ARCHIVES OF ACOUSTICS
6, 3, 239-252 (1981)

MODIFIED CORRECTION CURVES FOR NOISE HAZARD ESTIMATION

GABRIELA KERBER, JACEK KONIECZNY, ANNA PREIS

Department of Acoustics, Adam Mickiewicz University
(60-769 Poznań, ul. Matejki 48/49)

The harmful effect of noise at work stands is established by the ISO Standard of noise which gives the maximum permissible and the mean permissible values of the sound level expressed in dB (A).

Application of the correction curve *A* does not account for the effects of the temporary threshold shift (TTS) and the permanent threshold shift (PTS) in hearing which results from physiological aging of the hearing organ. Both effects influence the noise induced permanent hearing loss (NIPTS), depending only on the exposure to noise. In addition there is no correspondence between the noise spectrum corrected by the curve *A* and the distribution of hearing loss established on the basis of the audiogram of a person exposed to this noise.

The present proposal of modified correction curves for noise hazard estimation accounts for the effects mentioned above. Contrary to the previously used methods of noise spectrum correction (by the curves *A* and *D*), the distribution of the values of the sound level for individual frequencies, obtained by using the modified correction curves, accounts for the hearing loss induced by the noise. In particular, what is essential here is a good agreement between the position of the spectral maxima and the maximum hearing loss on the frequency scale.

The correction curves proposed were used in the estimation of the noise hazard at the work stand of a cutter-loader.

1. Introduction

The advisability of the correction curve *A* in noise hazard estimation has been recently more and more questioned [2].

If the curve *A* corrects well the noise spectrum in noise hazard estimation, the maximum values of the noise level in the corrected spectrum ought to correspond to the maximum hearing loss in the audiogram of a person exposed to this noise.

In practice this relation is not observed [2]. This results from the fact that the main purpose of the correction curve A in its original concept was to serve in the estimation of the noise level in the range of sound pressure levels (SPL) up to 55 dB. Therefore, its application to the correction of harmful noise spectra, i.e. the noise of SPL above 90 dB, does not permit correct evaluation of both the loudness of noise in question and its harmfulness.

2. Selected elements of the physiological principles of perception, used as the basis for the construction of the modified correction curves

The results of investigations of both the temporary (TTS) and the permanent threshold shift (PTS) can be useful in the estimation of noise hazard. Considering the effect of noise on creation of hearing loss apart from "the pathological" hearing loss" resulting from diseases, inflammations etc., the following assumptions should be taken into account.

(a) the sounds of such a low SPL that they do not cause the temporary threshold shift (TTS), do not lead to the permanent threshold shift in the form of occupational hearing loss — the effect of noise induced permanent threshold shift (NIPTS) [1, 6, 7];

(b) the values of hearing loss occurring in the audiogram of a person working under the conditions of noise hazard, are primarily affected by the following two factors: the character of the noise at a given work stand and the so called physiological hearing loss, i.e. the permanent threshold shift, depending on age [9, 12].

In [3] COHEN, ANTICAGLIA and CARPENTER gave three curves representing the temporary shift (TTS) resulting from the exposure to noise of the same SPL of 100 dB (A) but with different shape of the spectral envelope. The SPL of

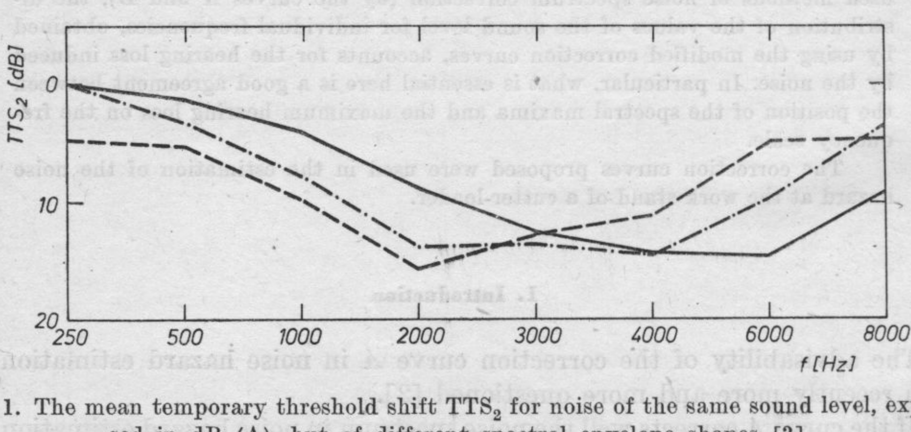

Fig. 1. The mean temporary threshold shift TTS_2 for noise of the same sound level, expressed in dB (A), but of different spectral envelope shapes [3]
"blue noise" — the inclination of the spectral envelope +6 dB/oct.; —·—·—·— "white noise" — the inclination of the spectral envelope 0 dB/oct.; — — — — — "pink noise" — the inclination of the spectral envelope — 6 dB/oct

