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APPLICATION OF AN AUTOMATIC AUDIOMETER IN THE MEASUREMENT OF THE DIRECTIONAL CHARACTERISTIC OF HEARING

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This paper describes a new version of the automatic audiometer with electronic level control, adopted for the measurement of the directional characteristic of hearing. It also presents the results of the preliminary investigations of the directionality of hearing under the conditions of the threshold stimulation by a tone and by narrow-band noise.

1. Introduction

The construction of a Bekesy automatic audiometer based on electronic circuits has provided the conditions for more accurate and comprehensive investigations of the hearing threshold. This is above all related to the technical abilities of the measurement apparatus used in the construction of the audiometer. These abilities are provided by the broad-range control of such parameters as the attenuation rate in the stimulus signal level (3, 10, 30, ..., ..., 100 dB/s), the variation rate in the frequency of a stimulus (20 Hz-20 kHz – from 10s to above 100 h), or of the rate and dynamic scale of recording (10, 25, 50, 70 dB). A selection of values of these parameters makes it possible both to obtain the entire threshold curve of hearing as a function of frequency and to choose a certain narrow frequency band to record the threshold curve with large accuracy [3]. It is also possible to analyze precisely the variation of the threshold as a function of time [3-5].

Knowledge of the directional characteristic of hearing is of great significance in many fields of acoustics, particularly in the room acoustics and the recording technique using the artificial head. In most papers [1, 2, 9] the magnitude of the acoustical pressure at the inlet of the auditory canal using a microphone probe is measured as a function of selected values of the angle of the position of the sound source. In some papers, e.g. [8], a method analogous to that used in a classical clinical audiometer is also used. There are, however, no measurement techniques suitable for fast and at the same time precise determination of the characteristics mentioned above.

This paper aims to present a new version of the electronic automatic audiometer adopted for measurements of the directional dependence of the hearing threshold. The results of preliminary investigations of the directionality of hearing with the stimulation by a tone and by narrow-band noise are also given.

2. Measurement apparatus

The automatic audiometer for the measurement of the directional characteristic of the threshold of audibility was set up using standard laboratory Brüel-Kjaer equipment. This audiometer is a version of the audiometer described in paper [7]. A block diagram of this device is shown in Fig. 1. In the system in Fig. 1 the amplitude of the stimulus signal is changed using a control ampli-

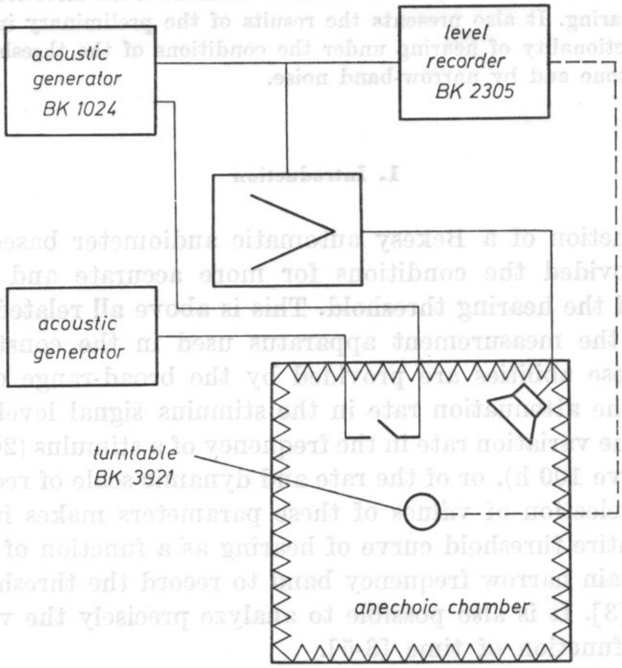

Fig. 1. A schematic diagram of an automatic audiometer for measurements of the directional characteristic of the threshold sensitivity of hearing

