Proceedings of The Institute of Acoustics

A COMPARISON OF DAMAGE RISK CRITERIA FOR IMPULSE NOISE

J.C. GOODCHILD and C. WAITES

ACOUSTICS GROUP, DEPARTMENT OF PHYSICS, LIVERPOOL POLYTECHNIC

Introduction

There are two main methods of assessing the risks of hearing damage associated with exposure to impulse noise.

1. The CHABA Damage Risk Criteria[1] (1968)

These were prepared for gunfire noise and are specified in terms of the impulse peak pressure level P_{MAX} (in dB re. 2×10^{-5} Pa) and the B duration, which is defined as the total time that the envelope of the pressure fluctuations is within 20dB of the peak pressure level. (See Figure 1). The CHABA criteria are illustrated graphically in Figure 2 in terms of the maximum allowable P_{MAX} as a function of impulse B duration, assuming exposure to 100 impulses per day (for protection of 75% of personnel). The criteria can in fact be fitted to the empirical relationship

$$P_{MAX} = 145 - \underbrace{\frac{20}{3}\log_{10}\left(\frac{B}{100}\right)}_{(A)} - \underbrace{5\log_{10}\left(\frac{n}{100}\right)}_{(B)} \quad \text{for} \quad B \leqslant 200 \text{ ms} \qquad (1)$$

Term A represents the trading relationship between B duration, in milliseconds and the impulse peak sound pressure level. Term B relates to the correction that is made if the number of impulses per day n, differs from 100.

The CHABA criteria were prepared as a result of temporary threshold shift (TTS) studies. Rice[2] however suggests that the assumption of a consistent relationship between TTS and permanent threshold shift (PTS) is unproven.

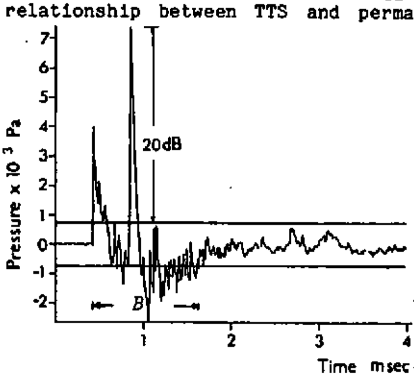

Figure 1

Waveform of Typical Impulse

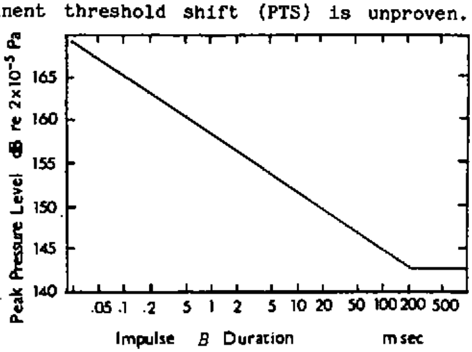

Figure 2

The CHABA Damage Risk Criteria

2. The energy immission principle (The U.K. Code of Practice[3]) in which the daily integrated, A-weighted sound energy is used as a measure of noise dose, the standard set at present being an L_{eq} of 90 dB(A) for an 8 hour day. In 1976, following earlier retrospective studies of hearing damage amongst drop forge workers, Martin[4] established that the equal energy principle may be extended to include industrial impact noise. He also suggests that there is circumstantial evidence that the equal energy concept may be extended to the gunfire situation.

If the daily noise dose is made up of exposure to many impulsive noise events then it is convenient to express the energy content of individual impulses in terms of a "single event noise exposure level, L_{AX}", as defined by Berry[5] "L_{AX} is the level which, if maintained constant for a period of one second would cause the same A-weighted sound energy to be received as is actually received from a given noise event."