100 dB (A) exposed for 30 minutes (based on the standard PN –70/B –02151) corresponds to the exposure to noise of less than 5 hours from the interval of the recommended mean permissible and the maximum permissible values. The above curves of the temporary threshold shift (TTS_2) were obtained 2 minutes after eliminating the source. It follows from analysis of Fig. 1 that the noise of the same SPL, expressed in dB (A), but of different spectral envelope shape, can cause temporay threshold shifts of different kinds, leading as a result to the permanent threshold shift. It is particulary interesting to note the shape of the curve (TTS_2) obtained for the case of white noise. It seems justified to define this curve as the basis of the estimation of the sensitivity of the hearing organ to the temporary threshold shift.

The permanent threshold shift (PTS) occurs not only as a result of harmful exposure of the organism to noise. Fig. 2 shows the curves of the audibility

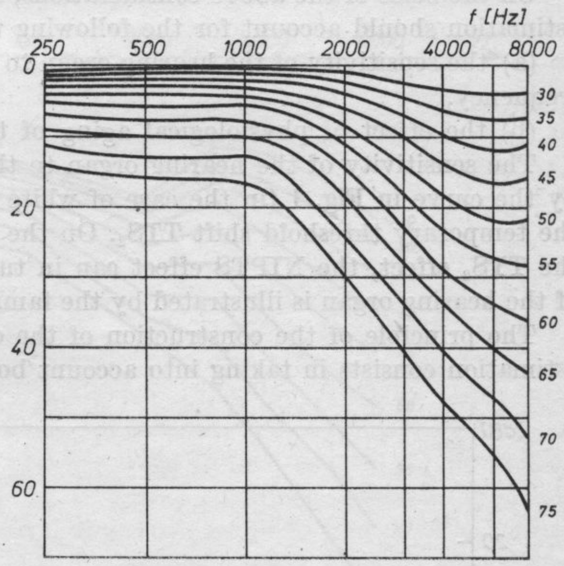

Fig. 2. The dependence of the permanent threshold shift on the frequency and the age of persons examined [3, 12]

threshold changing with age for persons who do not work in the conditions of noise hazard [9, 12]. In this case, therefore, the change in the threshold value of the SPL for components of different frequency is caused only by the physiological aging of the hearing organ. This fact seriously undermines the validity of the application of the curve A to the estimation of loudness, and to the estimation of its harmfulness. The concept of the curve of equal loudness is only valid in reference to the evaluation of the SPL of the individual spectral components by a person with normal hearing. In the case of noise loudness estimation by older persons or those with hearing loss (i.e. occupational hearing loss), the statement that the application of the correction curve A approximates the estimation of loudness, involves error. This results from the fact that there is a relation between the loudness of estimated sounds and the value of the hearing loss [4].

Another fact should be mentioned here, namely that the estimation of the loudness of sounds perceived including noise depends on the previous exposure of the organism to noise. This effect is well-known in the literature and is defined as "the temporary loudness shift" (TLS). The dependence of the TLS effect on the physical parameters of stimulation and the conditions of the exposure of the organism to noise is the same as that of TTS. This is additional argument for the necessity of including the TTS effect in constructing the correction curves.

3. The method for the construction of the correction curves for noise hazard estimation

On the basis of the above considerations, a correction curve for noise hazard estimation should account for the following two basic elements:

(a) the sensitivity of the hearing organ to the hearing loss, depending on the frequency,

(b) the effect of physiological aging of the hearing organ.

The sensitivity of the hearing organ to the hearing loss is best represented by the curve in Fig. 1 (in the case of white noise), since this curve represents the temporary threshold shift TTS_2. On the basis of knowledge of the value of the TTS_2 effect, the NIPTS effect can in turn be predicted [7, 8]. The aging of the hearing organ is illustrated by the family of curves in Fig. 2.