fier of a BK 1024 generator and an external generator. With a button the listener feeds a control signal with constant amplitude to the compressor input of the generator. Through the control amplifier this signal affects the amplitude of the stimulus signal, causing a decrease in its level at a specific rate. A break in feeding the control signal (by the release of the button) causes an opposite effect, a rise in the level of the stimulus signal at the same rate. The performance of the system for electronic level control of the output signal in the automatic audiometer is described in detail in paper [7]. The element which makes the present system different from that described in paper [7] is a BK 3921 turntable. The character of the measurement requires the stimulus to be presented binaurally in the free field. In the present case, measurements were performed in an anechoic chamber using a dynamic GK 1245 loudspeaker as the sound source. The position of the elements of the system with respect to one another is shown in Fig. 1.

3. Measurement procedure

In the course of the measurement the person examined sat on a stool made fast to the turntable with his or her head still. This situation is close to the real conditions of listening, with the conscious head movements eliminated. When the table was turning the listener's task was to keep the magnitude of the signal received at the threshold level by adjusting the control signal. The level of the stimulus signal corresponded to the threshold level of hearing sensitivity under the conditions of binaural perception and signal was registered by a recorder voltmeter as a function of variation in the position of the sound source and the listener in a horizontal plane with respect to each other.

The listener kept the stimulus signal at a level corresponding to the threshold sensation by causing a decay in the signal when it entered the level range above the threshold and, conversely, by causing a rise in the signal when it lowered below the audibility threshold*. This is a common technique used in automatic audiometry. The result was registered in the form of a polar curve of the level variation about the threshold value as a function of the angle of the position of the sound source with respect to the listener. The table did not turn for the first 40-60 s of a measurement session. In this time the listener adjusted the signal presented so as to keep it on the threshold level. When the threshold value was established, the table began to turn and the registration of the signal level was started. The variation in the signal for two successive full turns of the table was registered.

In the investigations directional characteristics were determined for tones and narrow-band noise with the width $\Delta f = 300$ Hz. The measurements were performed for frequencies of 1, 2, 5, 7 and 10 kHz. The variation rate in the

* A full measurement instruction for the listener, which is also used in the present investigation, is given in paper [3].

signal level was taken to be 10 dB/s. The table turned counterclockwise at a velocity of 0.75 rpm*, i.e. a double turn lasted about 160s. In all, one measurement took about 3.5 min. This procedure of the experiment prevented both the effect of the unstability of the threshold in the initial stage of signal expo-

