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# THE STAND FOR THE INVESTIGATION OF THE AUDITORY DANGER SIGNALS PERCEPTION — PRELIMINARY INVESTIGATION

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This article presents a stand for the investigation of the perception of auditory danger signals which are masked by simulating industrial noise. The test stand enables the generation of signals with specified parameters and the control of the course of an experiment. It also enables the processing of measuring data obtained. In the latter part of the paper, psychoacoustic experiments are described. Some results of preliminary measurements are discussed.

## 1. Introduction

A number of industrial accidents have been caused by the lack of a danger signal or its wrong interpretation due to its form. Taking into account the importance of this problem, appropriate standardizing [1, 2] and research work [7] has been undertaken. Within the research project No. 7S 10103404 "The method of design and generation of the danger signals used during the operation of machines and devices" which has been realized in the Central Institute for Labour Protection, there have been undertaken works aimed at the determination of the criteria of selection of auditory danger signals in dependence on the background noise and the psychoacoustic properties of the human being.

The test stand, described in the first part of this paper, consists of an instrument by that the planned goal may be attained by performing experiments connected with the auditory signal perception in the presence of the background noise.

Further in this paper two psychoacoustic experiments on the detection of warming signals in the presence of interfering noise are presented. The results of those preliminary experiments constitute a practical test of the created stand. The experiments have been aimed at selecting temporal and spectral structures of warning signals from the group of elementary signals, e.g. pure tone pulses or frequency- and amplitude-modulated tone pulsees of various temporal patterns.

## 2. Test stand

The basic foundation of the test stand project was the creation of conditions of the acoustic warning signal perception equal to those we are dealing at real work stands. The only difference between them and the real working conditions was that we could control all the factors influencing the perception's results. On the one hand, it means excluding of the exterior interfering signals (adequate test room) while on the other, it obliges us to generate all the signals which are taking part in the process of detection of the acoustic warning signals.

The basic elements of the stand are: a test room, two independent sonorizing electroacoustic channels, software used for: generation of the testing signals these signals are presented to the subject who has to signal their perception, control of the measurements course and generation of danger signals.

### *2.1. Instrumentation*

During the experiment the subject is positioned inside the test room which fulfils the requirements of the standard [4] concerning the measurement of the acoustical parameters of the hearing protectors by a subtective method.

In order to sonorize the room interior, two independent electroacoustical channels have been used. They consisted of an IBM compatible Personal Computer with a sound card, a power amplifier and a set of loudspeakers. One channel is the generation of the test (danger) signals and the second one for the generation of masking signals (simulating industrial noise) of specified amplitude and frequency parameters. By using two computers as a source of both the test and masking signals. It is also possible to perform the experiments together with a simple computer game which draws and distracts the subject's attention. This allows the experiment conditions to be very similar to the real ones existing at work. The scheme of instrumentation (Fig. 1) shows the architecture of the measurement system and the plan of the test room.