The value of L_{eq} over a time T seconds due to the combined effect of n events each of the same L_{AX} is:

$$L_{eq} = L_{AX} + 10 \log_{10} n - 10 \log_{10} T \qquad (2)$$

Substituting the Code of Practice maximum daily dose of 90 dB(A) for 8 hours and rearrangement gives a value of n, the total number of impulses required for the noise dose to reach this limit in terms of L_{AX}.

$$\text{Log}_{10}\, n = 13.48 - \frac{1}{10} L_{AX} \qquad (3)$$

In this report the impulse noise associated with a range of firearms is assessed in terms of the potential to cause damage to hearing using the damage risk criteria referred to above. In particular the number of rounds allowed each day, before the CHABA and the 90 dB(A) L_{eq} criteria are exceeded, is calculated in order to compare these two approaches to assessing damage risk.

Experimental Techniques

The recognised technique for measuring short duration impulsive noise has been to photograph the pressure time waveform from a storage oscilloscope trace. The microphone used in this study was a Bruel and Kjaer 1/8" microphone Type 4138 orientated at glancing incidence to the pressure waves from a range of firearms discharged under anechoic conditions. In addition to photographing the storage oscilloscope display, a digital transient event capture technique was employed which involved a Datalab Transient Event Recorder Type 901 which sampled the instantaneous sound pressure at 5μs intervals and stored 1024 samples. A computer graphplot of a typical impulse from a 0.38 Special revolver with 4" barrel from which P_{MAX} and B duration can be measured, is shown in Figure 1. The computer was programmed to perform a numerical integration of the sound energy associated with the impulse waveform and express this in terms of an L_{AX} value for the impulse. In Table 1 the data for impulses from a range of weapons at various distances from the signal microphone are summarized, including in particular, the values for P_{MAX}, B duration and L_{AX}.

A COMPARISON OF DAMAGE RISK CRITERIA FOR IMPULSE NOISE

Table 1. Compilation of Impulse Noise Measurements

Noise Source	P_{MAX} (dB)	L_{AX} (dB)	B duration (ms)	n CHABA	n 90 dB L_{eq}
Webley Starting Pistol	144.9	106.8	0.80	64,445	602
" "	146.0	107.0	0.90	33,703	575
" "	149.3	105.4	0.62	12,119	831
" "	151.4	111.9	0.79	3,335	186
" "	151.7	107.6	0.60	4,192	500
" "	151.8	108.2	0.63	3,751	436
" "	153.9	113.4	0.77	1,091	132
" "	154.6	114.2	0.91	633	109
" "	156.2	114.5	0.65	474	102
" "	158.3	116.4	0.79	139	66
" "	159.6	115.5	0.63	103	81
" "	161.7	118.6	0.82	28	40
Smith and Wesson Model 10	161.8	121.9	1.57	11	19
Webley Starting Pistol	162.1	119.3	0.87	21	34
" "	162.7	121.8	1.05	12.5	19
Smith and Wesson Model 10	164.3	124.0	1.44	4.0	11

Discussion of results and conclusions

Included with the data given in Table 1 are two values of n, the maximum allowable number of impulses per day to which personnel could be exposed. One value of n has been calculated from the CHABA recommendations using the peak sound pressure level P_{MAX} and the B duration and the other from the 90 dB(A) L_{eq} criterion using Equation 3. It should be noted that the measurement system did not include A-weighting the pressure impulses so that L_{AX} is quoted in dB(Lin) units. Estimates by Atherley and Martin[6] and the present authors indicate that L_{AX} and L_{eq} values are in consequence likely to exceed values in dB(A) by between 1 and 3 dB. No allowance has been made for this relatively small correction in calculating n in Table 1.

Estimation of the values of n, the maximum allowable number of impulses per day tabulated in Table 1, suggests the following conclusions.