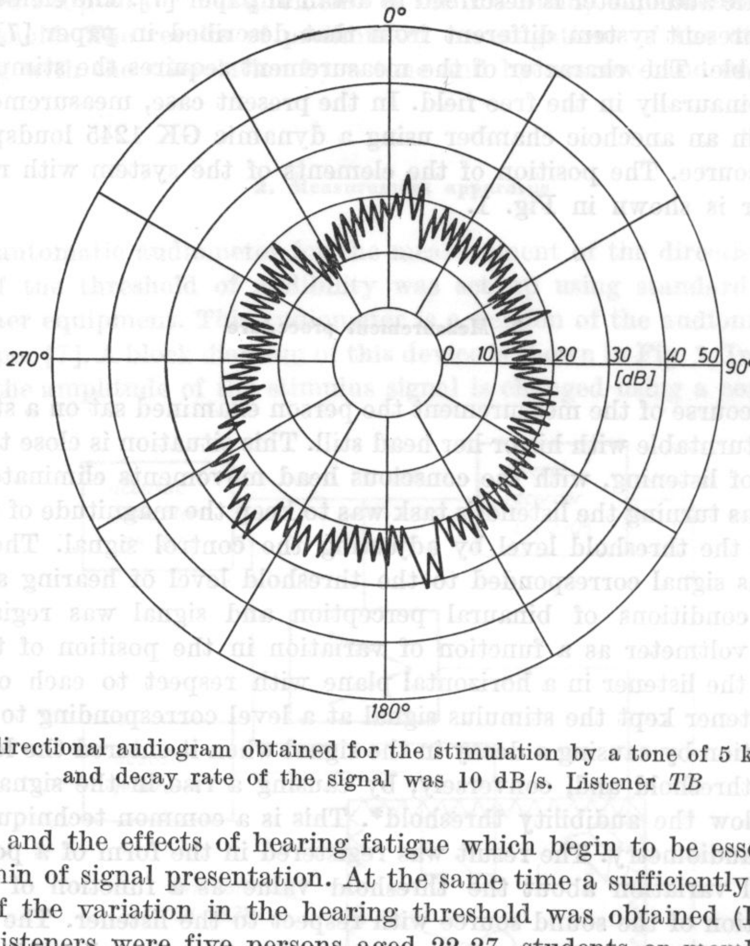

Fig. 2. A directional audiogram obtained for the stimulation by a tone of 5 kHz. The rise and decay rate of the signal was 10 dB/s. Listener *TB*

sition [4] and the effects of hearing fatigue which begin to be essential after about 5 min of signal presentation. At the same time a sufficiently precise recording of the variation in the hearing threshold was obtained (Fig. 2) [5].

The listeners were five persons aged 22-27, students or members of the staff of the Chopin Academy of Music, Warsaw, who had a large experience in psychoacoustic investigations. All had audiologically normal hearing.

4. Measurement results

As an example, Fig. 2 shows a directional audiogram. The angle 0° corresponds to the position of the sound source in front of the listener, in the plane of symmetry of the head. The angles 90° and 270° correspond, respectively,

* It is the only rotation velocity of the BK 3921 turntable.

to the right and the left side of the listener, while the angle 180° corresponds to the sound source at the back of the listener.

The threshold value was approximated by a line lying at middle of the saw-tooth recording. This procedure seems to be most justified by the conditions assumed for the investigations [5].

It should be stressed that, similar to the previous version of the electronic automatic audiometer, here higher levels recorded correspond to a lower hearing sensitivity. This is different from the traditional registration used in clinical audiometry in which higher levels correspond to a higher sensitivity. The differences in the nature of recording result from the properties of the apparatus used and have no effect on the interpretation of results.

In the investigations 3 to 16 threshold recordings were taken for particular persons and frequencies. In order to determine an average characteristic of the hearing threshold, points distant by 30 angular degrees (i.e. corresponding to the directions 0°, 30°, 60° etc.) were selected. This procedure is justified by the preliminary character of the investigations performed whose results only provide an illustration of the present measurement method and are not expected to determine a normalized threshold curve.

The pilot investigations showed that for the participants in the experiment the differences in hearing sensitivity between the right and the left ears do not exceed 5 dB for each of the frequencies investigated. On this basis, the assumption of a symmetry of the directional characteristic of hearing with respect to the medial plane of the head was found to be admissible. This permits

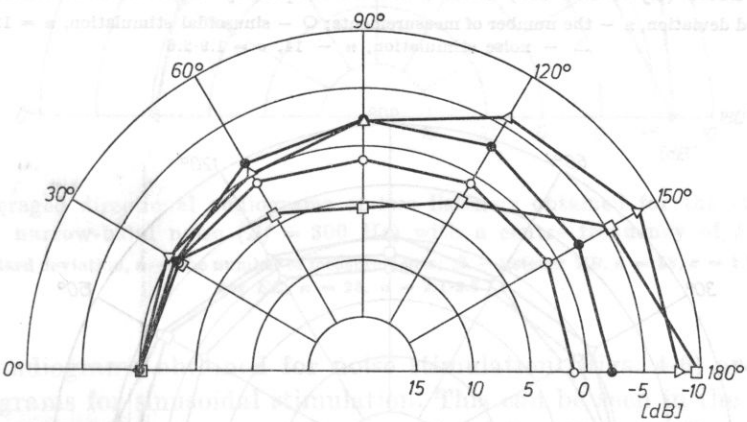

Fig. 3. Averaged directional audiograms for the stimulation by a tone. Listeners *TB*, *MB*, *KK* and *AM*