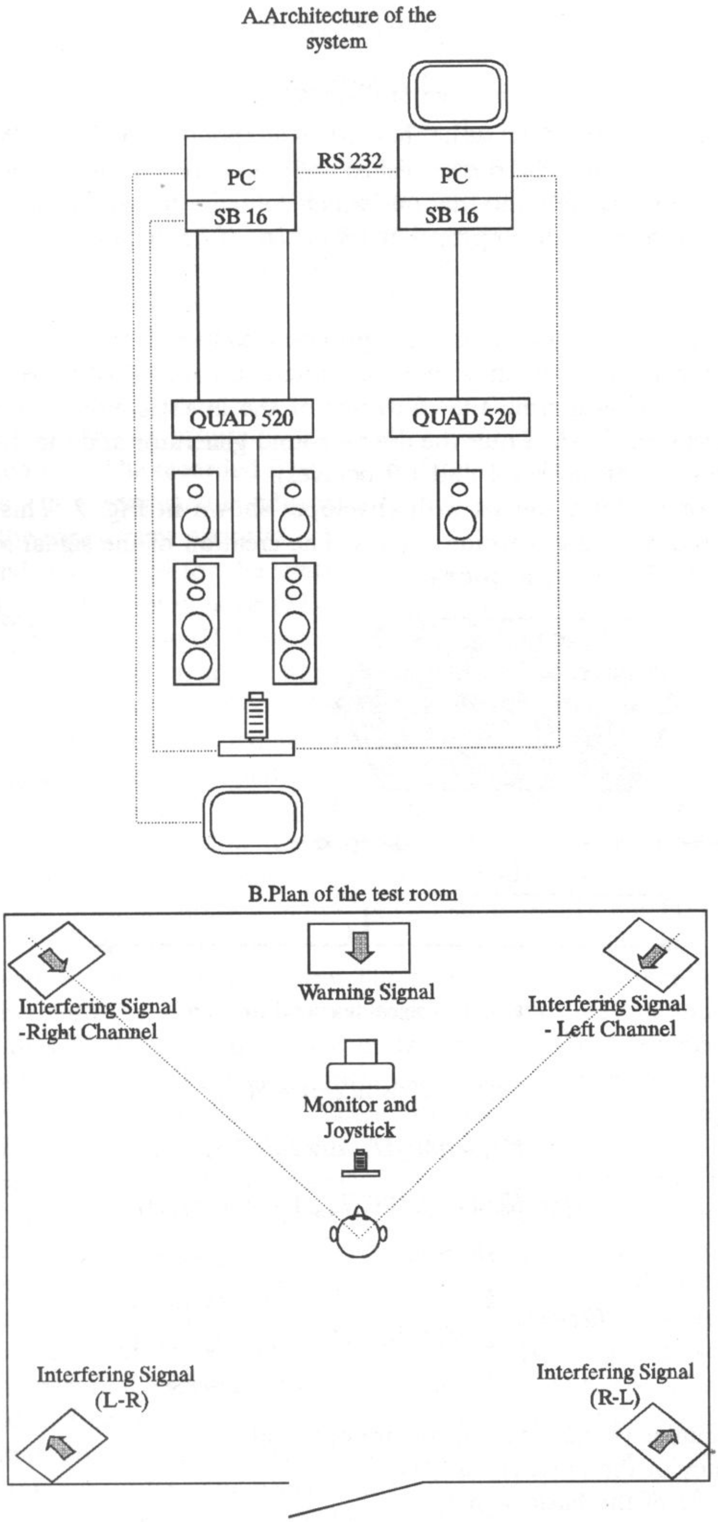


Fig. 1. Hardware part of the stand. Architecture of the measurement system and plan of the test room.

### 2.2. Software

The software of the test stand has been adapted to work in Windows 3.1. environment. There may be distinguished the software for the generation of the testing and masking signals and that one which controls the experiment course. They act together and prepare the appropriate sequences of files comprising the acoustical signals.

*2.2.1. Signal generation programs.* The program creates a set of files with sound information recorded by the most popular sound standard (WAV) in the Windows 3.1 environment. Considering the character of the investigation, two independent programs have been worked out: the digital sound generator and the digital filter of the WAV files (filtration in 1/1 and 1/3 octaves).

The first one creates signals with envelopes shown in Fig. 2. This part of the software is used to create warning signals. The creation of the signal $x(t)$ proceeds according to the following relations:

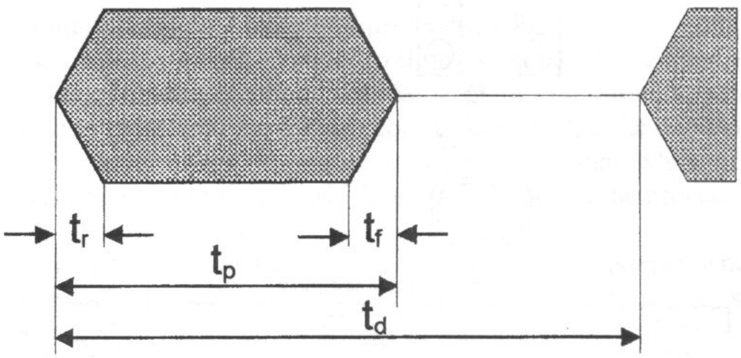


Fig. 2. Test signal temporal structure.

