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AUTOMATIC DIGITAL AUDIOMETER FOR MASS HEARING EXAMINATIONS*

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This paper presents the lay-out and design of an automatic digital audiometer. All audiometer functions are programmable thus eliminating the operator errors associated with conventional designs. The design is based on a modular concept resulting in simplification in servicing and the interchangeability of modules between various types of audiometers based on the above concept. The audiometer has been tested and is presently at the stage of serial production.

1. Introduction

Medical prophylaxis is one of the most important ways of limiting the harmful effects of noise in industry. The choice and determination of appropriate preventive treatments relies upon the introduction of obligatory mass audiometric examinations of industrial personnel. Such a program comprises both the preliminary examination of new employees, and the periodic examination of these personnel exposed to a noise level potentially harmful to the hearing organ.

In the Polish Mining Industry it is necessary to perform about 150000 audiometric examinations per year, i.e., about 1500-3500 examinations in a single mine ambulatory furnished with audiometric equipment, depending on the size of the mine. These figures should be supplemented with those of the audiometric examinations of employees suffering from hearing-organ diseases, and are therefore significantly under estimated.

Over 10 years of activity of the Central Mining Institute, Katowice, in this field have been concentrated, in the period 1972-1976, on the development of a programme for medical prophylaxis of the hearing organ [11-13] which would cover all coal mines in Poland. However, it soon became evident that a successful implementation of the programme would depend upon providing the mine ambulatories with appropriate technical equipment, the main compo-

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nents being an audiometer and a sound-proof chamber for audiometric examination [12].

In this paper we report on the development of the audiometric equipment.

2. Analysis of the existing status of audiometric equipment and the lay-out of audiometer design

Evaluation of existing audiometric equipment involved consideration of the following factors:

– the number of audiometric examinations anticipated per year to be made using a single instrument,

– the present state of furnishing of the Mining Industry Health Service with audiometric equipment,

– the availability of appropriate equipment in the country and abroad,

– the training level of specialized personnel for performing and interpretating the audiometric examinations,

– the reasons for faults in audiometric equipment and the feasibility of repair and periodic calibration required to maintain reproductibility, uniformity and comparability of the results of examinations and their recording. The analysis revealed that the existing state of this field was unsatisfactory [1, 10].

The above conclusion was the reason for initiating a wide research program in the Technical Acoustics Group of the Central Mining Institute, Katowice. The goals of the programme were derived from the results of the above analysis. It was decided to develop an audiometer for selective – screening mass examinations, satisfying the following requirements:

1. Total elimination of contact switches in the systems for sound-level and frequency switching. The fulfilment of this requirement would eliminate the most common source of audiometer faults.

2. Full automation of acoustic pressure level and frequency changes, provided by an appropriate programme controlling these changes.

3. Full conformation with the current international and national standards and requirements concerning audiometric equipment. This requirement is necessary in view of anticipated serial production and export.

4. Maximum use of indigenous components bearing in mind the technological possibilities of the expected producer.

In view of the above assumptions, it was necessary to reject the concept of a Békésy type automatic audiometer [6, 7, 9]. This audiometer satisfies conditions 1, 3 and 4 but the result of an examination is presented in the form of plot with a subject dependent fluctuation of the record about a threshold value. The determination of the essential effect of a number of factors on the fluctuation value [8, 9] requires considerable skill for proper interpretation of the results. This is unacceptable for the mass examination of a large population. Moreover the high cost of the recording system eliminates the Békésy type audio-meter from the range of considered design concepts.

3. Design considerations

Audiometric measurement in a threshold examination consists in determining the values of three variables:

A – an independent variable defining the type of signal generated by the audiometer.

This variable is described by two parameters: frequency f and acoustic pressure level p.

B – a dependent variable defining the reaction of the hearing organ to the signal described by variable A.

This variable is also defined by two parameters: the parameter describing the reaction of the central nervous system – B_1 and the so-called *effectoric reaction* – B_2 [5] describing excitation of effectors which signal the reaction of the hearing organ of the subject.

C – a mediating variable describing the psychic features of the subject, which trigger the reaction in agreement or in disagreement with the previously obtained instruction.