f — the stimulation frequency, σ — the standard deviation, n — the number of measurements; ○ — $f = 1$ kHz, $n = 6$, $\sigma = 1.1$-2.6; ● — $f = 2$ kHz, $n = 6$, $\sigma = 0.5$-2.1; △ — $f = 5$ kHz, $n = 6$, $\sigma = 0.9$-$2{,}7$; □ — $f = 7$ kHz, $n = 6$, $\sigma = 2.4$-5.7

the values of points lying symmetrically on both sides of this plane (0°, 30°, 330°, 60-300° etc.) to be averaged and a directional audiogram to be represented in

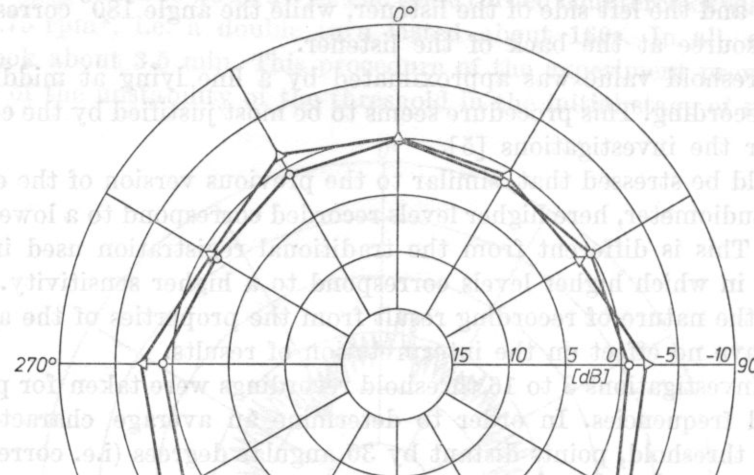

Fig. 4. Averaged directional audiograms for the stimulation of a 5 kHz tone and by narrow-band noise (Δf = 300 Hz) with a centre frequency of 5 kHz. Listener *TB*

σ – the standard deviation, n – the number of measurements; ○ – sinusoidal stimulation, n = 12, σ = 1.2-1.9; △ – noise stimulation, n – 14, σ = 1.9-2.6

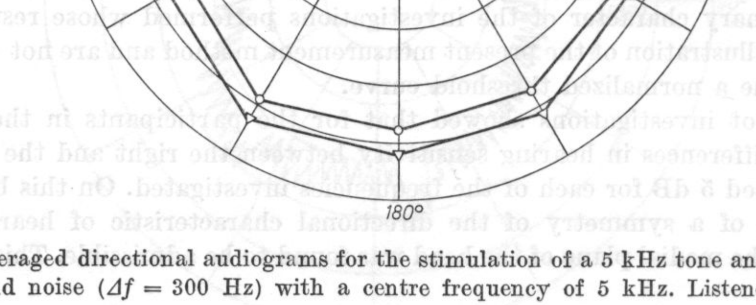

Fig. 5. Averaged directional audiograms for the stimulation by narrow-band noise (Δf = 300 Hz). Listener *TB*

f – the centre frequency of the noise band, σ – the standard deviation, n – the number of measurements; ○ – f = 1 kHz, n = 18, σ = 1.3-2.2; △ – f = 5 kHz, n = 28, σ = 1.9-2.6; □ – f = 7 kHz, n = 18, σ = 0.7-3.3

the form of a diagram which occupies half a full angle. In this situation each point of the individual audiograms given below was defined by 6-32 measurement results. Fig. 3 shows the audiograms obtained for the listener group examined with the stimulation by a tone. The plots show an omnidirectional hearing characteristic for medium acoustic frequencies (1 kHz and 2 kHz). For a frequency of 2 kHz an increase in the threshold value — by about 2 dB — becomes significant for the incidence of the wave from the back of the listener. A distinct deepening of this effect occurs for frequencies 5 kHz and 7 kHz (the significant between the front and the back of the head is about 10 dB). For a frequency of 7 kHz a significant lowering in the hearing threshold — by about 5 dB — can be observed for directions lateral with respect to the direction facing the listener. For the listener *TB* this effect also occurs for noise stimulation (Fig. 4). The question whether this feature is characteristic of hearing in this frequency range must, in view of the small set of data gathered from a group only four listeners, be left unanswered until futher, wider investigations have been performed.

