International Journal of Occupational Medicine and Environmental Health, Vol. 14, No, 2, 127—133, 2001

IMPULSE NOISE IN INDUSTRIAL PLANTS: STATISTICAL DISTRIBUTION OF LEVELS

JAN ŻERA

Department of Acoustic and Electromagnetic Hazards
Central Institute for Labour Protection
Warsaw, Poland

Abstract. Impulse noise generated by industrial machines and occurring at a workplace is a cause of substantial hearing loss in workers. The paper presents data on workplace impulse noise, recorded in three plants of the machine industry. The data were collected in drop-forge, punch-press and machinery shops. The results of the measurements are shown as cumulative relative frequency distributions of the C-weighted peak sound pressure level, L_{Cpeak}, the A-weighted maximum RMS sound pressure level (SPL), L_{Amax}, and the A-weighted sound exposure level, L_{EA} of isolated acoustic impulse noises. The survey shows that in the drop-forge shop over 90% of acoustic impulses generated by hammer strikes exceed permissible levels of L_{Cpeak} = 135 dB and L_{Amax} = 115 dB. In the stamp-press shop, only 10–20% of impulses generated during the technological process exceed maximum permissible levels.

Key words:
Noise, Noise hazards, Impulse noise, Noise limits

INTRODUCTION

Continuous noise and impulse noise occurring simultaneously are the most common types of noise in industrial plants. Research and observations have shown that the impulse noise occurring simultaneously with continuous noise can cause substantial hearing loss in workers [1–8]. It has been found that the equal-energy hypothesis does not hold for the impulse noise exposures but rather greater noise damage is caused by impulse noise [9–11]. The impulse noise of the same power spectrum as continuous noise is usually more damaging to hearing [12]. Even an exposure to a single burst of intense impulse noise can produce a permanent hearing loss in a small fraction of susceptible individuals [13]. This is attributed to the excessive displacements of the partitions of the hearing organ, resulting in direct mechanical and metabolic damage of the cochlea [14]. Impulse noise can be considered to be a major factor contributing to the hearing loss. Thus, controlling the levels of the impulse noise occurring in industry is an important part of industrial hearing conservation program.

One important parameter describing the level of impulse noise is the C-weighted peak sound pressure level, L_{Cpeak}, or linear peak (unweighted) sound pressure level, L_{peak}. Legal regulations concerning the limits of exposure to impulse noise advise the measurement of a number of parameters, among which peak level is of basic importance. According to Council Directive 86/188/EEC [15], a basic legal act concerning the protection of workers against noise hazards in the European Union, the maximum permissible L_{peak} level (unweighted) is 140 dB. Most countries accept this level as the maximum permissible level. According to Polish legal regulations [16] and standards [17], maximum permissible/allowable C-weighted peak

This research was conducted under the Strategic Governmental Program on Health Protection and Safety at Work, grant No. 03.7.21.
Address reprint requests to Dr J. Żera (Eng.), Department of Acoustic and Electromagnetic Hazards, Central Institute of Labour Protection, Czerniakowska 16, 00-701 Warsaw, Poland.

