slope of approximately 12 dB/octave in most of the positions. Furthermore, the sound does not present any tonal characteristics after being weakened by the helmet.

The effect of the attenuation of the helmet on the exterior noise depends on the emission spectrum of the noise. For instance, the attenuation on the engine noise of the motorcycle, in which low frequencies predominate, will be small. However, a good part of vocal frequencies will be attenuated.

Results show that there is very little dependency between the open and closed position of the vents. It can also be noted that the collocation of the helmet has little influence. The repeated appearance of negative values of insertion losses in low frequencies indicates that the helmet amplifies the noise in these bands, instead of attenuating it. The amplification of the low frequencies that occurs in all the helmets is not attributable to diffraction. Therefore, it would be interesting to try to explain this phenomenon through the study of the helmet as a resonant cavity.

In general, this behaviour of the helmet favours good driving because it allows the rider be aware of the environment of the road when he is not in motion, since traffic has a typical range of frequencies below 1500 Hz.

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