The instruction informs the subject of the necessity of immediate signalling of the moment of the first perceivable hearing impression of the tone emitted by the earphones. The purposeful or accidental (e.g. as a result of misunderstanding the instruction) refraining from signalling the hearing impression results in defining the reaction as being in disagreement with the instruction. It should be stressed that determination of the intermediating variable C is only possible when the subject is able to react correctly to the audiosignal, i.e., when his hearing organ reacts to an audiosignal with parameters described by variable A and he understands the meaning of the instruction received.

The procedure of a correct audiometric examination should enable all three variables to be controlled. Most of the so-called selective (screening) audiometers [3, 4] (e.g., Klaman Granert type MA-10, DDR), Medicor type Audiomin-2 (Hungary), Kamplex type DA-2) are based on the assumption that variable C does not influence the result of the examination. Consequently the control is limited to variables A and B which are supposed to be related to each other explicitly.

The authors assumed that when control of variable C is introduced to a selective audiometer, as is required by international standards, the measurement reliability will improve substantially and it will, moreover, be possible to make use of a number of the modules of the system which have been already developed when the design is further developed towards a clinical audiometer.

The result of an audiometric measurement is defined by the hearing state function

$$L_0 = \varphi(f), \qquad L_0 \in (L_{\min}\text{-}L_{\max}), \qquad f \in (f_d\text{-}f_g), \tag{1}$$

where L_0 is the threshold pressure level (in dB), L_{min} – the minimum acoustic pressure level produced by the audiometer (in dB), L_{max} – the maximum acoustic pressure level produced by the audiometer (in dB), f_d-f_g – the frequency range of the signal produced by the audiometer, $\varphi(f)$ – a function of the signal frequency (Hz).

Relation (1) can be obtained by means of two measurement procedures P_1 and P_2 defining the set of hearing threshold values, but retaining the scheme of determining the values of the three variables, described above.

Procedure 1 – P_1:

$$P_1 = \varphi(f_i, L_i), \qquad \text{where } L_i = L_0;\ L_0 \in (L_{\min}\text{-}L_{\max}). \tag{2}$$

Procedure 2 – P_2:

$$P_2 = \varphi(f_i, L_i), \qquad \text{where } f_i = f_0;\ f_0 \in (f_d\text{-}f_g). \tag{3}$$

The results of the measurements of threshold values of the acoustic pressure, obtained by using the above procedures may fall into one of two categories:

Category I: $P_1 = P_2$. The measurement results obtained from the procedures are identical. It means that each of the two procedures realized by the audiometer is correct.

Category II: $P_1 \neq P_2$. The measurement results are not identical. It thus makes a difference in this case as to which of the procedures will be applied.

The existing literature does not provide any example of the measurement of the category II. Therefore, in further considerations, it has been assumed that the audiometer will realize procedure P_1 as is commonly used in audiometers currently produced.

It should be pointed out here that the unequivocal choice of the procedure realized by the audiometer is of essential importance for the design of an automatic audiometer. In the case of an audiometer with manual control of the switches, the operator himself fixes the examination procedure and therefore there is no need to choose it in the course of designing the instrument.

The algorithm of the program realized by the audiometer has the form given by relation (2). In the instrument developed this algorithm is realized automatically thus eliminating the influence of operator on the course and accuracy of the measurement. The operator needs only to start the program and to control the intermediating variable C. The control consists in turning on a continuous or intermittent signal facilitating perception of the acoustic stimulus at a near – threshold level and starting the subprogram for repeating the examination several times at the same frequency for accurate determination of the value of the hearing threshold. The control of variable C has been thus included in the lay-out of the audiometer in an attempt to provide an easy and functional way of limiting the influence of the error introduced by the subject.

4. Description of the system

The audiometer is composed of two functionally interrelated circuits: a digital circuit and an analog circuit [14]. The digital circuit consists of:

– a control desk with a signal button to be pressed by the subject,

– a generator controlling the automatic circuits,

– a system for the automatic control of the acoustic pressure level and signal frequency,

– a system for displaying the level values and signal frequency.

The analog circuit consists of:

– acoustic generators

– a power amplifier,

– an attenuator for the acoustic pressure level output

– earphones.

The principle of co-operation of the blocks is presented in Figs. 1 and 2 is a photograph of the instrument which is serially produced by Śląskie Zakłady Elektronicznej Aparatury Medycznej (Silesian Factory of Electronic Medical Equipment). The manufacturer's code for the instrument is AUK 431.