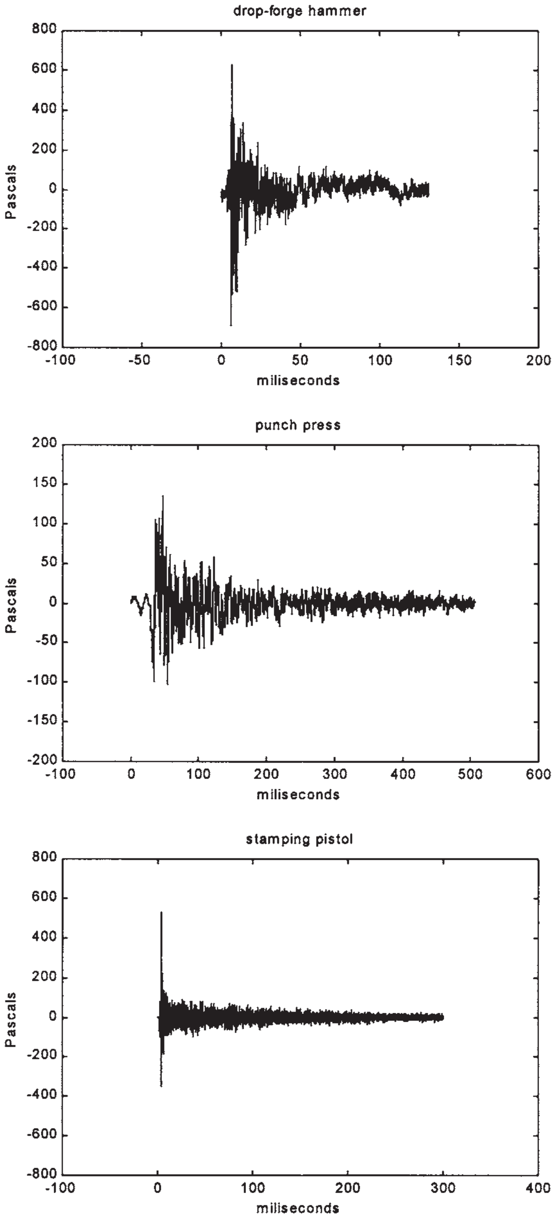

Fig. 1. Time waveforms of impulses produced by drop-forge hammer, punch press and stamping pistol recorded in industrial plants. Note that time scales are different, and the amplitude scale for punch-press waveform (middle panel) is four times smaller than for other recordings.

sound pressure level, L_{Cpeak}, of impulse noise is 135 dB.

Noise impulsiveness may be established either on the basis of the sound source if a measurement of a single impulse is possible, or by measuring continuous and impulse noise occurring simultaneously and averaging the data over a certain period of time. In the former case, apart from establishing the L_{Cpeak} level, it is advisable to use an A-weighted noise exposure level L_{EA}. In the latter, impulsiveness measures are used, such as the difference between $L_{AIeq,T}$ and $L_{Aeq,T}$, determined on the basis of the levels measured with a sound level meter over a time T, using the "I" and "S" time constants.

The measurement of impulse noise in an industrial plant is difficult to carry out since it occurs simultaneously with high level continuous noise, has a transient character, and is followed by secondary impulses i.e., reflected impulse waves. The time signature of a realistic impulse (Fig. 1) usually differs from ideal types of impulses such as described in ISO 10843 standard [18,19].

This paper presents selected parameters of impulse noise measured in three plants of the machine industry. To make the measurements possible, the noise was recorded and later the impulses were isolated. The measurements aimed at determining the characteristics of industrial impulse noise by establishing a statistical distribution of selected parameters, measured at a head position of the worker. The data were obtained during various work cycles of the machines in the course of technological processes generating the noise under study.

MATERIALS AND METHODS

The set-up for recording noise samples in industrial plants was carefully chosen to avoid any possible distortions of the waveform which might be caused by amplitude and phase response, and a limited frequency bandwidth of the instruments [20]. The set-up comprised a 1/2″ Bruel and Kjaer (BK) free-field microphone type 4133, a BK 2645 preamplifier, and a BK 2408 signal conditioning amplifier. The signal from the microphone was recorded on a DAT cassette using a Tascam DA-P1 digital recorder. To avoid peak clipping, the signal from the microphone was monitored on a Tektronix TDS 210 digital oscilloscope. A BK 4220 pistonphone was used for calibration of the recording channel. A 250-Hz sinusoidal calibration signal at a level of 124 dB SPL was recorded on the tape, prior to recording of noise samples. This signal was later employed to set the proper gain of the set-up used for signal analysis in the laboratory. Impulse response of the measurement set-up depended mainly on the frequency response of the DA-P1 recorder, and limited the minimum rise time of recorded impulses to about 50 ms.

To enable further analysis, time waveforms of recorded impulses were digitally transferred to a PC through a SP/DIF link between a Tascam recorder and an Audiomedia III Pro sound card installed in the PC. The dynamic range of the sound card was 90 dB (total harmonic distortion, THD <0.008%).