The principle of the construction of the correction curves for noise hazard estimation consists in taking into account both these curves. The shape of the

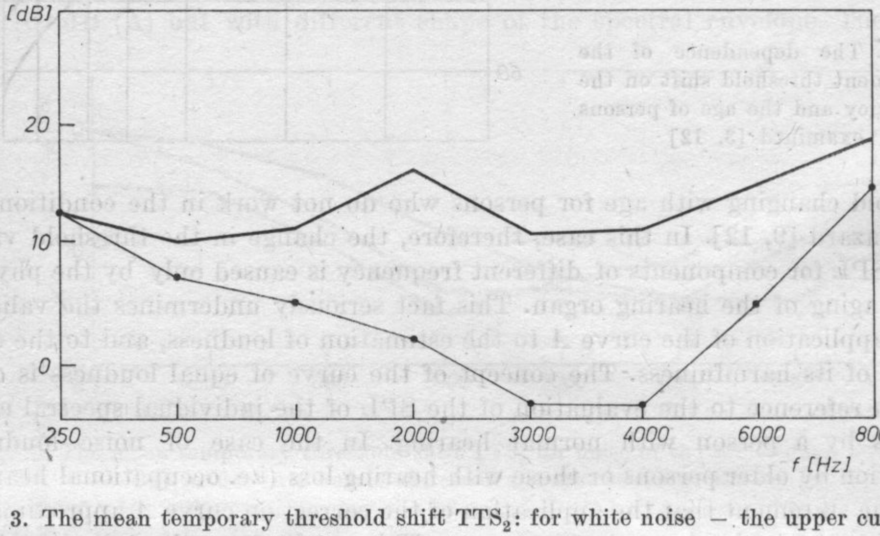

Fig. 3. The mean temporary threshold shift TTS_2: for white noise – the upper curve; the audibility threshold – the lower curve

correction curve is related to the shape of the TTS_2 curve for the white noise (100 dB (A)). Since this curve is calculated with reference to "the audiometric zero" (cf. Fig. 1), in order to use it for the correction of noise spectrum the threshold values of the SPL (Fig. 3) should be added to the values of the temporary threshold shift. Since the threshold values of the SPL for given frequencies vary depending on the age of persons examined (cf. Fig. 2), it seems correct to introduce a family of correction curves whose parameter is the age of a person exposed to noise. For healthy persons with normal hearing (under 30 years of age) the shape of the correction curve reflects exactly the shape of the curve for the temporary threshold shift shown in Fig. 3. For older persons the shape of the correction curve changes, since it is necessary to include the corrections resulting from physiological aging of the hearing organ (cf. Fig. 2). The correction curves thus obtained for different age groups are reversed with respect to the value of 0 dB and are shown in Fig. 4.

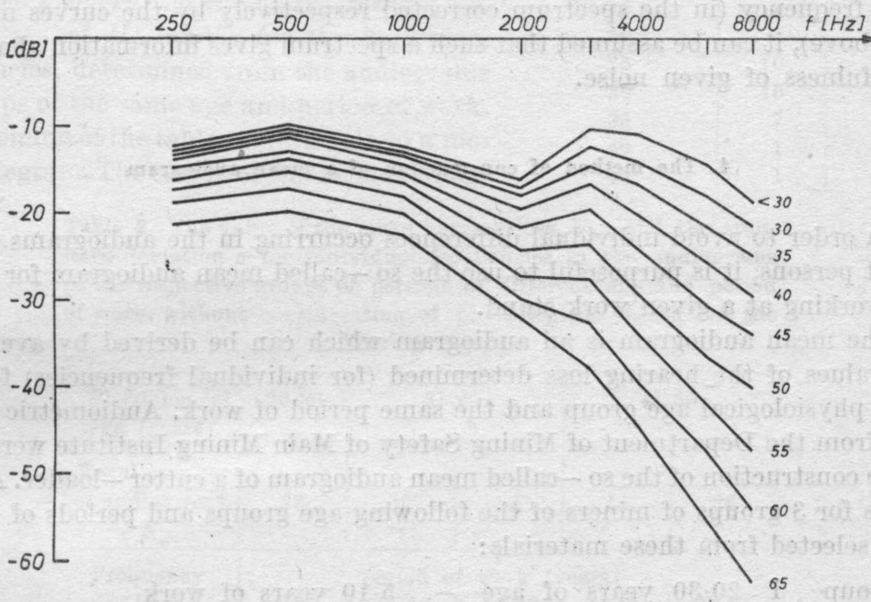

Fig. 4. The family of the correction curves proposed for noise hazard estimation. The parameter of these curves is the age of persons exposed to noise

For comparison, Fig. 5 shows the correction curve *A* and one of the correction curves proposed by the present authors (for persons under 30 years of age).