(1) For short duration impulse noise such as that produced by discharge of firearms in outdoor conditions (B durations typically 0.5 → 1.5 ms) the criterion for damage risk based on the energy immission principle using the standard employed in the UK Code of Practice, i.e. 90 dB(A) L_{eq} for 8 hours per day, is more conservative than the CHABA criterion of peak sound pressures up to approximately 160 dB. In view of the weight of evidence supporting the immission principle for both continuous and impact noise it would not seem appropriate to use the CHABA criteria for impulses with peak sound pressures up to 160 dB since it would allow exposure of personnel to a noise dose exceeding the 90 dB(A) for 8 hours, Code of Practice limit.

(2) For impulses with *B* duration around 1 ms the CHABA criteria (for 75% protection) terminates at a maximum peak sound pressure of 168 dB, for one exposure per day, above which personnel should not be exposed to any impulses without wearing hearing protection. Between 160 dB and 168 dB the CHABA criteria is the more conservative and would seem to be more appropriate to use.

A number of comparisons between available damage risk criteria have been made previously including those by Martin[4] and Rice and Martin[7] in which criteria are compared by plotting impulse peak sound pressure P_{MAX} against the composite parameter, " *B* duration x number of impulses n". The difficulty with this approach is that for the CHABA criteria, as indicated by the empirical relationship shown in Equation 1, P_{MAX} is not a single valued function of the *B* x n product. For the noise impulses from small arms recorded under anechoic conditions by the present authors (Table 1), the *B* durations are substantially the same, ranging from 0.5 to 1.5 ms. In Figure 3 the CHABA criteria have been redrawn (dotted) in terms of the number of impulses per day n, against peak sound pressure P_{MAX}, for constant values of *B* duration. The number of impulses allowed per day according to the CHABA criterion and the 90 dB(A) L_{eq}, 8 hour, criterion are also plotted on Figure 3. The conclusions to be drawn are essentially the same as (1) and (2) For peak sound pressure levels up to 160 dB the 90 dB(A) L_{eq}, 8 hour criterion is the more conservative, but between 160 dB and the maximum of 168 dB. (for *B* duration 1 ms) the CHABA criterion sets the more cautionary standard.

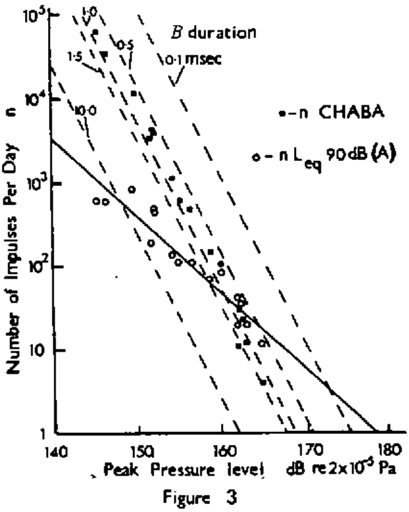

Figure 3

References

1. National Academy of Science, National Research Council Committee on Hearing, Bioacoustics and Biomechanics. 1968. Proposed Damage Risk Criteria for Impulse Noise (Gunfire): Report of Working Group 57.
2. C.G. RICE. 1974. Noise and Vibration Conference, Melbourne. Damage Risk Criteria for Impulse Noise and Impact Noise.
3. The Code of Practice for Reducing the Exposure of Employed Persons to Noise. 1971. Industrial Health Advisory Committee's Sub-Committee on Noise. Published 1972. H.M.S.O.
4. A.M. MARTIN. 1976. Effects of Noise on Hearing. 421-454, edited by D.Henderson. The Equal Energy Concept Applied to Impulse Noise.
5. B.F. BERRY. 1977. Proceedings of the Institute of Acoustics. The Concept of a Single Event Noise Exposure Level, L_{AX}, and its use in the description of the Overall Noise Environment.
6. G.R.C. ATHERLEY and A.M. MARTIN. 1971. Ann.Occup.Hyg. 14, 11-23. Equivalent Continuous Noise Level as a Measure of Injury from Impact and Impulse Noise.
7. C.G. RICE and A.M. MARTIN. 1973. J.Sound Vib. 28, 359-367. Impulse Noise Damage Risk Criteria.