The adequate waveforms were saved on a computer hard disk, and then segmented, i.e. single impulses were extracted from the recorded signal. Acoustic parameters of the impulses were determined using various computer program procedures written in the Matlab language. The software comprised procedures for calculating Lin, A or C-weighted peak levels and the RMS level values, with ”S”, ”F”, and ”I” time constants, as well as procedures for the measurement of rise and decay time of the impulses.

The collected data included 526 impulses recorded in 27 workplaces, in three plants. The samples of impulse noise were recorded in the drop-forge, punch-press, and machinery shops. The impulse noise recorded at a particular workplace was represented by 4 to 25 impulses produced by a single machine during the technological process. Examples of impulses representative for the recordings are shown in Fig. 1. It seems that the statistical representation of data is the best way of describing the levels and duration of impulse noise produced by a machine since the workers are exposed to varying noise levels during the production cycle.

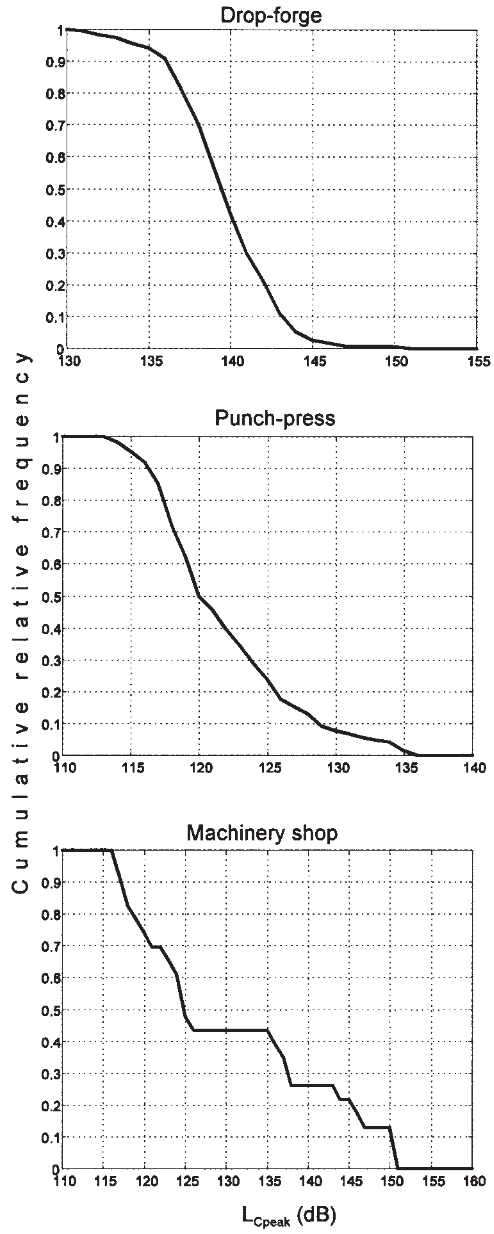

Fig. 2. Cumulative relative frequency of C-weighted peak sound pressure level L_{Cpeak}. Data based on 526 impulses recorded in 27 workplaces.

RESULTS AND DISCUSSION

Figures 2, 3 and 4 show cumulative relative frequencies of the three basic impulse noise parameters: C-weighted peak level L_{Cpeak}, A-weighted maximum RMS level L_{Amax}, and A-weighted sound exposure level L_{AE}. The data plotted in Fig. 2 show that in the drop-forge shop peak levels ranged from 132 to 152 dB. The distribution median was 139 dB. Therefore, as many as half of the 222 impulses recorded in the drop-forge shop exceeded the level of 139 dB. The peak levels of the 271 impulses recorded in the punch-press shop ranged from 116 to 136 dB, with a median of 120 dB.