In order to estimate to what degree the correction curve proposed is better in the estimation of noise hazard than, for example, the correction curve *A*, it is necessary to compare the noise spectra corrected by these two curves with the noise induced permanent threshold shifts (NIPTS) occurring in the audiogram of a person exposed to this noise. If this comparison shows that, for exam-

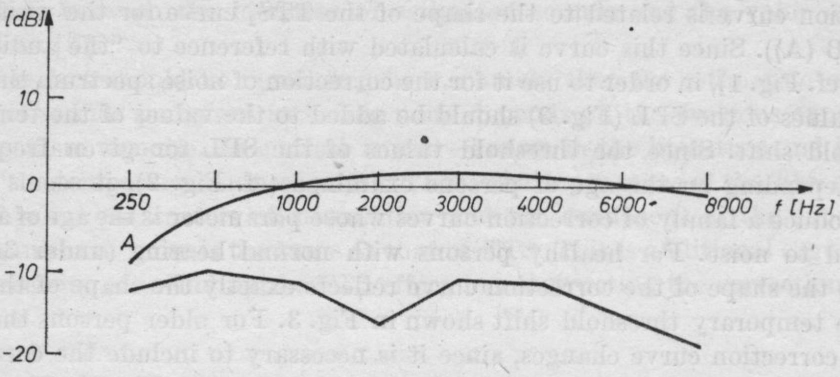

Fig. 5. The comparison of the curve A with the proposed correction curve

ple, the maximum hearing loss corresponds to the maximum noise levels at the same frequency (in the spectrum corrected respectively by the curves mentioned above), it can be assumed that such a spectrum gives information about the harmfulness of given noise.

4. The method of construction of a mean audiogram

In order to avoid individual differences occurring in the audiograms of different persons, it is purposeful to use the so-called mean audiogram for a person working at a given work stand.

The mean audiogram is an audiogram which can be derived by averaging the values of the hearing loss determined (for individual frequencies) for the same physiological age group and the same period of work. Audiometric materials from the Department of Mining Safety of Main Mining Institute were used in the construction of the so-called mean audiogram of a cutter-loader. Audiograms for 3 groups of miners of the following age groups and periods of works were selected from these materials:

group	I	20-30 years of age —	5-10 years of work
group	II	31-40 years of age —	11-15 years of work 16-20 years of work
group	III	41-50 years of age —	16-20 years of work 21-25 years of work

The values of the threshold shift at the following 5 selected frequencies: 500, 1000, 2000, 4000 and 6000 Hz were taken into consideration. The values of the threshold shift for the above frequencies are assigned for a given group of miners of the same age, also with consideration of the period of work. As an example, Table 1 shows the data for a frequency of 500 Hz and group III for a cutter-loader's stand. On the basis of the distribution of the value of the hearing loss for the individual groups of different periods of work the following data were calculated:

(a) the mean statistical threshold shift, i.e. the mean value of the hearing loss U_{av} for each group of persons with the same period of work, at a given frequency, obtained from audiograms,

$$U_{av} = \frac{\sum_{k=1}^{k=n} m_k x_k}{N},$$

where x is the mean value of the kth interval of the individual hearing loss, m is the number of persons with the hearing losses in the given interval k, and N is the total number of persons in a given group.

(b) the value of the standard deviation σ.

Table 2 shows the calculated results, i.e. the values of U_{av} and σ for the individual frequencies, determined from the audiograms of groups of the same age and period of work. Each column of the table corresponds to a mean audiogram. The curves of the mean audiog-

Table 1. The number of the hearing loss in the individual intervals k at a frequency of 500 Hz for a group of miners from 41 to 50 years of age working at a cutter-loader's stand

The value of hearing loss [dB]	Period of work [years] 16-20	21-25
5	1	
10	2	2
15	2	2
20	5	1
25	10	6
30	15	6
35	7	9
40	1	
45	1	

Table 2. The value of the mean hearing loss U_{av} and the standard deviation σ for individual frequencies in the audiograms of the respective groups of persons of different age and period of work, without consideration of physiological "aging" of the hearing organ

Physiological age [years]	20-30	31-40		41-50	
Total number of audiograms N	26	40	94	44	26
Frequency [Hz]	period of work [years] 5-10	11-15	16-20	16-20	21-25
500 U_{av}	27.31	25.75	26.54	26.93	27.50
σ	9.01	7.23	8.72	7.84	7.74
1000 U_{av}	17.11	16.62	17.34	18.52	18.65
σ	6.67	5.74	14.07	6.05	5.64
2000 U_{av}	16.54	17.00	17.97	21.36	17.11
σ	7.03	6.20	12.76	11.69	10.81
4000 U_{av}	18.84	20.00	26.65	30.79	36.90
σ	9.76	12.44	13.27	13.77	13.66
6000 U_{av}	20.00	25.87	28.67	30.34	35.00
σ	9.60	9.07	13.70	12.10	14.27

rams for the cutter–loader's stand are shown in Fig. 6. The average values of the hearing loss shown in Table 2 and Fig. 6 include both the noise induced hearing loss and the physiological permanent threshold shift related to the aging of the hearing organ.

