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A SPECIAL CALIBRATABLE ARTIFICIAL-HEAD-MEASUREMENT-SYSTEM FOR SUBJECTIVE AND OBJECTIVE CLASSIFICATION OF NOISE

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During acoustical noise measurements results are very often less than satisfactory because normally the sound situation is very complex with respect to the spectrum, the amplitude distribution and the shape of the signal in the time domain. The usual measurement technique concentrates all these parameters into a single value like the A-weighted sound pressure level, the equivalent noise level or something like that. Even the frequency response is not able to give all informations about a sound situation. Especially the classification of the annoyance-level caused by noise and the influence of sound damping is frequently impossible when using the well known measurement techniques. Sometimes the results of acoustical noise measurements disagree to the hearing event, for example a noise with a higher A-weighted level can be subjective less annoying than another noise with a lower level. The idea of recording sound events for classification and comparing by the human ear is known in principle, but a recording system whose attributes are comparable to the human ear was not available, which allows original reproduction of sound events.

PRINCIPLE OF AN ARTIFICIAL-HEAD-MEASUREMENT-SYSTEM

A correct transmission of hearing events with respect to the direction of sound incidence, distance and tone colour is only possible by an exact reproduction of the earsignals. That means two recording microphones have to pick-up the sound pressure in dependency on sound incidence and frequency like the external human ear. Using headphones these microphone signals reproduce the same signals in the earcanal of a person which can be measured when the person is in the original situation. Normal microphones with an omnidirectional pattern have to be replaced by an artificial head with a directional pattern like the human external ear. The principle of this acoustical measurement system using an artificial head for recording and headphones for playback is shown in fig. 1.

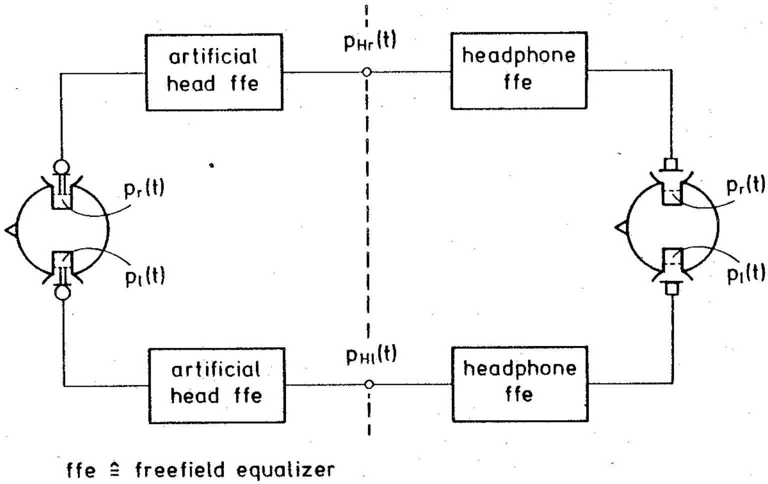


Fig. 1: The principle of an acoustical transmission using an artificial head as recording microphone and headphones for playback at the test person. The equalizers correct the transfer-functions of head and headphones in relation to the freefield sound incidence so that the signals $p_{Hr}(t)$ and $p_{Hl}(t)$ can be used for normal acoustical analysis.

But no artificial head existed which represented a correctly averaged human outer-ear-transfer-function and whose range of frequency and dynamic was comparable to the human ear. So the hearing events when reproducing sound situations using headphones differed from the original ones. A new artificial head was developed /1/ with an exact reproduction of the external geometry of persons with regard to the ear-position at the head, the shoulder, and the torso (look at fig. 2). That way the directional pattern is comparable to the human external ear. Special microphones with high dynamic range, low noise level and small diameter were coupled to the earcanal in such a manner that the resonancies of cavum conchae and earcanal amplify acoustically the sensitivity of the microphones. So the dynamic range of this artificial head extends from the hearing threshold up to more than 132 dB<spl> in a frequency range from 3 Hz to 20 kHz. The two freefield-equalizers filter the microphone signals of the head in such a way that for sound incidence in front of the artificial head the transfer-function of the head is equal to the one of measuring-microphones. The transfer-function of the headphone is corrected by equalizers so that the ear-signals are comparable to freefield sound incidence. Hearing tests with this artificial head -it can be used in psycho acoustical investigations, as a recording microphone in broadcasting /2/ and for acoustical noise measurements /3/- give good results with respect to the correct reproduction of direction of sound sources, and especially of tone colour.