In the drop-forge shop, the L_{Cpeak} level exceeded the maximum permissible level of 135 dB in 95% cases (Fig. 2), and the L_{Amax} level exceeded maximum permissible value of 115 dB in 10% of cases of the hammer strikes (Fig. 3). In the punch-press shop, however, the L_{Cpeak} and L_{Amax} levels exceeded the permissible values only marginally. However, the data reported in the literature [10] show

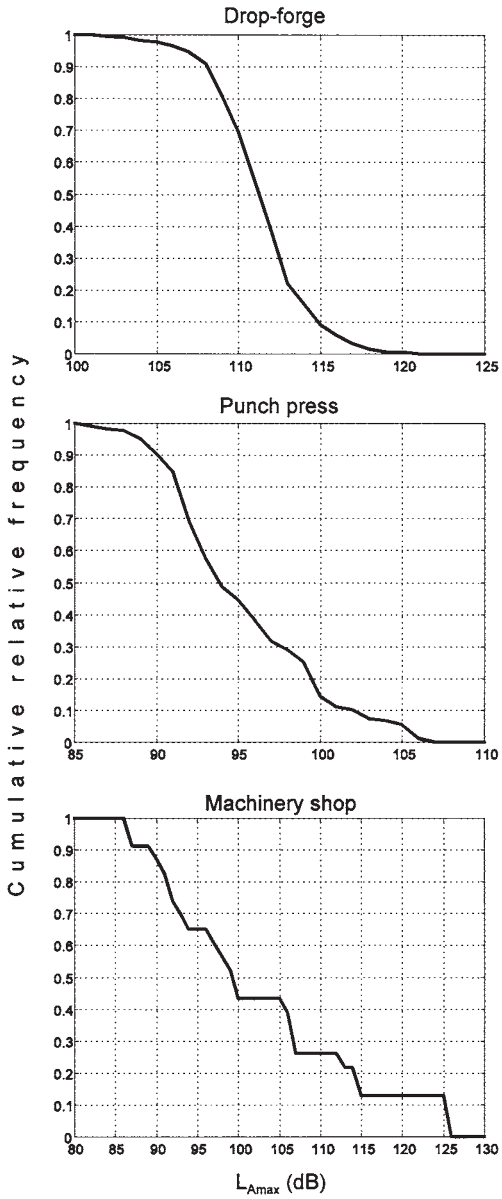

Fig. 3. Cumulative relative frequency of A-weighted maximum RMS sound pressure level L_{Amax}. Data based on 526 impulses recorded in 27 workplaces.

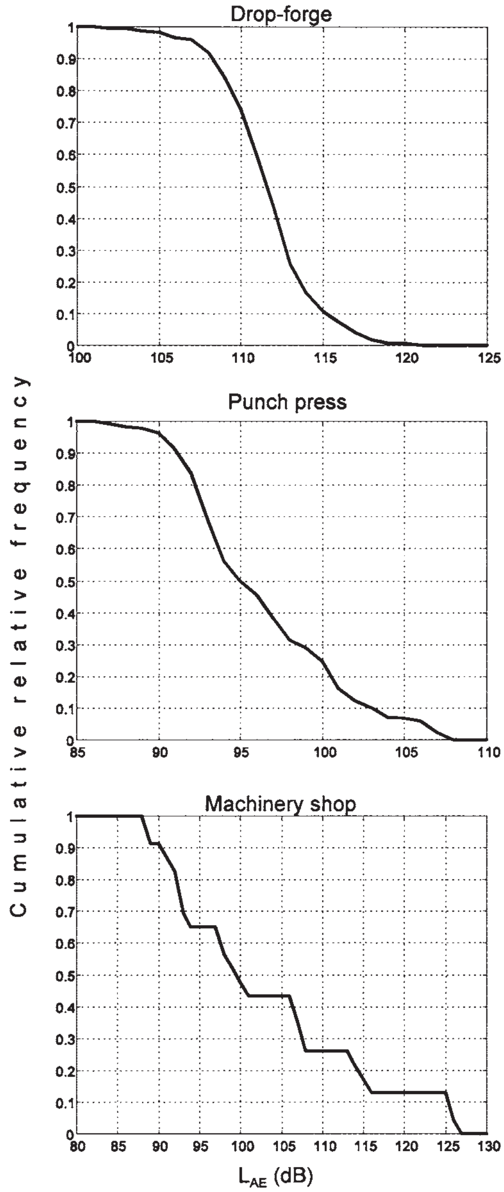

Fig. 4. Cumulative relative frequency of A-weighted sound exposure level L_{AE}. Data based on 526 impulses recorded in 27 workplaces.

that the level of 119–125 dB already creates an increased risk of hearing damage.

