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Hearing Protector Performance in Impulsive Noise (Part II: Laboratory Test Sources)

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1.0 INTRODUCTION

The current hearing protector attenuation assessment procedures such as EN 24869-1:1992 [1] determine the attenuation in steady noise. A means of describing the reduction in peak sound pressure achieved by a hearing protector is also needed, in order to be able to assess compliance with the 200Pa limit for those exposed to impulse noises.

If a hearing protector behaves linearly, the peak level effective to the ear can be calculated from the impulse response of the protector. However there is a body of evidence that even conventional passive hearing protectors exhibit non-linear behaviour when subjected to high level impulse noise. A classic example of this phenomenon is when the cushion of the ear defender lifts off the wearer's head. Additionally an increasing number of electronic or mechanical level-dependent protectors are being introduced into the marketplace, intended to respond selectively to transient and steady state noise.

To fully define the acoustic performance of a hearing protector to any specified impulse would require a detailed knowledge of the dependence of any non-linearity on the peak level, rise time, and duration of the impulse. In other words, a full parametric analysis of the protector's attenuation performance as a function of these variables would be needed.

Part one of this paper described impulse noise characteristics as well as an overview of the impulse noise levels found in industrial and military environments. These impulse sources were categorised into 4 group which were thought to represent all the types of impulse noise found at the workplace. The four groups are described below:

- GROUP 1; Long duration impulses which have most of their acoustic energy distributed in lower frequency ranges -below 2kHz (eg. Drop Forge).
- GROUP 2; Short duration impulses with most of the acoustic energy distributed in the higher frequency ranges -above 2kHz (eg. Stapler).
- GROUP 3; Long A-duration Friedlander type waves between 2 and 6ms with the majority of the acoustic energy in the low frequency ranges.
- GROUP 4; Short A-duration Friedlander type waves between 0.3 and 2ms with the majority of the acoustic energy in the high frequency ranges.

It is not always convenient to measure hearing protector attenuation in the workplace so a literature survey has been conducted to find appropriate impulse sources, reproducible in the laboratory, that model these four categories of impulse noise.

2.0 RESPONSE OF HEARING PROTECTORS TO IMPULSE NOISE

In seeking to define test noise sources with which to measure the impulse response of hearing protectors, it is important to take account of the ways in which such devices operate. An increasingly wide range of hearing protector types are now available, and are classified below.

2.1 Passive Ear Muffs

The conventional ear muff, when operating in its linear regime, may be regarded as a low-pass filter for impulse noise. In very simplistic terms, when the leading edge of the impulse pressure wave is incident on the protector, the ear muff is set into a damped oscillatory motion on the head, at its natural frequency. This resonant frequency, which is typically in the range 100-500Hz, is determined by the mass of the ear muff and the compliance of the cushion acting on the fleshy area of the head surrounding the pinna [2].

If the excursion of the ear muff on the head is large, a gap may be introduced between the cushion and the head, allowing sound energy to penetrate virtually unattenuated. This is more likely to occur when the impulse noise has either a very high peak level or a large low-frequency component.

2.2 Passive Ear Plugs

Depending on its construction, the conventional ear plug may be modelled as either a) a simple acoustic resistance element located in the ear canal, or b) a mass-spring system comprising the mass of the ear plug itself reacting with the shear compliance of the plug in the ear canal, and including the shear compliance of the flesh.

2.3 Mechanically Non-Linear Passive Ear Muffs and Plugs

Hearing protection devices claiming a non-linear attenuation for impulse noise have been in existence for at least thirty years. The principle of operation is that the incidence of a high-level impulse at the protector gives rise to additional attenuation due to either the generation of turbulence in a number of small orifices or the closure of a valve in the sound path.

For steady-state noises, such devices in general provide low attenuation, since the sound wave is able to penetrate the protector without impediment.

Tests on such devices in the past have found that, in some cases, non-linear attenuation might only be achieved when the incident peak sound pressure exceeds 160dB. Since the use of these "claimed" non-linear protectors in the workplace (and in leisure pursuits such as shooting) is increasing, often in circumstances where peak levels may lay in the 140 -160dB range, reliable attenuation data covering this range of sound levels are urgently needed.

2.4 Active Electronic Non-Linear Protectors
An increasing number of protectors fitted with a level-dependent "hearing-aid" electronic circuit are being used in the workplace in impulse noise situations.

External sounds are detected by a microphone placed on the outside of the protector, whose output is fed, via a level-dependent electronic amplifier, to an earphone mounted in the protector. More usually, these circuits are incorporated in ear muffs, although ear plug devices are under development.

