Artificial Head with Simplified Mathematical Describable Geometry

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Abstract

Since many years different artificial head systems exist which possess different head and outer ear forms. At the beginning the use of artificial heads was focused on broadcasting recordings. Since aspects of sound quality and sound design of products - especially with respect to vehicles - became very important during the last 20 years the application of artificial heads for sound measurements and sound analyses can often be observed. That means artificial head recordings will be used for sound analyses and subjective evaluation tests by listening with headphones. Regarding the standardization and the comparability of artificial head measurement signals an artificial head measurement system would be reasonable which is based on simplified mathematical describable geometry. It can be demonstrated that such an artificial head measurement system with simplified mathematical describable geometry shows a comparable directivity pattern in comparison to an artificial head with natural shaping. The difference between the two artificial head systems – one with natural shaping, the other with simplified mathematical describable geometry – lies in the dimension which two individual test subjects create with their individual differences regarding head shaping, outer ear position and outer ear dimensions. Furthermore, an artificial head measurement system with simplified mathematical describable geometry can be adapted easier to different head shapes. Then, based on the same design, it would be possible to form a representative head for male and female test subjects and also for the reproduction of artificial child heads. This article describes the development and construction of an artificial head with simplified mathematical describable geometry which was defined according to ANSI S 3.36-1985.

Introduction

It has been previously known in a wide-band, low noise artificial head of a great dynamic range to combine accurate reproductions of the acoustically essential geometrical structures of the head, auricles and shoulders of an electro-acoustical sound recording system (artificial head) with special acoustical, electro-acoustical and electronic means so that optimum high-fidelity acoustical transmission is achieved. The essential means by which this purpose is to be achieved in the known artificial head consist in that the acoustically essential geometrical dimensions are reproduced on the imitated head and also on the imitated auricles, via dimensionally accurate impressions in plastic material, to truly reflect the corresponding dimensions of selected living persons for which purpose the imitated head is to provide a dimensionally true reproduction of the head of a test person whose head has dimensions closely approximating the average. Accordingly, such a known artificial head permits high-fidelity transmission of aural phenomena, but is problematic insofar as no complete calibration of the system can be reached, and this exactly because of the attempt to imitate the head accurately as possible. This means, however, that the outer-ear transmission function of the respective artificial head must be established every time anew by corresponding measurements and that, accordingly, one cannot simply draw conclusions from the measured signals as to the nature and characteristics of the acoustical phenomenon acting on the artificial head as measuring system – a fact which is of considerable importance for acoustical measuring techniques. However, measuring results must be reproducible, just as the measuring system used for measuring and therefore the present invention has the object to provide an artificial head measuring system which in spite of the extremely complex total structure apparent to the man skilled in the art and comprising e.g. reproductions of the head, the neck, shoulders and the auricles, is still capable of being calibrated.

Advantage of an artificial head with simplified geometry

This kind of artificial head is for use as measuring system for acoustical phenomena which is effective throughout the full aural range and fully calibratable and which being reduced to simple bodies or partial bodies which are calculable at least for the man skilled in the art as regards their acoustics behavior (reflexion, diffraction, ear resonance, and the like) lends itself as a whole for reproduction of the artificial head microphone signals via a free-field equalized headset, without any restriction of the directional reproduction, due to its exactly defined simplified outer geometry. Accordingly, such a fully calibratable artificial head measuring system can be used with particular advantage as a useful measuring, control and monitoring instrument in acoustic measuring techniques and also as a studio microphone in the broadcasting filed.