As far as all the data is concerned, the cumulative frequency distribution of the A-weighted sound exposure level L_{AE} of the recorded impulse noise (Fig. 4) was a few dB higher than the frequency distribution of maximum levels L_{Amax}. The median values of the distributions, shown in Fig. 4, were 112 dB at the drop-forge shop and 95 dB at the punch-press shop. The values of sound exposure level, L_{AE}, shown in Fig. 4, indicate an equivalent A-weighted level of a signal, 1 sec in duration, which releases the same energy as a single recorded impulse. According to the available data [21,22], the observed levels create a significant risk of hearing damage to unprotected ears. The workers operating hammers and presses in the plants under study wore earmufs and earplugs to achieve suitable adequate protection.

The data from the machinery shop comprise 23 recordings of impulse noise (Figs. 2–4, the diagrams at the bottom).

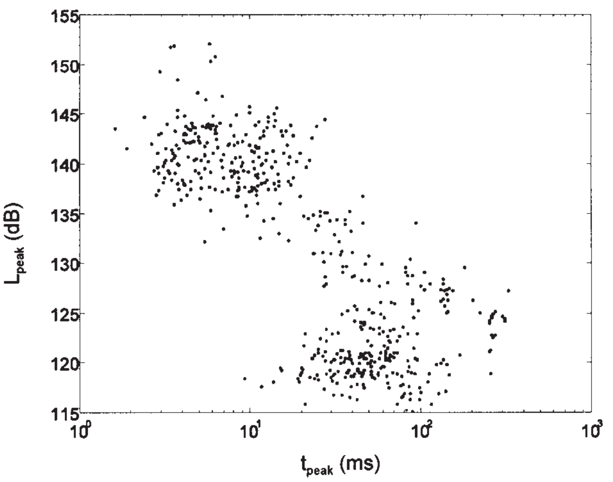

Fig. 5. Unweighted peak sound pressure level time vs. peak level L_{peak} observed in industrial recordings of impulse noises in drop-forge and stamp-press shops.

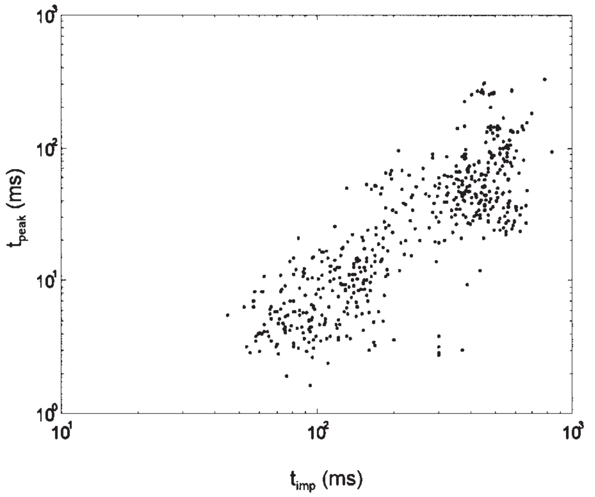

Fig. 6. Duration of impulse vs. peak level time for recorded industrial noise in drop-forge and stamp-press shops.

The recorded noises were generated by two types of machines: a guillotine shear and a stamping pistol. The shears generated the noise of L_{Cpeak} level not exceeding 120 dB. In the case of the stamping pistol, the L_{Cpeak} levels were very high and ranged from 140 to 151 dB. These values exceeded the maximum permissible L_{Cpeak} and L_{Amax} levels in Figs. 2 and 3.