The level-dependent electronic circuit may be either a simple peak-clipping circuit, restricting the maximum signal delivered to the earphone to that allowed by the amplifier voltage supply rail, or a more sophisticated automatic gain control (AGC) compressor circuit in which the level of loud sounds is reduced by a control loop which senses the time-averaged r.m.s. signal level but in which quiet sounds are transmitted without attenuation.

In either case, the electronic circuits may allow transmission of external sounds to the ear at (well) above natural levels in the unattenuated mode. Devices providing 20dB amplification of sounds up to 80dBA external level have been found during testing at Salford University.

These protectors may either provide a single (monaural) amplifier circuit fed to one ear, or a twin channel stereo system to aid localisation of external sounds.

In a related series of tests on such protectors, all the devices investigated were found to effectively limit the transmission of impulse sound to that achievable by the protector used in its passive mode - either by the setting of an appropriate maximum feed level to the earphone, or by the use of a fast-acting AGC circuit.

2.5 Active (Noise Cancellation) Protectors
This class of hearing protector is fitted with an "antiphase" acoustic noise cancellation electronic circuit whose purpose is to increase the total attenuation provided by the protector. The term Active Noise Reduction (ANR) is sometimes used to describe such protectors, which were originally developed for applications involving exposure to high levels of pseudo steady-state low frequency noise (military vehicles and aircraft).

ANR protectors are generally based on high (passive) attenuation ear muffs although ear plug devices are under development. The ANR electronic circuit comprises a microphone mounted inside the protector which detects the internal sound level, a feedback or compensation filter, and amplifier, and an earphone which transmits the "antiphase" signal (and any speech or communications signals needed).

The additional attenuation provided by an ANR circuit is typically up to 20dB in the frequency range 100-500Hz, with the possibility of an unwanted "in-phase" component which can reduce effective attenuation by typically 3-5dB in the range 2000-4000Hz.

Typically, no pre-knowledge of the external sound is required, and the device will attempt to follow variation in the instantaneous sound pressure level at the sensing microphone, within the bandwidth-time constraints of the electronic circuit. Maximum reproduced sound levels of typically 130dB will be limited by supply voltage rails or protection circuits.

2.6 Passive Protectors with Communication/Relayed Sound

In some workplaces, employees may use hearing protectors with "piped" music or with speech communication facilities hopefully at levels equivalent to less than the 85/90dBA action levels. In terms of their impulse response these devices behave the same as passive muffs.

3.0 LABORATORY SOURCES

A literature survey on methods of producing impulse noise in laboratory conditions has been carried out. Information from this survey and a survey of military and industrial impulse noises have been consolidated in an attempt to model industrial and military impulse with sources reproducible in laboratories.

The literature survey has reviewed a number of different methods of producing impulse noise, most of these methods have been developed to facilitate the measurement of hearing loss due to impulse noise. Impulse sources utilise one or more of the following techniques using mechanical, electromechanical or electro-mechano-acoustic methods.

The impulse producing methods are described below including their classification.

3.1 Compressed Air Release (Classification - Type 3 and 4).

In this method a sound wave is generated by rupturing a diaphragm situated between a compression chamber and an expansion chamber. Hamernik *et al*[3] used two different methods of generating impulses using compressed air. The first used a bursting diaphragm and the other a rapid-acting valve to initiate the shock front. Peak levels of 160dB where achieved from all methods, they were found to be repeatable and adjustable.

It was noted that the output from the plate rupturing was similar to a 105mm Howitzer and the output from the rapid acting valve was similar to an M-16 rifle.

At PTB Fedtke and Richter [4] developed a foil blaster for generating impulsive noise. This device consists of a cylindrical tube filled with compressed air and terminated by a thin foil. To shape the pulse, another tube with an open end is mounted in front of the inflated one. The foil bursts after having been scratched with a sharp needle. At an air pressure of 2.05 bar, peak sound pressure levels of 170dB at a distance of 0.5 m were achieved with typical A-durations of 1 ms. The system repeatability was 0.7 dB.

3.2 Cricket (Classification - Type 4).
A piece of concave spring steel is fastened at one end to a holder. When the cricket is squeezed the steel snaps abruptly to its other stable position (ie. concave or convex) generating a loud click. Ward *et al*[5] used this method to measure the TTS of humans subjected to impulse noise. Peak levels of 145dB were recorded which could be controlled by varying the distance between source and receiver. The signal's time-domain content was modified by changing the cricket size.

