Very high level impulse noises and hearing protection

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Summary
Although the European noise regulation seems to be well adapted to the industrial context and, in the military context, problems concerning exposure to continuous noise may be resolved by using better performing Hearing Protection Devices (HPDs), problems subsist for impulse noise. In certain countries (e.g. France) the European noise regulation has been implemented in a way that, for weapon noise, the requirement regulation cannot be met with existing HPDs. But, if double hearing protection is used, the soldier will be isolated from his acoustic environment. The consequences are that more accidents during training on the firing range will occur and/or the use of HPDs will be refused during combat. This is the reason why it is important to adapt the effective regulations for specificity of military noises. In the same time, it is necessary to characterize the HPD's attenuation for impulsive noise exposure. This presentation will present the problems that arise due to the present implementation of the European recommendation (2003/10/EC) in France. It will also show how HPDs are tested at the ISL with impulse noise at very high peak pressure levels. These procedures allow to characterize the nonlinear behavior of the HPDs at peak pressure levels which will be experienced during training and combat. A reflection concerning a new metric describing the nonlinear behavior of HPDs in impulse noise will be discussed.

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1. Introduction

In military environment, most of noise (as vehicle noise) may be considered a "continuous noise event" as personnel are generally exposed to the sound energy over a period of time spanning from possibly just a few seconds up to a number of hours. However, "impulse noise events", such as those experienced during the firing of a weapon or the discharge of an explosive are characterized by a sharp initial pressure rise followed by an exponential decay which is determined by the absorbing character of the environment in which it is heard. The energy from most impulse noises is normally focussed into just a few milliseconds and can be sufficiently high to produce auditory impairment in an unprotected ear. In exceptional cases it may even result in damage to other organs of the human body, such as the lungs, the windpipe, the stomach etc.

Since March 2006 the European directive 2003/10/EC [1] had to be implemented by the member states of the EU. Until this time, the Damage Risk Criteria (DRC) for continuous noise used in the European military community were close to those used for civilian; A-weighted exposure level (LEX,8h).

For weapon noise, however, no civilian legislation was applicable. Therefore different DRC, especially developed for weapon noise, where used in different countries. These criteria, like the MIL-STD-1474(D) [2], the Pfander and Smoorenburg Criteria were used by different countries in order to protect soldiers and other personnel exposed to high level impulse noise. They are based on the peak pressure level and on related durations (A-duration, B-duration …). Other DRC are based on A-weighted energy (Dancer [3], Asherly and Martin [4]), or on the full pressure time history (Price and Kalb [5]).

All these criteria used for continuous or for impulse noise take the spectral distribution and the total energy into account when evaluating the hazard of the noise exposure. This may be done directly through the A-weighted energy or indirectly through the peak pressure level and duration.

After recalling the European directive 2003/10 and describing briefly the real military noise exposure, the methods for evaluation of hearing protectors in very high impulse noise is described. Then the attention is focused on the ISL artificial test fixture and eventually a new structural nonlinear cue is proposed.

2. The European directive 2003/10

"This Directive, …, lays down minimum requirements for the protection of workers from risks to their health and safety arising or likely to arise from exposure to noise and in particular the risk to hearing". The expressed scope of this directive is mainly intended for industrial noise and defines different measures to be taken when defined noise exposure levels are reached. Three distinct levels are defined for continuous and impulse noise:

i) The lower exposure action values:
continuous noise: $L_{EX,8h}$ = 80 dB(A)
impulse noise: p_{peak}= 112 Pa (L_{peak} = 135 dB(C))
The employer has to make available individual hearing protectors to the employees.

ii) The upper exposure action values:
continuous noise: $L_{EX,8h}$ = 85 dB(A)
impulse noise: p_{peak} = 140 Pa (L_{peak} = 137 dB(C))
The individual hearing protectors have to be used

iii) The exposure limit values:
continuous noise: $L_{EX,8h}$ = 87 dB(A)
impulse noise: p_{peak} = 200 Pa (L_{peak} = 140 dB(C))
This exposure level shall not be exceeded. For the determination of the effective exposure, the attenuation provided by the protection devices is taken into account.

The Directive states that "If the risks arising from exposure to noise cannot be prevented by other means, appropriate, properly fitting individual hearing protectors shall be made available to workers and used by them in…". This means that the noise reduction at the source has to be considered before hearing protectors shall be made available and used. In the military environment the life cycle of equipment is usually very long and therefore does not allow modifications at the noise source. New developed equipment which could permit lower noise levels at the source, however, often has higher performance and therefore produces usually equal or higher noise levels as the older one.