$$x(t)=A(t)\sin(2\pi ft+F(t)), \tag{2.1}$$

$$F(t)=0.01fG_{AF}\sin(2\pi f_F t)/f_F, \tag{2.2}$$

$$A(t)=K(t)(1-0.005G_{AA}(1+\sin(2\pi f_A t))), \tag{2.3}$$

$$K(t)=\begin{cases} Ae^{-\pi k_r(t_r-t)^2} & 0\leqslant t<t_r \\ A & t_r\leqslant t\leqslant t_{s1}-t_d \\ Ae^{-\pi k_d(t-t_{s1}-t_d)^2} & t_{s1}-t_d<t<t_{s1} \\ 0 & t_{s1}\leqslant t\leqslant t_s \end{cases} \tag{2.4}$$

where the parameters indicated below are optional:
$f$ — frequency of the basic signal [Hz],
$A$ — amplitude of the basic signal,

$G_{AF}$ — depth of frequency modulation of the basic signal [%],
$f_F$ — frequency of the signal which modulates the basic signal frequency [Hz],
$G_{AA}$ — depth of amplitude modulation of the basic signal [%],
$f_A$ — frequency of amplitude modulation of the basic signal [Hz],
$k_r$ — factor forming a rise of the basic signal envelope,
$k_d$ — factor forming a fall of the basic signal envelope,
$t_r$ — rise time of the basic signal [s],
$t_d$ — fall time of the basic signal [s],
$t_{s1}$ — basic signal duration [s],
$t_s$ — total duration of the signal recorded in the digital form [s].

A special function in the program can create a sequency of files in which danger signals are recorded. The recorded files have different levels of the samples. They can be reproduced in a sequence conditioned by a selected algorithm applied in the program of the experiment operation.

The second one is used for the synthesis of signals obtained by means of digital filtration of the white or pink noise (33 parallel third-octave band Butteworth's filters of infinite impulse response (IIR) were used). This program filters one WAV file to another one. One of the particular implementation is a situation when these filters synthesize the interfering signals corresponding to the standard spectrum (one of five so called noise classes) which are determined by the Polish Standard [5]. This part of the software creates masking signals.

Due to the psychoacoustic investigations concerning the project, the software has been extended. A new function (described in details in section 2.2.3), which is generating warning signals based on the recorded WAV file (containing real industrial noises) or direct noise monitoring (via sound card), has been added.

*2.2.2. Experiment operation programs.* The programs of experiment operation act closely together with the above-mentioned programs of generation and filtration of digital signal files. From the point of view of its operation, the experiment consists of two parts both using two different algorithms of the experiment operation.

In the first part the threshold of danger signals hearing is investigated in the presence of the masking signals. In this method (method of tracking [3] — Fig. 3) the subject indicates the presence or absence of the signal by pressing or releasing a button (as in automatic audiometry). By pressing the button the sound pressure level decreases and by releasing it, the direction of the level changes is opposite (i.e. it forces a SPL's increase). It is possible to adjust the rate of the sound level changes and control the accuracy of subject's reaction tracing. During the experiment extreme sound pressure level values causing predetermined subjects reactions are recorded.

The second part of the software enables the realization of the so called algorithms of the method of free response (MFR). It is based on a continuous submission of $N$ presentations divided into 4 periods to the subject (Fig. 4). Test signals are presented in random order. The hearing threshold level is statistically estimated as a level with 75% of observations provided by the subject.