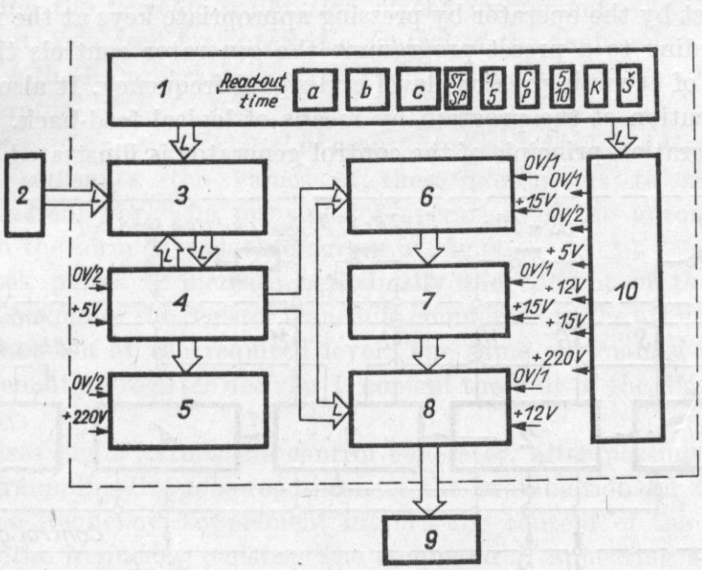

Fig. 1. Block diagram of the automatic audiometer with digital display

1 – Control desk: (a) left ear, (b) read-out, (c) right ear, 2 – Button, 3 – Control generator, 4 – Automatic system, 5 – Displays, 6 – Acoustic generators, 7 – Power amplifier, 8 – Acoustic attenuator, 9 – Earphones, 10 – Power supply

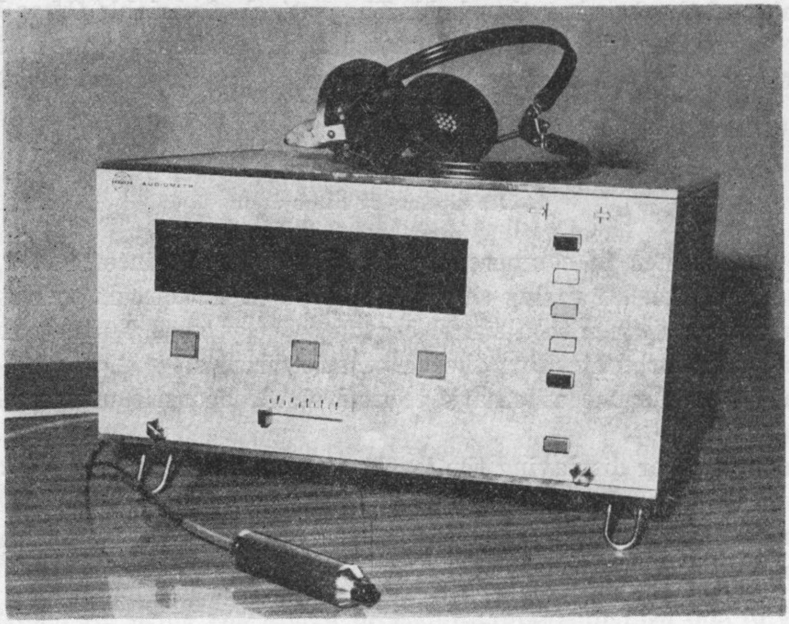

Fig. 2. Automatic audiometer with digital display manufactured by Śląskie Zakłady Elektronicznej Aparatury Medycznej w Zabrzu (Type AUK 431)

4.1. Control generator. The main block of this system is formed by a generator controlling the automatic systems. The functions executed by this generator are preset by the operator by pressing appropriate keys at the manipulation desk. According to a preset programme the generator controls the automatic adjustment of acoustic pressure level and signal frequency. It also controls the correct execution of the program by means of logical feed-back.