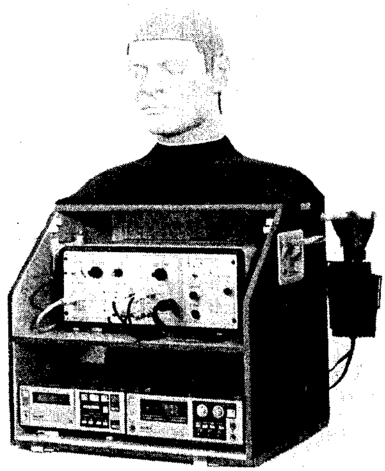
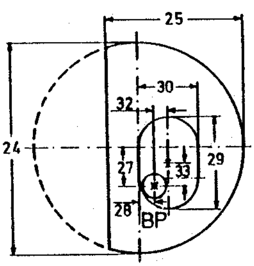
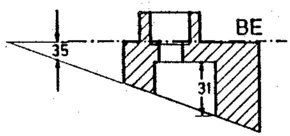


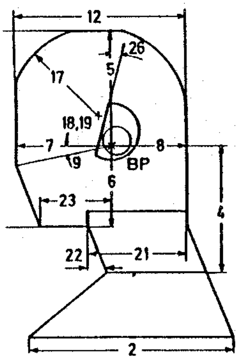
Fig. 2: Artificial-head-measurement-system with exact reproduction of the external geometry. The directional pattern, dynamic and frequency range are comparable to the human ear. The torso contains the complet recording (digital) and playback systems, no main power supply needed.

CALIBRATABLE ARTIFICIAL-HEAD

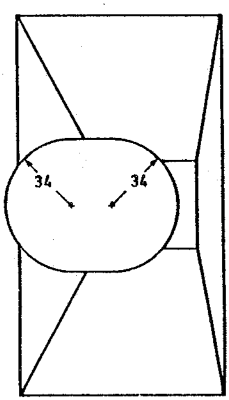
The described artificial head is calibratable starting from the microphone (using a pistonphon) up to the headphone. It is possible to reproduce the exact loudness or sound pressure level. In order to determine an exact describable transfer-function a reproduction of the human external ear is not desirable. The resonancies, reflections, and diffractions caused by the external geometry -head, torso, shoulder, pinnae, cavum conchae, earcanal and eardrum- determine the outer-ear-transfer-function. An exact mathematical description of the disturbed sound field caused by the external ear in dependence on sound incidence is unknown. The attempt /4/,/5/ to describe this transfer-function in an obvious model leads to the perception that it is possible to define the directional pattern by a few parameters. Only by keeping up the structure of the transfer-function and without any exact solution of the mathematical description the geometry can be reduced. These reductions allow an approximate estimation of the sound pressure in the microphone plane. But on the other hand these reductions allow the developement of a calibratable artificial head too. The geometrical parts consist of mathematical describable parameters like cylinders, spherical segments and so on. So exact reproductions of the artificial head are possible based on knowledge of the geometrical data. A first prototype of such a calibratable artificial head with respect to averaged geometrical data of 6 male persons is shown in fig. 3.







No.	parameter	median	
1	shoulder width	496	<mm>
2	shoulder depth	269	<mm>
3	shoulder angle	23.3	<deg>
4	BP above shoulder	160	<mm>
5	BP from top	156	<mm>
6	BP from bottom	105	<mm>
7	BP from front	116	<mm>
8	BP from back	102	<mm>
9	BP angle	11.9	<deg>
10	head width	176	<mm>
11	head height	261	<mm>
12	head depth	217	<mm>
13	head radius top	86	<mm>
14	centre above BP	70	<mm>
15	head radius bottom	66	<mm>
16	centre above BP	25	<mm>
17	head radius side	119	<mm>
18	centre above BP	41	<mm>
19	centre beside BP	14	<mm>
20	neck width	104	<mm>
21	neck depth	117	<mm>
22	neck angle	35.9	<deg>
23	chin in front of BP	94	<mm>
24	pinnae height	70	<mm>
25	pinnae width	35	<mm>
26	pinnae inclination	12.4	<deg>
27	centre above BP	13	<mm>
28	centre beside BP	5	<mm>
29	cavum conchae height	30	<mm>
30	cavum conchae width	21	<mm>
31	cavum conchae depth	19	<mm>
32	centre beside BP	8	<mm>
33	centre above BP	4	<mm>
34	head radius top	71	<mm>
35	pinnae angle	19.5	<deg>