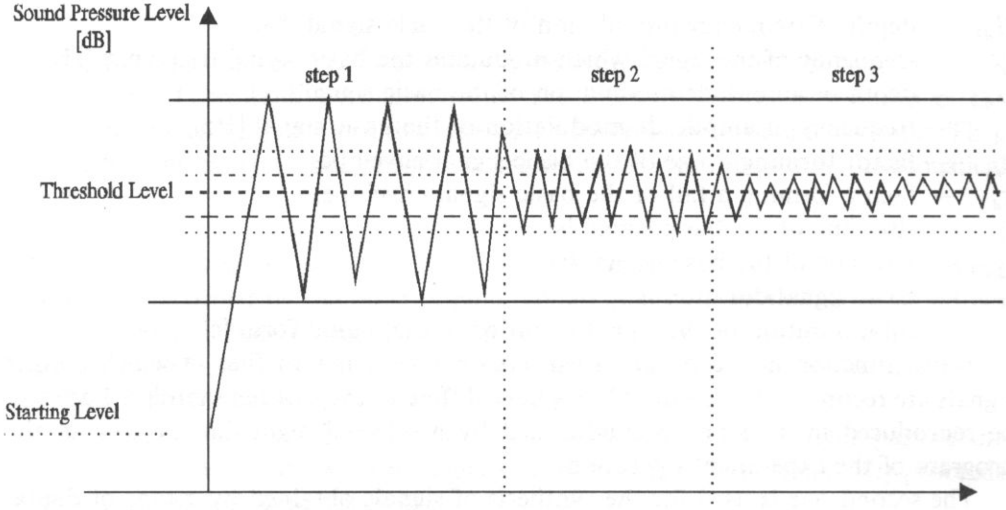


Fig. 3. Tracking of the threshold level according to the algorithm implemented in the presented software.

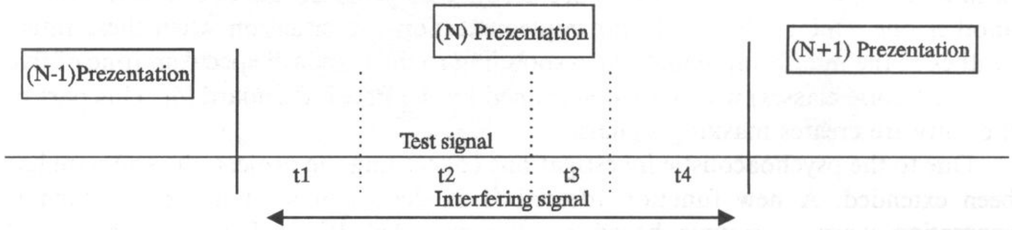


Fig. 4. A description of the MFR algorithm.

A suitable test signal is played only during one of the periods, while the interfering signal occurs during all the time of presentation. In this method, the subject also indicates the presence or absence of the signal by pressing or releasing a button, but his does not change the sequence prepared previously. For each successive presentation a set of 4 numbers is obtained. They show how many times a subject signalled (by means of the button) the test signal perception. A sequence of presentations is selected in a random manner.

In the first part of the experiment the program generates the danger signals according to the subjects reaction, generates the masking signal, controls the results by monitoring the subject's reaction state. It also performs the preliminary statistical processing and sends the collected data in a form which makes the analysis of them possible by means of other programs working in the Window 3.1 environment.

In the second part of the experiment the program generates a sequence of random successive presentations, generates the testing and interfering signals and controls the duration of the appropriate periods. The program enables the monitoring and recording of the subject's behaviour during the experiment and provides information about the interchange between the signal channels.

Optionally, a function concerning the absorbing of the subject's attention, i.e. the simulation of a situation in which a subject is engaged in the realization of activizies distracting its attention during the perception of the danger signal, can be switched on.

*2.2.3. Warning signal generation program.* The task of the warning signal generation program is to simulate the work of an adaptable signalling apparatus. Its activity is optimized in order to guarantee the best perception conditions for the subject (worker at a certain work stand). Because the program does not work in a real time, it can be used only at a work stand at which the creation of stationary perception conditions is possible. The simulation of one working cycle (steps' sequence) of the adaptable signalling apparatus is presented in Fig. 5.

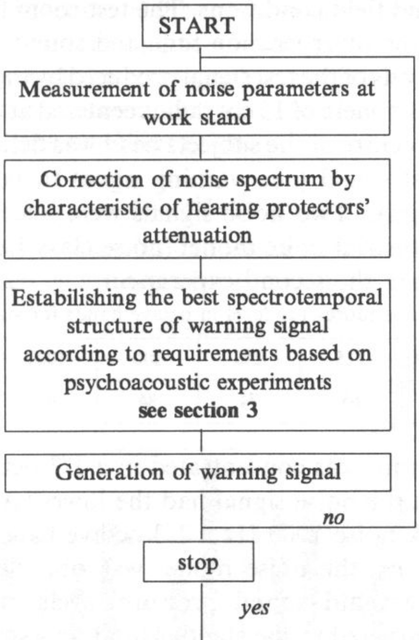


Fig. 5. Algorithm of the adaptable signalling apparatus work.