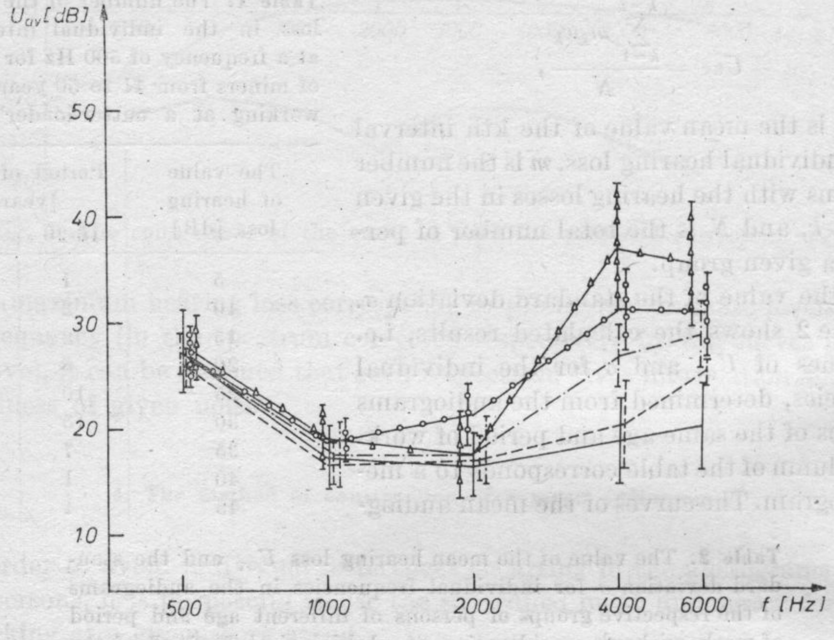

Fig. 6. The mean audiograms of cutter-loaders without consideration of the corrections concerning physiological "aging" of the hearing organ

—— 20-30 years of age, 5-10 years of work; – – – 31-40 years of age, 11-15 years of work; –.–.–. 31-40 years of age, 16-20 years of work; –o–o– 41-50 years of age, 16-20 years of work; –△–△–△– 41-50 years of age, 21-25 years of work

The confidence intervals were determined for the mean values of the hearing loss in the population for each frequency at a confidence level of 0.95. It was assumed in the determination of the confidence intervals in the case when the number of samples was $n > 30$ that the distribution of the mean of the sample was normal. For the group of 20-30 years of age and 41-50 years of age (the group of 21-25 years of work) the number of sample was $n = 26$. In these cases the confidence intervals were determined under the assumption that the sample distribution was a t-distribution [3]. The value of the confidence intervals are plotted in the diagram in Fig. 6. The values of these intervals are on average $\pm$ 3 dB. The minimum confidence interval is $\pm$ 1 dB, while the maximum one is $\pm$ 6 dB.

In order to avoid different values of the physiological permanent threshold shift for different ages the values shown in Table 2 should be corrected in terms of the curves for physiological aging of the hearing organ [9, 12]. Table 3 gives

Table 3. The value of the mean hearing loss U_{av} for individual frequencies in the audiograms for the respective groups of persons of different age and period of work, with consideration of the corrections for physiological aging of the hearing organ

Physiological aging [years]	20-30	31-40		40-50	
Total number of audiograms N	26	40	94	44	26
Frequency [Hz]	period of work [years]				
	5-10	11-15	16-20	16-20	21-25
500 U_{av}	27.31	24.75	25.54	23.33	24.50
1000 U_{av}	17.11	15.62	16.34	15.52	15.65
2000 U_{av}	16.54	15.00	15.97	15.86	11.61
4000 U_{av}	18.84	14.50	21.15	17.79	23.90
6000 U_{av}	20.00	18.87	21.67	14.34	19.00

the hearing loss corrected in terms of physiological age. The corresponding audiograms are shown in Fig. 7. The audiograms corrected in such a way permit comparison of the value of the hearing loss for persons of different physiological age.