The operation principle of the control generator is illustrated by the block

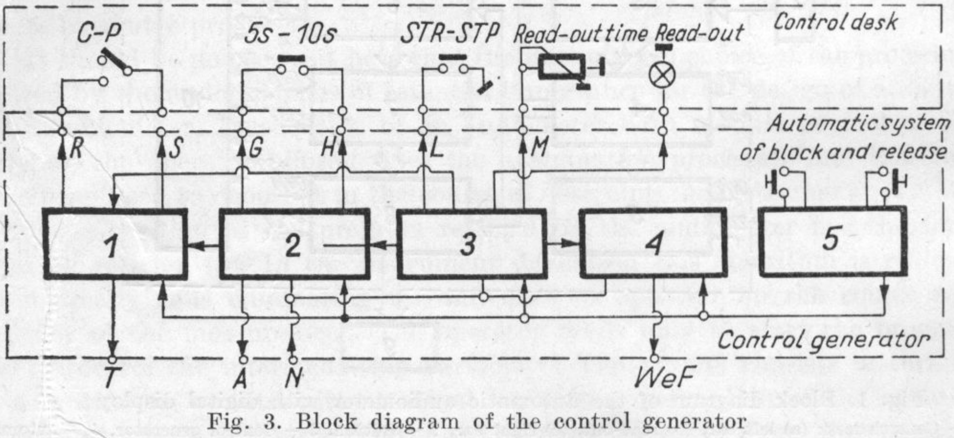

Fig. 3. Block diagram of the control generator

1 – Signal-level reduction system logic, 2 – Generator, 3 – Monostable multivibrator, 4 – Single-pulse generator, 5 – Automatic system block and control generator

diagram presented in Fig. 3. The rhythm of operation is fixed by a 1 Hz/0.5 Hz generator. At output A there appear pulses which change the state of the register of the acoustic pressure level divider. The repetition time of the pulses is controlled by the operator and is either 5 or 10 seconds. The logical systems of signal level reduction, operating synchronously with the generator, fulfil four functions:

– lowering the level of the signal in the earphones at the moment of changing the state of the level divider register,

– lowering the level of the signal in the earphones at the moment of changing the state of the frequency register,

– choosing the signal emitting system; continuous or intermittent,

– lowering the signal level in the earphones at the moment of subject reaction.

A monostable multivibrator controls the period reserved for the operator for registration of the hearing threshold of the examined person at a given frequency. The operator may control the read-out time within the range 0.5 - 50 s. The multivibrator starts at the moment of the reaction of the subject to the signal of a particular frequency. As a result the 1 Hz/0.5 Hz generator becomes blocked and the tuning out system is triggered.

After a preset operation time the multivibrator triggers a singlepulse generator. The pulses at the output of the generator serve for erasing the level attenuator register, and for increasing the value of frequency register. A possibility is provided for blocking the action of the control generator, which is utilized during the periodic calibration of the instrument.

The input *N* is used for automatic control of the conformity of the preset programme with the programme carried out by the automatic systems of the control generator.

4.2. System of automatic control of acoustic pressure level and signal frequency. This block transmits the values of these parameters to the generator and output attenuator. The principle of operation of the automatic unit is illustrated in the form of a block diagram in Fig. 4.

The clock pulses *A* increase periodically the content of the attenuator register. The output of the register transmits commands to the attenuator unit to set the attenuation at the required level. The same commands, suitably decoded in attenuation register decoder I, control the unit of the digital pressure-level display.

The pulses "in *F*" from the control generator, after passing through the system programming five-fold repetition of the examination for the same ear and the same frequency, supplement in turn the content of the ear-selection register and the frequency register. The command *U* appearing at the output of the ear selection register is transmitted to the amplifier unit and selects the ear to be examined at this moment. The output of the frequency register is supplied to attenuator register decoder I and frequency register decoder II.