Proceedings of The Institute of Acoustics

3C18

AUTOMATIC CALCULATION AND CATEGORISATION OF THE RESULTS OF SELF-RECORDING AUDIOMETRY

D. W. PETCHEY

METAL BOX LTD. RESEARCH & DEVELOPMENT DIVISION

Introduction

Metal Box Ltd employes about 30,000 people spread over about 50 factories, some of whom in each factory are exposed to noise levels above 90 dB(A) Leq. It was decided about three years ago to introduce audiometry and the installation of equipment, a Kamplex BA2 audiometer and a booth, in the 45 factories requiring them, was completed eighteen months ago. Audiograms have been produced since then.

Concurrently with the installation programme training courses were run for factory doctors (part time local GPs) and full-time nurses on hearing problems and the use of the equipment.

The proceedure used to read and categorise the audiograms is that given in the HSE Discussion Document 'Audiometry in Industry' an early version of which we were lucky enough to see. It was found that the proceedures given were very time consuming, about 15 mins per audiogram, and that the risk of inaccuracy was quite large.

It was therefore decided to try to mechanise the proceedure using a microprocessor. The rest of this paper outlines the system developed.

System Requirements

A number of basic requirements of a system were recognised. These were:-

a) The results must be produced as 'hard' copy as transference of figures could lead to error.

b) The system employed should not detract from the ability of the operator to make a clinical judgement in difficult cases.

c) No difficult new skills were to be required of the operator.

d) Sufficient information about the subject should be included in the print out for easy recognition and possible use in a central statistics bank.

e) The system developed should be cheap and cost less than the audiometer.

AUTOMATIC CALCULATION AND CATEGORISATION OF THE RESULTS OF SELF-RECORDING AUDIOMETRY.

The more specific requirements were:-

f) Calculation of the hearing level of each frequency according to the HSE rules, indicating if these were broken.

g) Enable the operator to repeat any frequency because of a failure.

h) Provide a print out of hearing level for each frequency tested.

i) Produce the low and high frequency sums.

j) Categorise the results according to the HSE system.

k) Enable the operator to feed in appropriate data to enable categorisation to be carried out.

Equipment Development

a) Microprocessors : The intention was to choose the system which offered the required facilities of a hard copy out-put and a full keyboard input plus adequate processing capability for the minimum cost. This turned out to be the Rockwell Aim 65 system. This has two 8-bit input ports and four control lines, two to each port. One port is used for the digital 8-bit value of the pen position on the audiogram as read from a linear potentiometer driven by the pen motor and encoded by a simple analogue to digital converter. The other port is used to monitor the status of the audiometer during the test (ear, frequency, yes/no etc)

b) Audiometer : The only modification to the audiometer has been the introduction of a linear potentiometer, the slider of which is connected to the pen movement, and the connection of leads to the status indicating lights in the machine. This has been deliberate to limit the modifications to a minimum.

c) Program : All the programming has been done in Basic, which is available in the Aim 65 system. It has been done deliberately to make modifications easy, but the final decision to use either this high level language or machine assembles for the production version has not been taken. The latter would offer a cheaper final model, the former enables further modifications to be made easily for different users.

Current Position

We have managed to fulfil this specification almost in its entirety. The only missing item is automatic categorisation to category 1, the comparison with the previous audiogram.

AUTOMATIC CALCULATION AND CATEGORISATION OF THE RESULTS OF SELF-RECORDING AUDIOMETRY.

This we feel is not difficult for the doctor or nurse to do manually when they review results. The equipment is currently in a separate case connected to the audiometer by a multicore cable.

We believe the system can be manufactured and sold for about £900.

Acknowledgements

I would like to thank all my colleagues in the Company who had a hand in this development, especially John Read who did the hardware development and programming.

I also thank the Directors of Metal Box Ltd for permission to publish this paper.