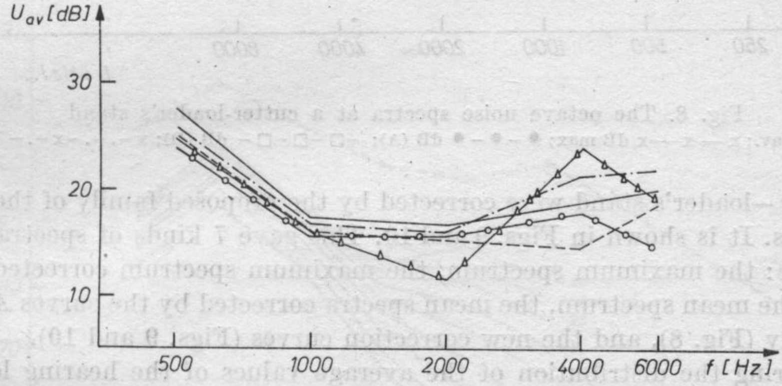

Fig. 7. The mean audiograms of cutter-loaders with consideration of physiological "aging" of the hearing organ
—— 20-30 years of age, 5-10 years of work; — — — 31-40 years of age, 11-15 years of work; —.—.— 31-40 years of age, 16-20 years of work; —o—o— 41-50 years of age, 16-20 years of work; — △ — △ — △ — 41-50 years of age, 21-25 years of work

5. The characteristic of noise at a given work stand

Using a 3347 Brüel and Kjaer Real—Time analyser, the noise at a cutter—loader's stand was analysed four times in order to give:

– the mean spectrum for the time period of 15 s,
– the maximum spectrum,
– the mean spectrum corrected by the curve A,
– the mean spectrum corrected by the curve D.

The above spectra refer to the form of octave spectra (Fig. 8). In addition the maximum spectrum obtained in this way was corrected by the curve A. It is shown in Fig. 8. The mean spectrum and the maximum spectrum of noise

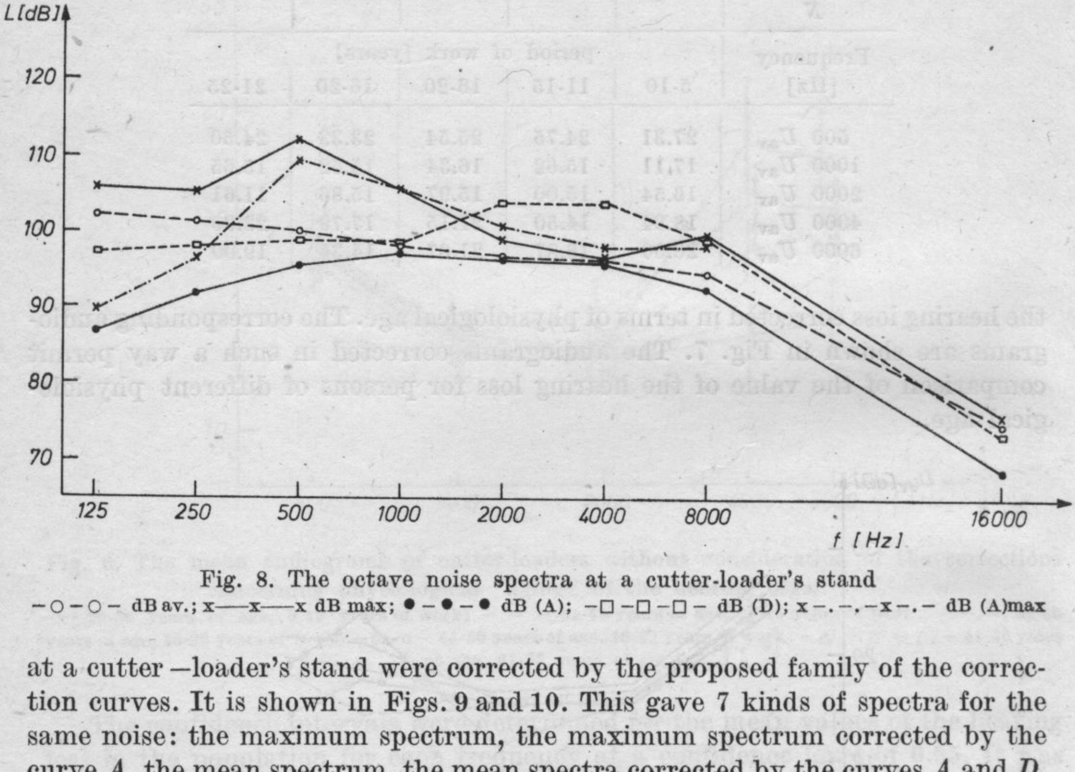

Fig. 8. The octave noise spectra at a cutter-loader's stand
–○–○– dB av.; x——x——x dB max; ● – ● – ● dB (A); –□–□–□– dB (D); x–.–.–x–.– dB (A)max