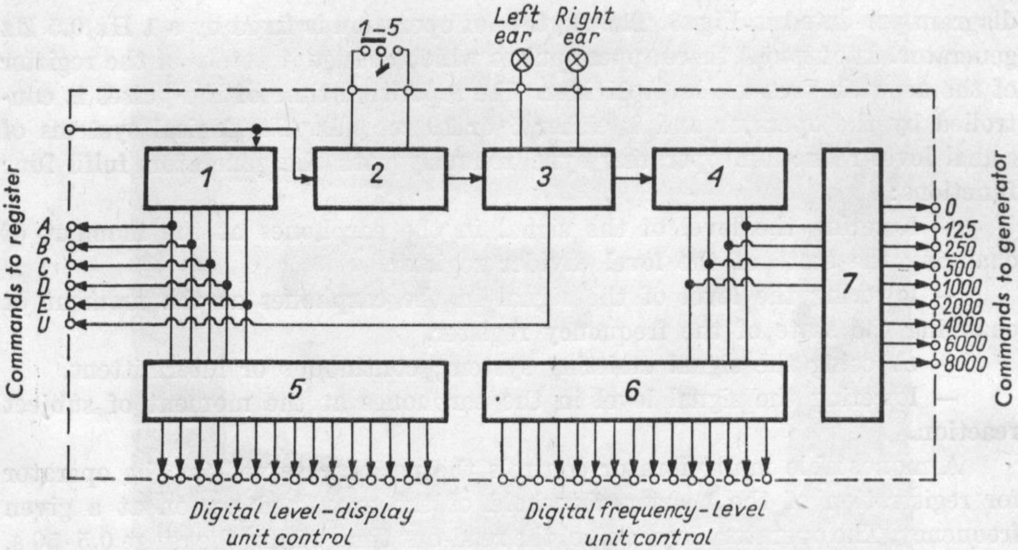

Fig. 4. Block diagram of the system for automatic control of the acoustic pressure level and the frequency

1 – Attenuator register, 2 – Five-fold repetition programme, 3 – Ear register, 4 – Frequency register, 5 – Frequency register decoder II, 6 – Attenuator register decoder I, 7 – Frequency register decoder II

The output of decoder I transmits commands to the generator to generate the signal of the required frequency. The output of decoder II produces pulses controlling the unit of digital display of the current frequency value.

4.3. Audio signal generators and power amplifier. The audio generators of the normalized frequencies required in audiometric examinations are built in the conventional lay-out of a three stage D.C. amplifier with a positive feed-back loop between the first and third stages. The amplifier contains a set of variable resistors for fixing the calibration of the output signal level and its frequency. The generator is protected against the influence of loading by subsequent units of the instrument and provided with circuits necessary for output voltage and frequency stabilization.

The power amplifier amplifies the signal from the generators to a value dictated by the input impedance of the attenuator. The circuit of the amplifier contains an optically – coupled isolator used for disconnecting the link between the amplifier stages and lowering the signal level in the earphones to a level set by standards [4]. The lowering of the level occurs at moments: of a change of signal frequency, of a change of acoustic pressure level, of receiving a signal from the subject that the test tone has been heard, and periodically testing with intermittent signal.

4.4. Output attenuator. The output of the power amplifier is connected to a step attenuator controlling the acoustic pressure level in 5 dB steps. The application of the step attenuator results both from standardization requirements [2, 4], and the adopted concept of digital presentation of the examination data. The operation principle of the attenuator is presented in Fig. 5. The power amplifier supplies a sinusoidal signal to the input denoted by "In T". The frequency decoder switches one of keys K21 - K24 to open and directs