Rise time is another signal parameter used to characterise noise impulsiveness. Since the relationship between this parameter and hearing damage has not as yet been fully elucidated, rise time is not used as a criterion for setting limits of impulse noise in industry. Rise time of impulses recorded in the drop-forge division ranged from 1 to 15 ms. Rise time shorter than 2 ms was displayed by as many as 50% of all impulses. In the punch-press shop, the impulses generated by low-impact-noise presses exhibited longer rise time, ranging from 5 to 100 ms. Forty percent of measured rise time of strikes were longer than 20 ms. Quite differently, the rise time of impulses generated by the stamping pistol was extremely short, usually shorter than 1 ms.

Most of the recorded impulses were of type B, according to the commonly used classification described by Coles et al. [23] and in ISO 10843 standard [19]. Such an impulse type is characteristic of industrial noise produced by collision of objects. A typical example of such a source of noise is a drop-forge hammer hitting steel metal on a matrix (Fig. 1).

For type B impulses, it is difficult to establish the exact rise time from the recorded waveform because of the complexity of the impulse time envelope. In addition, a high level of continuous background noise, clearly seen in Fig. 1 (upper and middle panels), typically exceeding 90 dB(A), adds to the signal's waveform and makes it difficult to determine the moment of the impulse onset. Therefore, it turned out easier to measure the duration of the impulse and the delay time of its peak level occurrence. This delay is a measure of the signal impulsiveness, correlated with the rise time of the signal. In Fig. 5, all the recorded data are shown in peak time vs. peak level coordinates. The data points plotted in Fig. 5, representing single noise recordings, clearly form two groups. The first group, reflecting higher peak levels, and shorter delay after which the peak level occurred, comprises the data recorded in the drop-forge division. In the second group, formed by the data obtained in the punch-press division, there peak levels measured are lower and the delays are larger. The data presented in Fig. 6 show the impulse duration and the delay of occurrence of the peak time. The data spread is an indicator of the correlation between the impulse duration and the time of the peak level.

The analysis presented here was carried out with reference to impulses isolated from the background noise. In such a case, not all accepted measures of noise impulsiveness parameters provide values, which are within reasonable limits. For instance, such measure of impulsiveness as previously mentioned $L_{AI,T}$–$L_{Aeq,T}$, defined in IEC 804 [24] and often used in modern sound level meters, would lead to unreasonably high values when applied to isolated impulses. This is due to the fact that the ”I” time constant of 35/1500 ms for on/off conditions causes an overestimation of the integrated $L_{AI,T}$ value. The values obtained for noise impulses in isolation will be much higher than those obtained *in situ* when noise measurements are conducted under conditions in which impulse noise is only a component combined with the background of continuous noise.

CONCLUSIONS

The main conclusions of this study are as follows:

1. Among the three discussed parameters characterising impulse noise, L_{Cpeak} is the most sensitive indicator of impulse noise hazard.
2. In the drop-forge shop, over 90% of recorded impulses exceeded the critical L_{Cpeak} value of 135 dB, whereas only 10% exceeded the L_{Amax} limit of 115 dB. Hammers in the drop-forge division generated the noise impulses with peak levels, L_{Cpeak}, of about 20 dB higher than those measured in the punch-press division. The stamping pistol used in the machinery shop generated impulses of L_{Cpeak} level, exceeding 150 dB.
3. Short rise time is a significant factor increasing the risk of hearing damage. In a large class of observed impulses the rise time was shorter than 1 ms. The rise time is correlated with more easily measurable delay time of occurrence of the maximum peak level, or duration of the impulse. The rise time, however, has not yet been included among risk criteria in standards.