The following are the three applications of the fully calibratable artificial head measuring system of the invention (see Fig. 1):

1. The artificial head measuring system may be used as reference test person in psychoacoustics since, contrary to the a living test person with inserted sensor microphones, it forms a so called LTI (linear time invariant) system with transmission characteristics which remain unchanged and capable of being verified under all test conditions.
2. The artificial head measuring system can be used as measuring microphone in acoustic measuring techniques (e.g. for measurements on headsets and ear muffs) and in noise diagnosis. Previous measuring methods used e.g. microphones with spherical directional characteristic for determining the A-weighted sound level. The human outer ear has, however, a completely different directional characteristic. Measurements that do not give consideration to this subjective directional characteristic of the human outer ear cannot be generalized and do not really meet the objective of the measuring process. By using the artificial head of the invention as a measuring microphone one now has the possibility to store sounds by means of a recording unit and to proceed to a subjective assessment of sounds or noise-reducing measures – it being understood that the term subjective as used herein refers to the specificity to the "receiver" constituted by the "human sense of hearing". Such a subjective measuring process will then as a rule very quickly lead to a clear judgement because the human sense of hearing evaluates a larger number of parameters of an offered acoustical phenomenon than is evaluated by "objective" measuring techniques. So, it has been known e.g. from practical experience that a sound of a higher A-weighted level may under certain circumstances be classified as less troublesome.
3. The calibratable artificial head measuring system may be used as a studio microphone in the sound engineering filed. An acoustical phenomenon is composed as a rule of the sound components originating directly from the location of the sound source, and the time-delayed reflexions arriving from different directions. In conventional recording methods, either only the direct sound components are recorded, or the reflexions are not weighted using a directional characteristic equivalent to the outer ear. This problem is solved by the invention in a decisive and, above all, due to its calibrating capabilities, generally applicable way.

Fig.: 1: HMS III

Investigations and measurements carried out on the artificial head measuring system have shown that the directional characteristics of the latter corresponds to the mean directional characteristic of man, that no background noise is audible so that hearing tests are rendered possible also in the area of the threshold of hearing, and that the dynamic range corresponds to the human sense of hearing up to the threshold of pain so that even level peaks can be recorded undistorted.

By reducing the outer geometry of the artificial head measuring system to the acoustically relevant geometry, the outer ear transmission functions which heretofore were not calculable mathematically (not calculable because of their complex outer bordering formed by the auricle and head, and the complex inner structure of the auricle, and the like which necessarily precludes exact calibration) can now be described mathematically and in terms of measuring techniques, i.e. recorded and pre-determined, and it can now be shown that the outer ear transmission function realized by the artificial head measuring system corresponds to that subjectively present in really existing test persons either identically or with only minor variations so that for the technical purpose they can be regarded as practically identical. Accordingly, the head with simplified geometry provides by its geometrical structure an artificial head measuring system capable of being calibratable, this approach being based on the realization that it can be shown that one does not have to solve the exact diffraction integrals normally necessary for calculating the transmission function, but that by reducing the system to calibratable, calculable bodies such as spheres, cylinders, cylinders with bores, ellipses, and the like, a reproducible total system can be provided which, being calibratable in its parts, is also calibratable in its entirety.

The basic concept of the artificial head with simplified geometry consists in making the entire artificial head measuring system capable of being calibrated by reducing the outer describable geometry, in terms of the geometrical structure determining the directional characteristic of the system, to the acoustically relevant geometry as determined by calculations and measurements, and, in consequence thereof, in building up the artificial head measuring system from individual partial bodies which have pre-determined dimensions and pre-determined positions relative to each other and which as such can be derived from geometrically simple bodies such as cylinder, ellipse, cuboid or sphere and can, therefore, be calculated mathematically.

Fig. 2 shows an example of such a head with a simplified mathematical describable external geometry. In this figure the most important parameters for the geometry are shown. More detailed description is given in [2] and [4].