3.3 Hammer and Plate (Classification - Type 2)
The impact produced by a hammer falling onto a plate can be used to generate an impulse whose peak level and duration can be varied.

Tremolieres and Hetu[6] used a hammer beating a metal plate and a hollow metal rod in a highly reverberant room. Different temporal patterns of acoustic waveforms were obtained either by; (a) varying the distance between the location of the shock and the recording microphone, (b) by damping out the oscillations of the metal structures caused by the shock, or (c) By varying the weight of the hammer. Peak levels of 137dB where produced with 'B' durations of 140-470 ms.

3.4 Loudspeaker (Classification - Type 1-4)
Loudspeakers have been used as the 'front end' of many different impulse sources. Although loudspeakers offer good repeatability and, with the aid of signal processing, more accurate impulse source modelling, the limitations of the loudspeaker with respect to frequency response, directivity, power handling capabilities and the dynamic range required to achieve high level impulse noise severely restricts the use of conventional amplifier/loudspeakers configurations. The driving signals come from a number of different sources including synthesised signal [7] [8] [9] [10], actual recordings [11] and electrical discharge [5].

Although loudspeaker systems can be used to investigate the characteristics of hearing protector devices at lower levels, they have limited use for generating impulses in excess of 140 dB.

3.5 Spark Discharge (Classification - Type 4).
These devices produce an arc between two electrodes, the resulting pressure pulse is dependent upon the voltage and spacing between the electrodes. The discharge system has been developed over the years [12][13][14] but the principle of operation has not altered much. The central part of Brinkmann's device is a 100μF capacitor that is charged by a voltage of 3.5kV. Two brass bars are mounted on top of the capacitor and held in a polyethylene block. Two tungsten electrodes are mounted in the brass bars , the distance between the ends being variable from 6 to 12mm. The system was found to be reproducible and peak levels of 155.5 dB are produced.

3.6 Pistol (Classification - Type 4)
The best method of producing impulses to model military noise is obviously to use the weapon itself. However, this is not always possible due to the practicalities of firing the weapons under the correct measurement conditions.

Starting pistols have been used as impulse sources to study the effect of impulses on TTSs [15]. Peak level variations can be made by moving the subject away from the source.

Lamothe and Bradley[16] studied the acoustical characteristics of various types of guns with different calibres. They conclude that a 0.38 calibre gun firing black powder blank cartridges are a suitable source of acoustical impulse.

Measurements undertaken in this project using a 9mm starting pistol firing both black and white powder cartridges have produced peak levels of 158dB with very high repeatability (differences less than 3dB).

It has been found that white powder blank cartridges offer greater repeatability than black powder cartridges.

3.7 Propane Cannon (Bird Scarer) (Classification - Type 1/3)
Impulses provided by a propane cannon were studied to see if they could be used to model impulse noises found in industry. The propane cannon tested runs off compressed Propane gas. The gas fills a set of bellows inside the body of the cannon and is then compressed by a mechanical mechanism. Once the gas has been compressed to its set pressure a piezoelectric igniter lights the gas thus causing an explosion which then propagates down a tube and out into free space. Associated with the explosion is the production of exhaust flames therefore all measurements of spectra and time histories are taken from approximately 1 metre behind the cannon. Peak levels of 147dB were recorded using a B&K 6mm microphone and a FM recorder. Initially the propane cannon produces a "muffled" impulse noise, but after approximately 4 impulses the propane cannon produces louder more crisp impulses which are repeatable (with differences less than 4dB) once the device is 'warm'.

3.8 Pyrotecechnic Devices
There are a wide variety of pyrotechnic devices which are capable of producing short duration Friedlander impulses. However the safety issues associated with their use within laboratory conditions make then unsuitable for acceptance as 'standard' sources, given that alternatives exist.

4.0 CONCLUSIONS

A literature survey on methods of producing impulse noise in laboratory environments has been carried out to model impulse noises found in the workplace to facilitate the measurement of hearing protector attenuation against impulse noise.

Methods of modelling three of the four types of impulse noise have been found, however methods of modelling type 4 impulses which are produced by large calibre weapons have not been found. The peak levels and the extent of the low frequency energy produced by such weapons is extremely difficult to produce in a laboratory environment. However some success using a membrane device for medium calibre weapons is reported. For testing lower level impulses, loudspeaker systems can be utilised which can produce impulse noise with various characteristics, although at restricted peak levels.

5.0 REFERENCES

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