REFERENCES

1. Akay A. *A review of impact noise*. J Acoust Soc Am 1978; 64: 977–87.
2. Cohen A, Kylin B, La Benz P J. *Temporary threshold shift in hearing from exposure to combined impact/steady-state noise conditions.* J Acoust Soc Am 1966; 40: 1371–80.
3. Hamernik R P, Henderson D, Crossley J J, Salvi R J. *Interactions of continuous and impulsive noise: Audiometric and histological effects.* J Acoust Soc Am 1974; 55: 117–21.
4. Hamernik R P, Ahroon W A, Hsueh K D, Lei S-F. *Audiometric and histological differences between the effects of continuous and impulsive noise exposures.* J Acoust Soc Am 1993; 93: 2088–95.
5. Kuźniarz JJ, Swierczynski Z, Lipowczan A. *Impulse noise-induced hearing loss from industry*. Impulse Noise Symposium, Institute of Sound and Vibration Research, University of Southampton, England; 1971.
6. Passchier-Vermeer W. *Hearing loss due to continuous exposure to steady state, broadband noise*. J Acoust Soc Am 1974; 56: 1585–93.
7. Taylor W, Pearson J, Mair A. *Study of noise and hearing in jute weaving.* J Acoust Soc Am 1964; 38: 113–20.
8. Thiery L, Meyer-Bisch C. *Hearing loss due to partly impulsive industrial noise exposure at levels between 87 and 90 dB (A).* J Acoust Soc Am 1988; 84: 651–9.
9. Danielson R, Henderson D, Gratton M A, Bianchi L, Salvi R. *The importance of ”temporal pattern” in traumatic impulse noise.* J Acoust Soc Am 1991; 90: 209–18.
10. Henderson D, Subramaniam M, Gratton MA. *Impact noise: the importance of level, duration, and repetition rate.* J Acoust Soc Am 1991; 89: 1350–7.
11. Price GR. *Relative hazards of weapons impulse.* J Acoust Soc Am 1983; 73: 556–66.
12. Dunn DE, Davis RR, Merry CJ, Franks JR. *Hearing loss in the chinchilla from impact and continuous noise exposure.* J Acoust Soc Am 1991; 90: 1979–85.
13. Embleton T. *Report by the International Institute of Noise Control Engineering Working Party on ”Upper limits on noise in the workplace”.* Noise/News International 1994; 2 (4): 230–7.
14. Henderson D, Hamernik RP. *Impulse noise: critical review.* J Acoust Soc Am 1986; 80: 569–84.
15. Augustyńska D. *European legal regulations – protection from noise and vibrations.* Bezp Pr 1996; 10: 2–8 [in Polish].
16. *Directive of 17 June 1998 concerning maximum allowable concentrations and intensities of factors hazardous to health in the work environment issued by the Minister of Labour and Social Policy.* Official Journal of the Republic of Poland 1998; 79: 513 [in Polish].
17. PN-N-01307:1994. *Noise. Allowable noise levels in the working environment. Measurement requirements* [in Polish].
18. Hamernik R P, Hsueh K D. *Impulse noise: some definitions, physical acoustics and other considerations.* J Acoust Soc Am 1991; 90: 189–96.

19. ISO 10843:1997. *Acoustics: Methods for the description and physical measurement of single impulses or series of impulses.*
20. Bogusz B. *Errors of setup in direct methods of acoustic impulse measurements*. In: *Proceedings of the 63rd Open Seminar on Acoustics*, 1996; 113–8 [in Polish].
21. Sułkowski WJ. *Hearing impairment caused by impulse noise: survey in the drop forging industry.* International Symposium on Effects of Impulse Noise on Hearing, Malmö, 25–27 August. Scand Audiol Suppl 1980; 12: 307–17.
22. Taylor W, Lempert B, Pelmear P, Hemstock I, Kershaw J. *Noise levels and hearing thresholds in drop forging industry.* J Acoust Soc Am 1984; 76: 807–19.
23. Coles RRA, Garinther GR, Hodge DC, Rice CG. *Hazardous exposure to impulse noise.* J Acoust Soc Am 1968; 42: 336–43.
24. IEC 804:1985. *Integrating-averaging sound level meters,* (including Amendment 1:1989 and Amendment 2: 1993).

Received for publication: July 26, 2000
Approved for publication: April 30, 2001