3. Military noise exposure

Typical continuous noise exposure in terrestrial military (vehicles) are in the range between 80 dB(A) for light vehicle and 110 dB(A) for a Tank. It can be summarized, that in the case of continuous noise the implementation of the exposure limits, imposed by the European

Regulation, seems to be possible for ground vehicles. However, the crews of armored vehicles have to be equipped with adequate hearing protection. The same is true for most of the helicopters and propeller aircraft. For ground crews working close to jet aircraft (e.g. on aircraft carriers) even these protection devices will not be sufficient. In this case, sound attenuation helmets with face shields have been developed.
For small calibre weapons, like handguns or assault rifles, a typical signature is shown in Figure 1 (upper graph). The peak pressure level for these weapons is typically in the order of 160 dB. The A-duration is quite short, typically 300 to 600µs. For large calibre weapons, like howitzers or mortars, Figure 1 (lower graph) the peak pressure at the servant's ear is up to 190 dB and A-durations exceed 2 ms.

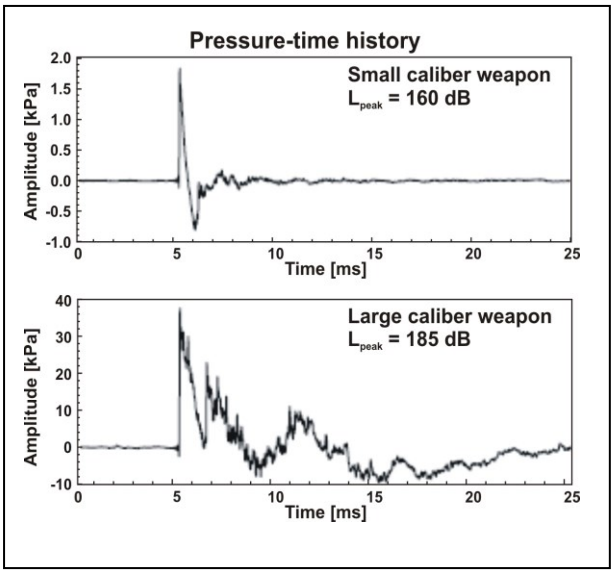

Figure 1. Typical pressure-time history of a small (upper graph) and a large (lower graph) caliber weapon.

The differences in peak pressure level and A-duration have an impact on the spectral composition of these signals. If sole the peak pressure is modified and the A-duration of the signal is kept constant, only the amplitudes of the spectral components are shifted proportionally to the change in peak pressure. The shape of the spectra is not affected. In the case that the peak pressure of a shockwave is kept constant, a longer duration induces more energy in the low frequency bands; whereas the high frequency content of the spectrum stays the same. As the damage risk to the auditory organ depends on the frequency, this should be taken into account, for exposure criteria.

4. Methods for the evaluation of hearing protection devices in impulse noise

The evaluation of hearing protectors for the use in continuous noise is well known, and normalized in different standards. There are mainly two different types of evaluation procedures of hearing protectors: i) subjective methods (subjective response of human subjects), ii) objective methods (physical noise measurements).

4.1. Subjective methods:

The best known of the subjective evaluation methods for hearing protectors is the so called REAT (Real Ear At Threshold) method [6]. The principle of this method consists in measuring the threshold of hearing of a subject in free sound field conditions with and without a hearing protector. The difference of the threshold between the measurement with protected and unprotected ears is defined to be the Insertion Loss (IL). This method is widely used and accepted. As the behaviour of a hearing protector being exposed to a 180 dB peak pressure level impulse noise may not be the same than when being exposed to continuous noise at threshold, the REAT method is at risk to produce unrealistic IL values when the hearing protector is used in a military impulse noise environment.

4.2. Objective methods:

Objective methods determine the insertion loss by the means of physical measurements. There are two main types:

- Method MIRE (MIcrophone in Real Ear) method [7],
- Method using an ATF (Artificial Test Fixture) or "artificial head".

The MIRE method consists basically in measuring the pressure at the entrance or inside the ear canal of a human subject. There are different ways how the microphone is placed in the ear canal or close to its entrance:

- Fixing the microphone with adequate means near the entrance and leaving the ear canal open. This method has the advantage to preserve the input impedance of the ear canal, what is important for the evaluation of ANR devices.
- Fixing the microphone on top of an ear plug which will be inserted in the ear canal. As the protection of the subject is assured by the earplug, this method is usable for high noise levels.