The temporal structure of the generated signal is presented in Fig. 2. Depending on the noise parameters, the values of the basic frequency (*f*) and amplitude (*A*) are subjected to modification. The usage of a signal with determined duty cycle enables the measurements of noise parameters when the warning signal is inaudible.

## 3. Preliminary investigations

The first two experiments [8] consisted in the establishing the influence of the temporal structure (in the first case) and of the spectral structure (in the second case) on the hearing treshold level of the examined group. A tracking method, used in these experiments, was applied to various signal structures in the presence of noise signals.

### *3.1. Experimental methods*

**Subjects.** Five subjects (AP, BM, EC, MM, MO) participated in the first experiment and seven subjects (AP, BM, EC, MM, TR, WZ, MO) in the second one. All they had a hearing loss of less than 15 dB in the frequency range 125 – 8000 Hz and participated voluntarily in the experiments and were paid for their services.

**Measurement conditions.** Experiments were performed in a test room normally used for measurements of the hearing protectors attenuation. Noise signals were presented in diffuse sound field conditions. The test room fulfills the requirements of ISO 4869 [4] regarding the reverberation time and sound field diffuseness.

The sound pressure levels of the test signal produced by the pair of loudspeakers (JBL 4208) at positions within a sphere of 15 cm radius centered at the reference point differed by less than $\pm 3$ dB. The centre of the subjects head was defined as the reference point.

**Test signals.** The test signal (i.e. warning signal to be detected) was presented together with a noise signal. Two noise signals were selected : a noise signal based upon a standardized industrial noise model (noise class 1 of the Polish standard [5], Table 1) and pink noise in the second experiment.

**Table 1.** A-weigthed soundpressure level in octave bands for standardized noise signal

| Octave band center frequency, Hz | 125 | 250 | 500 | 1000 | 2000 | 4000 | 8000 |
|---|---|---|---|---|---|---|---|
| A-weighted SPL, dB | 65 | 74 | 84 | 92 | 96 | 97 | 93 |

The test signal spectrum was concentrated in a 1/3 octave band (from the range 315 – 2500 Hz) at which the noise signal had the lowest A-weighted sound pressure level. In the case of pink noise 1000 Hz a 1/3 octave band was selected.

In the first experiment, the noise model was obtained from the octave band filtered pink noise. A-weightd sound pressure levels in the octave bands were proportionally lower compared to the standardized nois signal with relative relations between octave band levels being preserved. Therefore, the A-weighted sound pressure level of the noise signal was 90 dB.

Nine test signals were presented. Each signal consisted of 1000 Hz tone pulses. The repetition frequencies were 0.2, 1 and 5 Hz, and the duty cycles 25, 50 and 75%. The rise/fall time was 5 ms for pulses of a 5 Hz repetition frequency and 25 ms for all other cases.

In the second experiment, pink noise was used as the background noise model. The A-weighted sound pressure level was 72 dB. Five test signals were presented, each having a duration time of 750 ms, repetition frequency 1 Hz, rise/fall time 25 ms. The following signal structure were used:

— 1000 Hz tone pulse (SINE);

— amplitude modulated sine wave, modulation frequency 10 Hz (AM 10), 100% modulation depth;

— amplitude modulated sine wave, modulation frequency 100 Hz (AM 100), 100% modulation depth;

— frequency modulated sine wave, modulation frequency 10 Hz, frequency deviation 90 Hz (FM 10);

— linear sine sweep in the range 900 – 1100 Hz (SWEEP).

All the singals were generated digitally. The signal decrement/increment speed was set at 2.5 dB/s, typical to audiometric measurements [3].