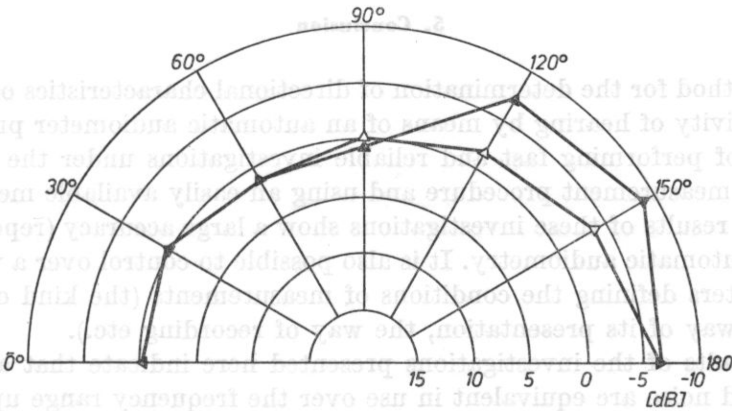

Fig. 6. Averaged directional audiograms of two listeners obtained for the stimulation by narrow-band noise (Δf = 300 Hz) with a centre frequency of 5 kHz

σ – the standard deviation, n – the number of measurements; △ – listener *TB*, n = 28, σ = 1.9-2,6; ▲ – listener *EZ*, n = 28, σ = 2.1-3.7

The audiograms obtained for noise stimulation (Figs. 4-6) are similar to the audiograms for sinusoidal stimulation. This can be seen in the audiograms of listener *TB* obtained for a frequency of 5 kHz (Fig. 4). These curves are presented for the range 0-360°. The differences between the threshold values on both diagrams do not exceed 2.5 dB.

For medium frequencies, e.g. 1 kHz, the curves of the two audiogram types are close to omnidirectional (Fig. 5). For higher frequencies, e.g. 5 or 7 kHz, the conditions of hearing signals from the back of the head become worse (Figs. 5 and 6).

It is interesting to note the large individual differences observed the audiograms of listeners *TB* and *EZ* (Figs. 5 and 6). For a frequency of 5 kHz these differences are related to the waves from the back of the head and are quantitative, while the shape of the characteristic remains unchanged.

In the case of 10 kHz signals distinct differences were observed between the directional audiograms of the listeners. It can be supposed that the main reason for the differences is the effect of the acoustic shade which, increasing as frequency increases, results from the geometrical dimensions of the heads of particular listeners. In the course of measurements performed for this frequency it was possible to observe an undesired effect of the anechoic chamber where reflections of sound waves occur over this frequency range. Hence, measurements over this frequency range were distorted by side effects which are difficult to eliminate. In view of this, the data obtained for $f = 10$ kHz could not be used as the basis for essential conclusions and were neglected in the analysis.

5. Conclusion

The method for the determination of directional characteristics of the threshold sensitivity of hearing by means of an automatic audiometer provides the possibility of performing fast and reliable investigations under the conditions of a simple measurement procedure and using an easily available measurement set up. The results of these investigations show a large accuracy (repeatability), typical of automatic audiometry. It is also possible to control over a wide range the parameters defining the conditions of measurements (the kind of stimulus signal, the way of its presentation, the way of recording etc.).

The results of the investigations presented here indicate that a tone and narrow-band noise are equivalent in use over the frequency range up to about 5 kHz. For higher frequencies it seems better to use noise bands in view of a smaller scatter of measured results and an agreement between the type of a stimulus and the width of the critical band.

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