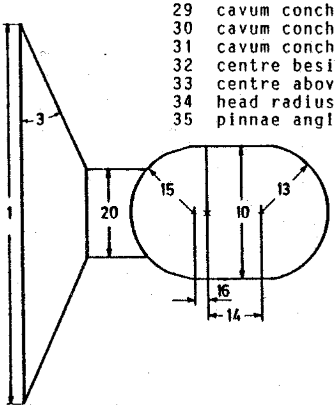


Fig.: 3 Prototype of a calibratable artificial-head BP means the reference point in the reference plane (BE), here 4 mm inside the earcanal.

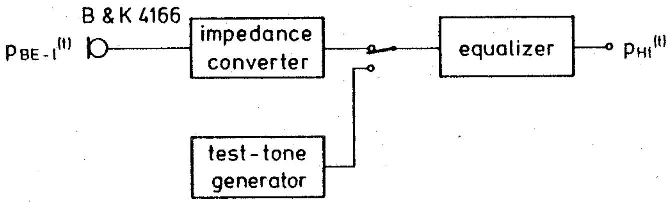


Fig.: 4 Block diagram for one channel of the artificial head

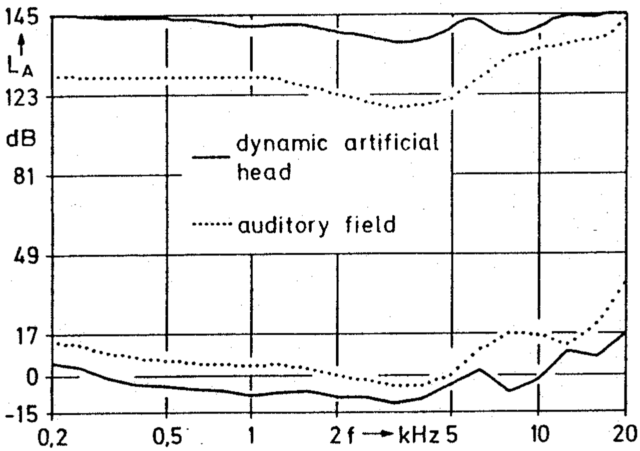


Fig.: 5 Dynamic range (——) of the artificial head in comparison to the human auditory field (...)

To be sure that the playback level is correct the electronic circuit of the artificial head contains a test tone generator which produces a voltage equivalent to 94 dB sound pressure level at 240 Hz (look at fig. 4). So it is possible to calibrate the correct playback sound pressure level of the headphones independent of the gain caused by the recording and transmission technique. The equalizer in fig. 4 corresponds to the artificial head freefield equalizer in fig. 1. The dynamic range -given by the noise level of the microphone and the impedance converter on the one hand, and by the 3% distortion on the other hand shows fig. 5 in comparison with the auditory field given by the hearing and pain threshold.

SOME APPLICATIONS

The main advantage when using the artificial-head-measurement-system in comparison with usual microphones is filtering of the sound waves in dependence on sound-incidence like the human ear. So it is possible to get a subjective classification of noise using the own ears and on the another hand the well known objective analysing techniques are practicable. A very important application of this artificial-head-measurement-system is the subjective and objective analysis of sound inside and outside of cars or archival registration for making checks of the series. A lot of annoying noises are masked by the basis noise of the car. The acoustical energy of this signals is often very small so that the A-weighted sound pressure level or even the frequency response would not change whether the noise is present or not. But as the human ear is able to select, a single noise can be detected among different noises. So only by using the artifical head it is possible to check whether damping of sound is successful or not. On the other hand it is possible to reduce the annoyance of noise by filtering the microphone signals of the artificial head. The filter parameters give informations about the possible noise source. This is helpful because in many applications the noise source -e.g. in a car- is unknown.

There are many further applications for example the acoustical judgement of concert halls or different loudspeakers in different rooms. Anytime if you want to judge acoustical situations of sound or noise you may operate independent from time and room with this artificial-head-measurement-system. A further advantage is avoiding any optical influence on the classification.

CONCLUSIONS

A new high-quality calibratable artificial-head-measurement-system consisting of a mathematically describable external geometry was developed for the improvement and extension of the acoustical measurement technique. This system enables to analyse sound and noises in the usual way but additional the classification by the human ear too. For several years this artificial-head-measurement-system was tested succesfully in different applications, especially in the car industry like Daimler Benz.

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