**Procedure.** Before the test, subjects were familiarized with the test signals. Subjects were instructed to press the button as soon as the test signal is heard and release it immediately once the signal is no longer heard, according to ISO 8253-1 [3]. The test signals were presented at random order in a computer-controlled procedure. Each trial consisted of two phases. The duration time of the first phase depended on the subject's reaction. After a direction of the signal level increment/increment had been switched four times; the second phase allowed during that all levels were recorded. An average sound pressure level of the test signal was taken as the result. Each subject completed five trials for each measurement point. In the first experient subjects were having hearing protectors (Bilsom Viking) on.

### *3.2. Results*

The results of the detection thresholds measurements are shown in Figs. 6 – 10. The thresholds are expressed as averages for each subject and for the group as well.

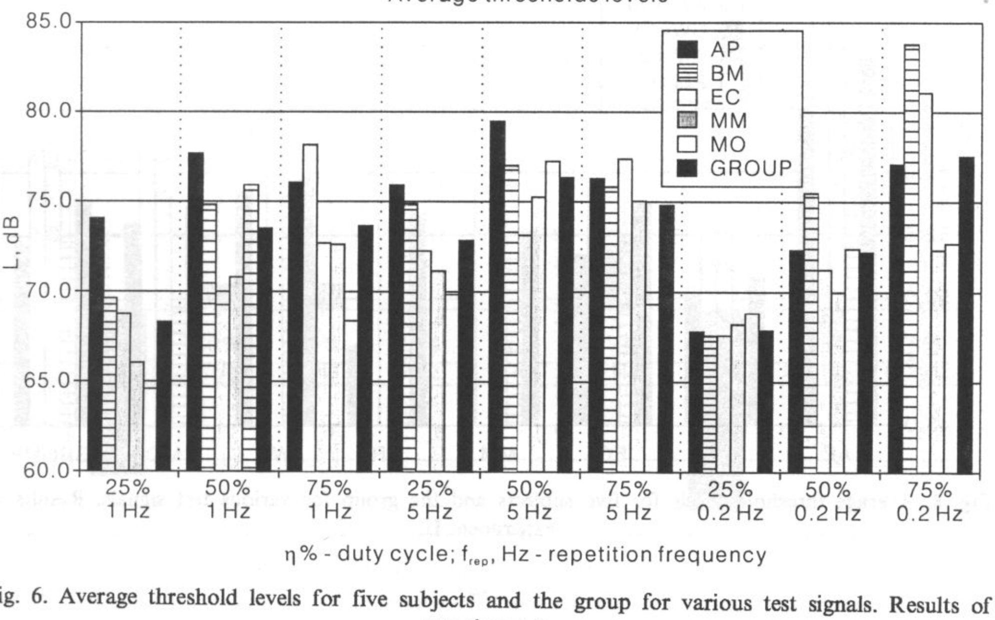


Fig. 6. Average threshold levels for five subjects and the group for various test signals. Results of experiment I.