at a cutter –loader's stand were corrected by the proposed family of the correction curves. It is shown in Figs. 9 and 10. This gave 7 kinds of spectra for the same noise: the maximum spectrum, the maximum spectrum corrected by the curve A, the mean spectrum, the mean spectra corrected by the curves A and D, respectively (Fig. 8), and the new correction curves (Figs. 9 and 10).

Comparing the distribution of the average values of the hearing loss with the distribution of the values of the noise levels in the spectra corrected (7 forms of spectrum) we can notice some relations between the corresponding maximum and minimum values (i.e. the hearing loss and the noise levels) in these two diagrams.

6. Results

The following conclusions can be drawn from the comparison of the distribution of the average values of the hearing loss with the distribution of the values of the noise level in the noise spectra corrected:

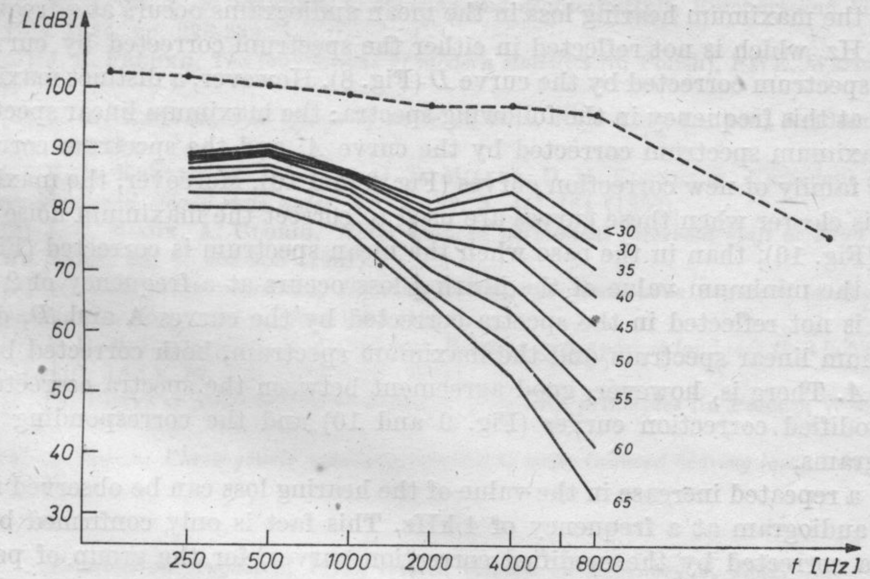

Fig. 9. The dashed curve – the mean octave of noise spectrum at a cutter-loader's stand, the continuous curves – the same spectrum corrected by the modified correction curves for different age

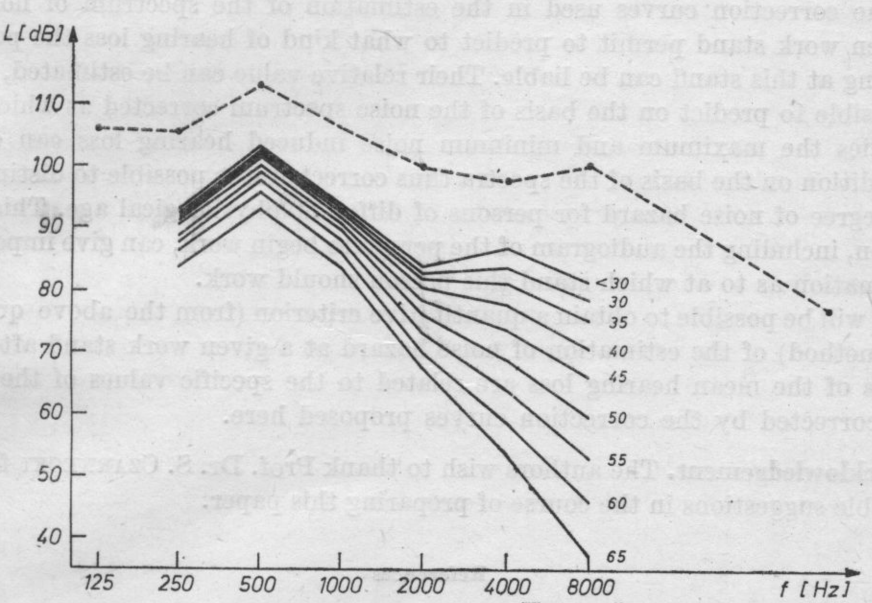

Fig. 10. The dashed curve – the maximum octave noise spectrum at a cutter-loader's stand, the continuous curves – the same spectrum corrected by the modified correction curves for different age