The evaluation of hearing protectors with this method has the advantage of taking into account

more accurately the mechano-acoustical behavior of the soft tissue surrounding the ear and the morphological differences between subjects. However the evaluation of earplug is not possible by means of this method (because the earplug is then modified by the measuring equipment) and there are still ethical problems in exposing human subjects to levels that may damage hearing.
The limitations of use that are found with the MIRE method are not applicable to artificial heads (ATF, Acoustical Test Fixtures). Artificial heads are equipped with ear simulators with a microphone. Therefore ATFs allow the evaluation of earplugs and IL measurements with the open ear up to the physical limits of the transducers. Moreover, as the ear simulator reproduces the acoustical impedance at the drum comparable to human data, ANR headsets can be tested.

5. Evaluation of hearing protectors using high level impulse noise

5.1. The ISL ATF

However, when using an ATF for the evaluation of hearing protectors, one has to be certain that the artificial head is suitable for these tests. Most of the commercial available devices are developed for sound recording or for the evaluation of communication devices. However it is important, that the acoustical insulation is high enough when the outer ear canal is acoustically sealed (eg. with a metallic ear plug).

Figure 2. The ISL ATF in his version adapted to ANSI/ASA S12.42-2010 with heating regulation.

An ATF fulfilling these requirements [8][9] has been developed at ISL [10] (Figure 2) for evaluation of the nonlinear acoustic behaviour of small orifices [11] and hearing protectors. The acoustic insulation is more than 60 dB for all frequencies (see Figure 3) and therefore complies with the ANSI/ASA S12.42-2010 requirements [12] (the ISL ATF is a reference in this standard concerning impulse noise measurements).
To obtain the insertion loss of hearing protectors, we proceed in the same way as already described for the MIRE method: two measurements are made, one with and one without the hearing protector; the difference between these measurements being the IL calculated versus frequency.

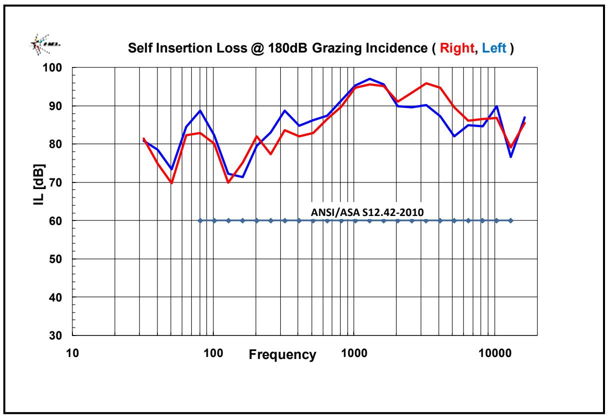

Figure 3. Self insertion loss for grazing incidence of the ISL ATF measured with a blocked ear canal for an impulse with a peak pressure level of 180 dB in the free sound field

5.2. Generation of the impulse noise

It is practically impossible to easily generate impulse noise with maximum level of 190 dB with classical devices, (loudspeaker or others). There are two possibilities left: i) shooting with real ammunition, or ii) using detonation of explosives
For our tests, the shock waves are generated by explosive charges (C4, or primers) of different weights, being placed at different distances from the artificial head (Figure 4). This technique allows to obtain well defined acoustical waves in the free field with peak pressure levels between 150 dB and 190 dB (or more if necessary) with A durations between 0.4 and 2 ms.
The type and the mass of explosive as well as the distance between the explosive charge and the artificial head depend on the peak pressure level and the duration of the required signal. In Table I, different explosive charges (type and mass) and distances for the generation of the different shock waves are shown.

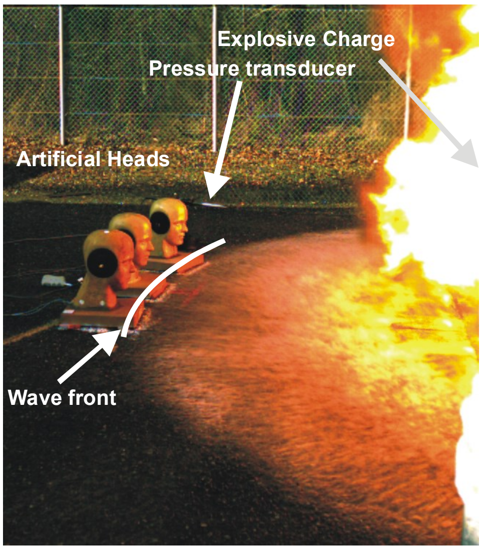

Figure 4: Setup of a test on ISL shooting range

Table I. Required type and mass of explosive charge and distance between artificial head and explosive charge for different peak pressure levels.