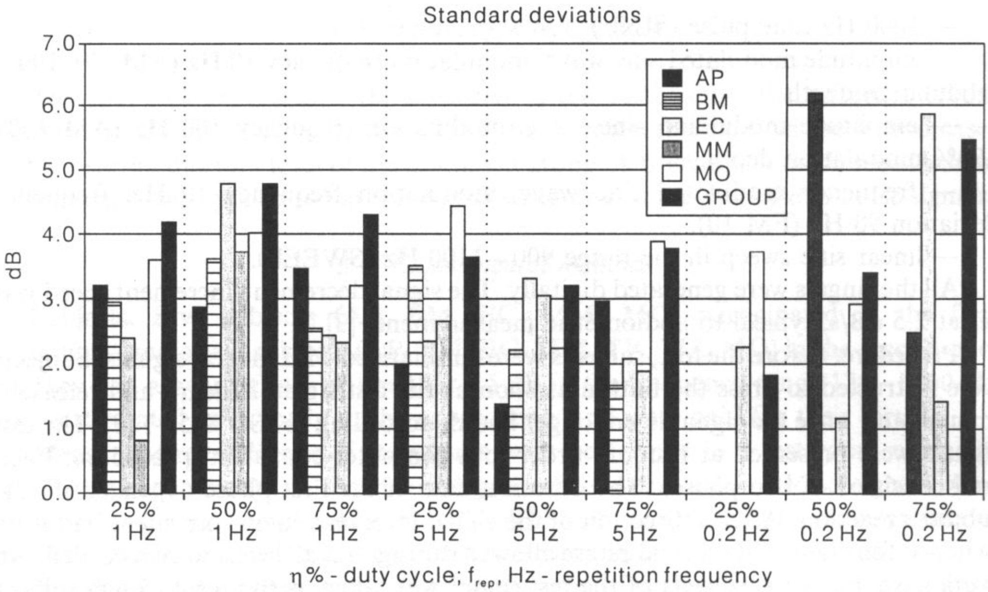


**Fig. 7. Standard deviation of thereshold levels of each subject and the group for various test signals. Results of experiment I.**

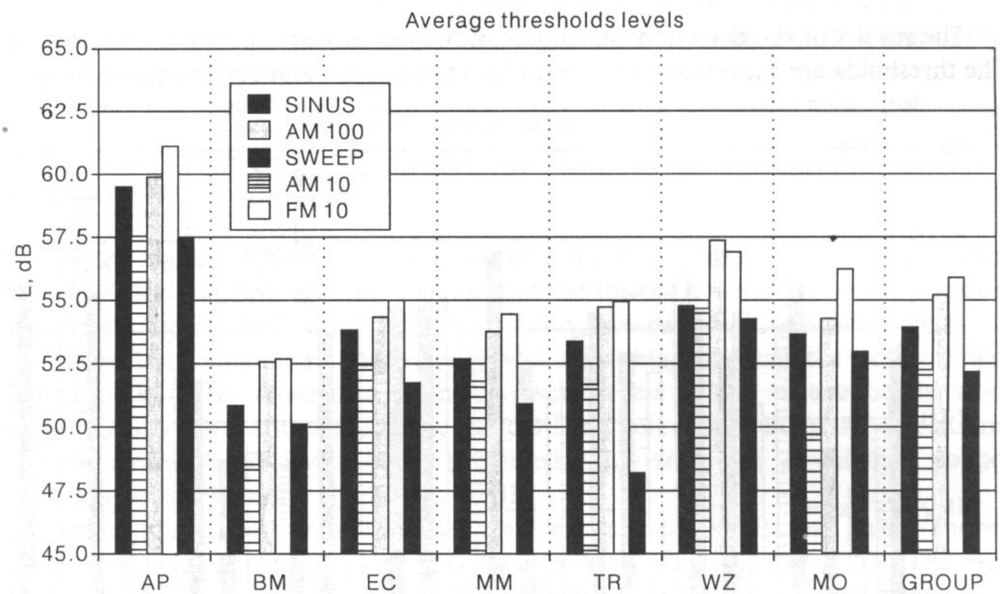


Fig. 8. Average threshold levels for five subjects and the group for various test signals. Results of experiment II.

These results are presented in Figs. 6 and 8. Standard deviation are plotted in Fig. 7 and 9. In order to eliminate the influence of the differences in the detection levels for different subjects, the final results were normalized by subtracting the average of all the data for each subject from partial results. The normalized detection thresholds are shown in Fig. 10.