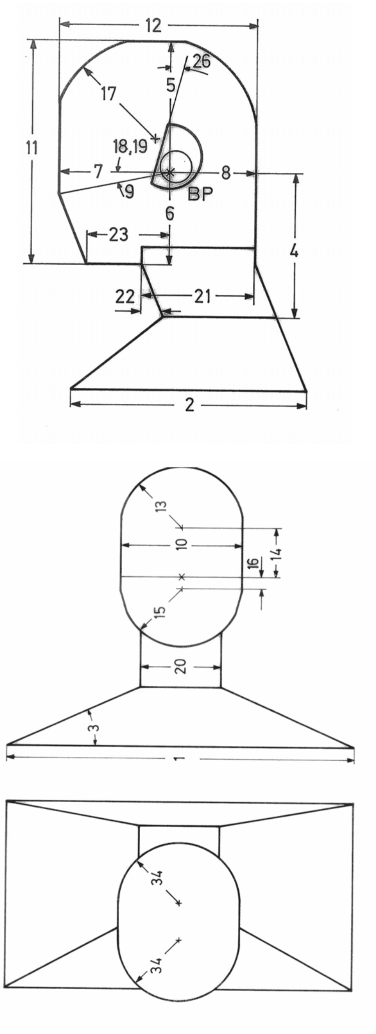

Fig. 2: Head with a simplified mathematical describable external geometry (more detailed information is given in [2] and [4])

Fig.3 shows the same principle of a simplified pinna which is reduced to the dimensions which are important for the directional pattern of the external ear transfer function.

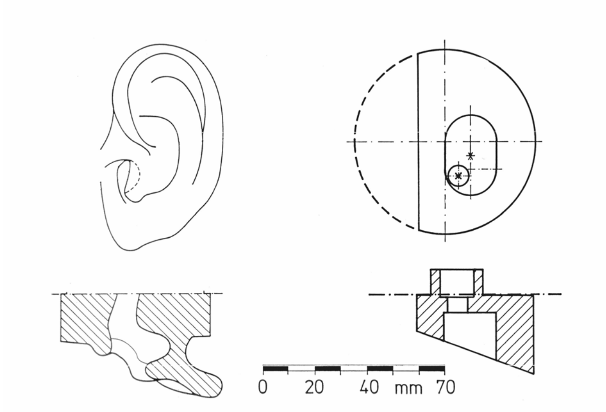

Fig. 3: Pinna with a simplified mathematical describable external geometry, reduced to the dimensions important for the directional pattern of the external ear transfer function

The outer ear transmission functions of the artificial head, the directional characteristic, and the like, are determined in a decisive manner not only by the dimensions, but also by the relative position of the individual partial bodies, for example and in particular the nature of approximation and the position of the auricles.

An exact mathematical description of the disturbed sound field caused by the external ear in dependence on sound incidence is unknown. But by using the Kichhoff's diffraction integrals it is possible to describe the influence of the transfer function caused by head, torso, shoulder and pinna approximately. Only by keeping up the structure of the transfer function and without any exact solution of the mathematical description the geometry can be reduced and the mathematical calculation can be simplified. These reductions allow an approximate estimation of the sound pressure in a point on the surface of the reference plane.

When comparing the transfer function of this model with a measured human outer ear transfer function the directional pattern has to be weighted with the transfer function caused by the cavum conchae- and earcanal-resonances. The model for these parameters of the outer ear transfer function which are independent of sound incidence are described in [1], [2], [3]. Fig. 2 shows the calculated outer ear transfer function of one individual ear in comparison to the minima and maxima given by six measurements at the same ear.