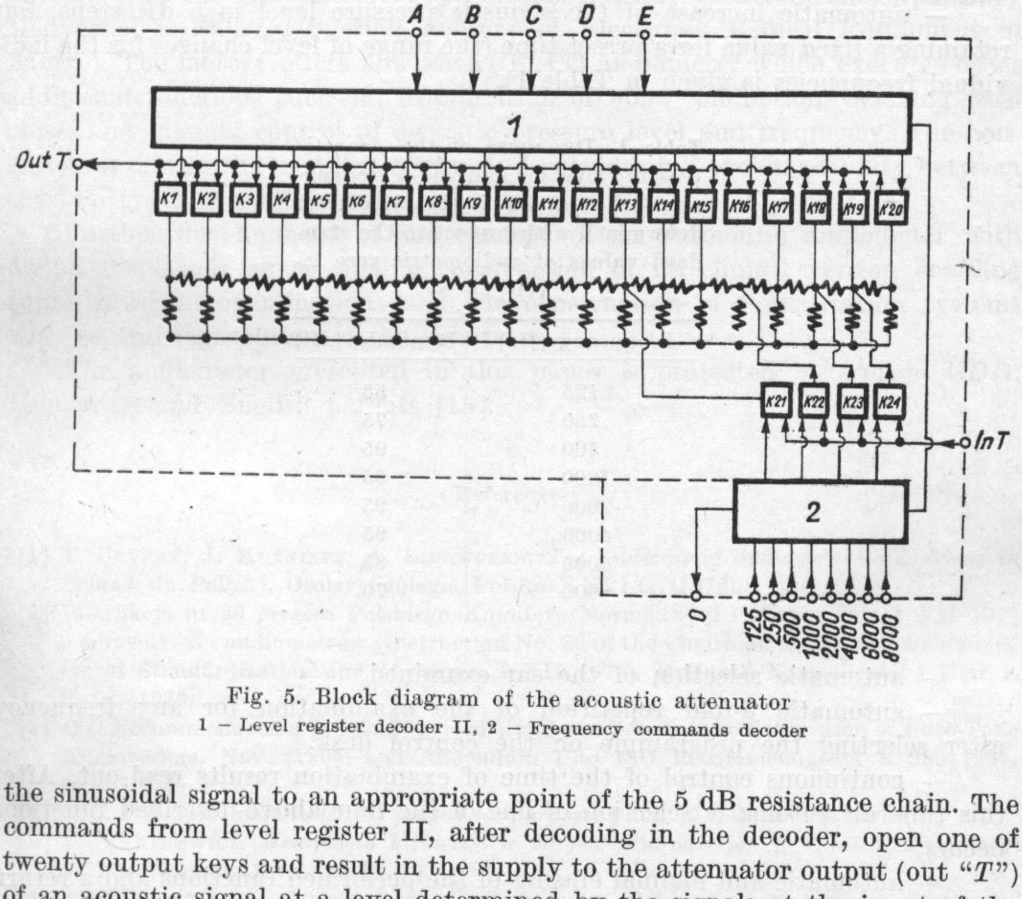

Fig. 5. Block diagram of the acoustic attenuator
1 – Level register decoder II, 2 – Frequency commands decoder

the sinusoidal signal to an appropriate point of the 5 dB resistance chain. The commands from level register II, after decoding in the decoder, open one of twenty output keys and result in the supply to the attenuator output (out "T") of an acoustic signal at a level determined by the signals at the input of the logic control A, B, C, D, E.

The logical state (0 or 1) of the voltage at output N controls the maximum value of the acoustic signal level supplied to the output attenuator for successive frequencies.

4.5. Display unit and power supply. The display unit is installed on the front plate of the instrument. It comprises two groups of digital display's (giving values of the acoustic pressure level and frequency) and three optical indicators which indicate the ear examined, i.e. left or right, and indicate a signal from the subject. The stabilized power supply built with a conventional lay – out provides the necessary voltages for supplying the functional units of the instrument.

5. Summary

The device described above performs the following functions:

— automatic selection of the frequency of the test tone for 8 normalized signal frequencies,

— automatic increase of the acoustic pressure level in 5 dB steps, but retaining a fixed value for a preset time (the range of level changes for the individual frequencies is given in Table 1),

Table 1. Dynamics of the acoustic pressure level for individual frequencies of the test tone in the audiometer determined with respect to the standard values of audiometric zero level [2]

Frequency (Hz)	Dynamics (dB)
125	55
250	75
500	95
1000	95
2000	95
4000	95
6000	85
8000	70

— automatic selection of the ear examined,

— automatic 5-fold repetition of the examination for any frequency after selecting the programme on the control desk,

— continuous control of the time of examination results read-out. After this time an automatic selection of one of the four above-described functions occurs,

— automatic and manual erasing of the performed functions and a return to the initial states.

The device is constructed in a modular form. This feature facilitates servicing by the customer. The service consists in replacing a defective module and subsequent repair of the module in the factory work shop. The design of the basic modules of the instrument permits their use in further development of the audiometer.

The block for acoustic pressure level and frequency calibration is separated from the system to enable precise periodic calibration of the audiometer. The audiometer is provided with high quality Telephonics TDH – 39 earphones which, together with establishing the audiometric zero in agreement with existing standards, make the instrument conform with all national and international requirements [2-4]. The operation of the audiometer is reduced to turning on the supply and registering the results at the moment of signalling by the subject. There is a future possibility of coupling the audiometer with a printer.

The audiometer based on the above-described principle has been further developed by the manufacturer, i.e., Śląskie Zakłady Elektronicznej Aparatury Medycznej w Zabrzu (Silesian Factory of Electronic Medical Equipment in Zabrze). The factory offers now an AUK 432 audiometer which executes other additional functions such as: examination of bone conduction, masking with noise, and manual control of acoustic pressure level and frequency. The construction retains the modular system and provides full exchangeability between the two types of audiometers.

Further development of the concept of an automatic audiometer with digital display is aimed at the construction of its clinical version enabling supra-threshold examinations and the construction of multi-station systems with central registration of the results.

The audiometer presented in this paper is protected by Polish, GDR, Hungarian and English patents [15].

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