	Explosive		
Peak Pressure Level	*Mass*	*Type*	*Distance*
150 dB	7 g	Primer	26 m
180 dB	70 g	C4	4 m

5.3. Peak level nonlinear criteria

Usual cue for characterizing nonlinearities of hearing protectors versus external peak levels is the noise reduction peak (NR Peak) which is the reduction of the peak pressure level from the free field to the microphone of the ATF. A new parameter is now available in ANSI/ASA S12.42-2010: the Impulsive Peak Insertion Loss (IPIL) [12]. This is the reduction of the peak sound pressure level of an impulsive noise provided by a hearing protector device determined from noise reduction measurements corrected using the free-field to open-ear transfer function. At this time there is no standardized method of estimating IPIL from REAT values, but it is calculated with ATF measurements.

The NR Peak has been commonly used in development of level dependent attenuation devices like nonlinear earplugs [11]. However, when the hearing protector is not stable enough in the ear canal, his own movement can be responsible of nonlinearities. This can be observed with a classical earmuff submitted to very high impulsive level up to 190 dB Peak. The time signals underneath an earmuff for four levels (150, 170, 185 and 190 dB) is reported in Figure 5.

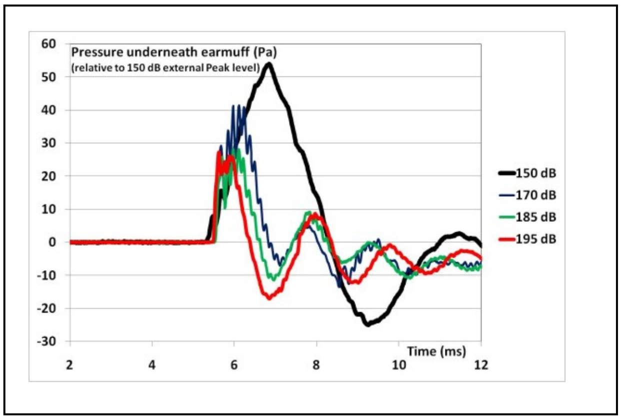

Figure 5: Time signals underneath a classical earmuff for different high level impulse noises (150 dB, 170 dB, 185 dB and 190 dB).

The new criterion proposed here for characterizing the effect of structural nonlinearities consists in representing the minimal negative peak pressure underneath the protector divided by the corresponding maximal positive peak pressure versus the external maximal peak pressure. A first example reported on Figure 6 shows the difference of behavior between the structural nonlinearity of a classical preformed earplug and the one of a classical earmuff. The stability of the criterion for the earplug is good while for the earmuff the criterion shows an important variability due to the movement of the protector during passage of the shock wave.

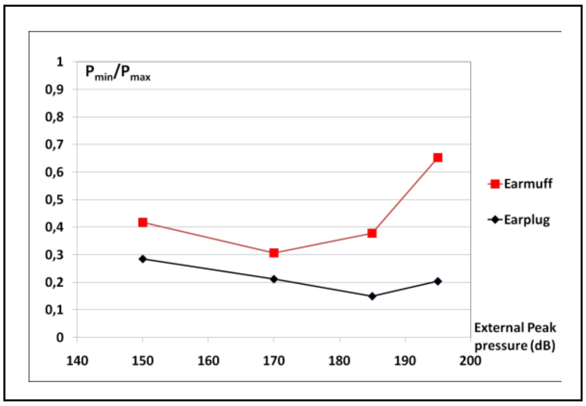

Figure 6: Representation of the ratio of the minimal negative peak pressure underneath the protector to the corresponding maximal positive peak pressure versus the external maximal peak pressure for two typical hearing protectors.

6. Conclusions

The acoustic environment of the soldier is very different from the noise that is usually found in industry. However standards and measurement procedures are made for the civilian environment.

When using only these methods, some of the specificities of the military environment may not be taken into account. Therefore the hearing protectors should be evaluated with signals and in an environment to which soldiers are exposed.
The testing of different types of hearing protectors with high level impulse noise has shown that the attenuation is not constant over the whole range of levels. Special artificial test fixtures as the ISL ATF allow to measure signals with very high level noise in accordance to ANSI/ASA S12.42-2010 requirements [12].
To be able to assess structural nonlinearities of different kind of hearing protectors, a new simple criterion is proposed and submitted to the community for more improvement.

Acknowledgement

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