— the maximum hearing loss in the mean audiograms occurs at a frequency of 500 Hz, which is not reflected in either the spectrum corrected by curve *A*, or the spectrum corrected by the curve *D* (Fig. 8). However, a distinct maximum occurs at this frequency in the following spectra: the maximum linear spectrum, the maximum spectrum corrected by the curve *A*, and the spectrum corrected by the family of new correction curves (Fig. 9 and 10). Moreover, the maximum value is clearer when these curves are used to correct the maximum noise spectrum (Fig. 10), than in the case when the mean spectrum is corrected (Fig. 9).

— the minimum value of the hearing loss occurs at a frequency of 2 kHz, which is not reflected in the spectra corrected by the curves A and *D*, or the maximum linear spectrum and the maximum spectrum, both corrected by the curve *A*. There is, however, good agreement between the spectra corrected by the modified correction curves (Fig. 9 and 10) and the corresponding mean audiograms,

— a repeated increase in the value of the hearing loss can be observed in the mean audiogram at a frequency of 4 kHz. This fact is only confirmed by the spectra corrected by the modified correction curves, for the group of persons under 40 years of age. For persons above this age the maximum vanishes in the noise spectra corrected.

7. Gêneral conclusions

The correction curves used in the estimation of the spectrum of noise at a given work stand permit to predict to what kind of hearing loss the persons working at this stand can be liable. Their relative value can be estimated, i.e. it is possible to predict on the basis of the noise spectrum corrected at which frequencies the maximum and minimum noise induced hearing loss can occur. In addition on the basis of the spectra thus corrected it is possible to distinguish the degree of noise hazard for persons of different physiological age. This estimation, including the audiogram of the person to begin work, can give important information as to at which stand this person should work.

It will be possible to obtain a quantitative criterion (from the above qualitative method) of the estimation of noise hazard at a given work stand after the values of the mean hearing loss are related to the specific values of the noise evel corrected by the correction curves proposed here.

Acklowledgement. The authors wish to thank Prof. Dr. S. Czarnecki for his valuable suggestions in the course of preparing this paper.

References

[1] J. H. Botsford, *Theory of temporary threshold shift*, JASA, 49/2, 2, 440-446 (1971).

[2] P. V. Brüel, *Noise — Do we measure it correctly*, Naerum-Denmark 1975.

[3] A. Cohen, J. R. Anticaglia, P. L. Carpenter, *Temporary shift in hearing from exposure to different noise spectra at equal dB (A) level*, JASA, 51, 2, 503-507 (1972).

[4] H. Davis, S. R. Silverman, *Hearing and deafness*, Holt, Rinehart and Winstron, New York 1974, pp. 226-232.

[5] J. E. Freund, *The foundations of modern statistics* (in Polish), PWE, Warsaw 1971, p. 217.

[6] K. D. Kryter, *The effects of noise on man*, New York-London, Academic Press 1970, pp. 140-144.

[7] K. D. Kryter, W. D. Ward, J. D. Miller, D. M. Eldredge, *Hazardous exposure to intermittent and steady-state noise*, JASA, **39**, 3, 451-464 (1966).

[8] J. C. Nixon, A. Glorig, *Noise induced permanent threshold shift at 2000 Hz and 4000 Hz*, JASA, **33**, 7, 904-908 (1961).

[9] W. Passchier-Vermeer, *Hearing loss due to continuous exposure to steady-state broad-band noise*, JASA, **56**, 5, 1585-1593 (1974).

[10] F. D. McPherson, C. V. Anderson, *Relation of temporary loudness shift to temporary threshold shift*, JASA, **49**, 4/2, 1195-1202 (1971).

[11] Cz. Puzyna, *Noise control in industry – general principles* (in Polish), WNT, Warsaw 1974.

[12] A. Spoor, *Phresbycusis values in relation to noise induced hearing loss*, Int. Audiol., **6**, 52 (1967).

Received on August 1, 1979; revised version on February 4, 1981.