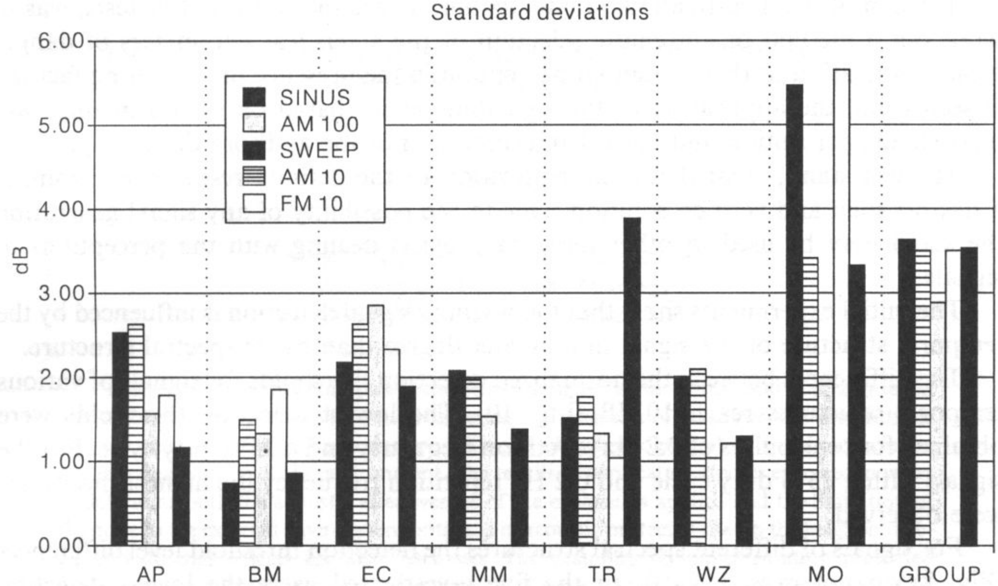


**Fig. 9. Standard deviation of thereshold levels of each subject and the group for various test signals. Results of experiment II.**

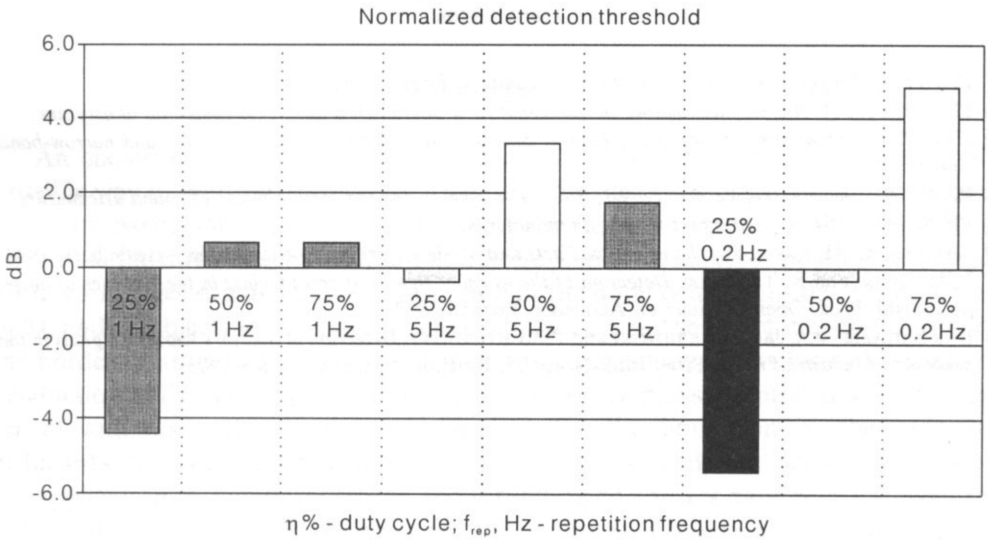


**Fig. 10. Normalized detection threshold levels for various test signals. Results of experiment I.**

## 4. Conclusions

The presented test stand enables to investigate the perception of auditory signals (of different time and frequency parameters) which occur in the presence of continuous noise of a freely formed audible spectrum (in the third-octave bands).

The aim of the investigation, conducted on the ground of subjective tests, was to work out a method of automatic selection of the acoustical parameters of danger signals in relation to their optimum perception in the presence of interfering factors. It seems that the application of the signalling device based on such a method will increase the perception and correct interpretation of the auditory danger signals.

The test stand, created for the realization of the definite research program, is a flexible solid and verified solution. Due to the possibility of any signal generation the stand may be used in other research projects dealing with the perceptions of signals.

The initial experiments show that the warning signal detection is influenced by the temporal structure of the signal in a greater degree than by its spectral structure.

The differences between the normalized detection thersholds for signals of various temporal structures reach 10 dB (Fig. 10). The lowest detection thresholds were obtained for tone pulses of 0.2 Hz repetition frequency and a 25% duty cycle. For the signals with a 75% duty cycle and 0.2 Hz repetition frequency the highest thresholds were observed.

For signals of different spectral structures the detection threshold level differences (Fig. 8) do not exceed 4 dB. In the five investigated cases the lowest detection thresholds were obtained for sweep signals.

## References

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