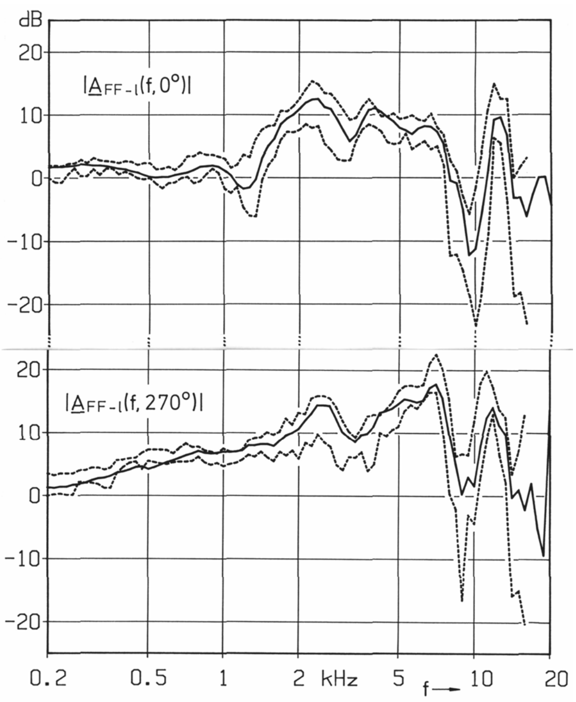

Fig.4: Calculated outer ear transfer function of one left human ear in comparison to the minima and maxima (…) given by six measurements at the same person

In the meantime the ITU has based on this kind of artificial head with simplified mathematical describable external geometry standardization with respect to the artificial head (ITU-T P.58) [5] as you can see in fig. 5.

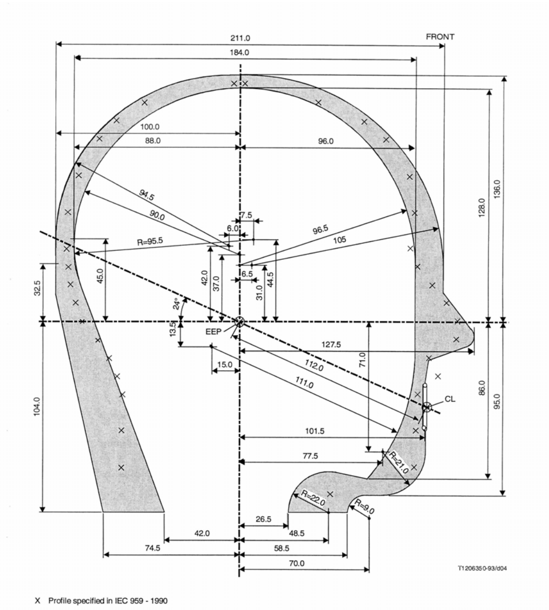

Fig. 5: Limits of the head cross-section in the vertical plane – dimensions in mm, ITU-T P.58

Fig.6 shows the simplified pinna simulator of the ITU-T P.57 [6]. It is recommended to use this artificial ear for measurements of circum-aural, supra-aural and supra-concha earphones as well as intra-concha earphones. This so called type 3.4 artificial ear is also applicable to all kinds of free-field applications. The use of type 3.4 artificial ear is recommended for all applications where pressure depended measurements of receiver characteristics are needed. The type 3.4 artificial ear produces a typical leakage for pressure forces of 1N and 13N which is comparable to normal use conditions of headsets when choosing an appropriate positioning.

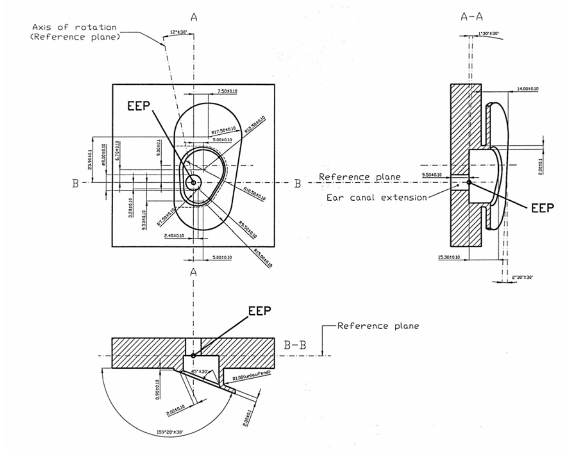

Fig. 6: Artificial ear, type 3.4, ITU-T P.57

Conclusion

It is possible to reduce the geometry of the external ear in such a way that a mathematical estimation and a systemtheoretical description of the outer ear transfer function in dependency on the significant geometrical data of the test person lead to similar results as a measured transfer function. Using averaged geometrical data the averaged transfer function can now be calculated. On the other hand it is possible to calculate and to construct a calibratable artificial head for acoustic measurements which is discussed in [4].

References

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[6] ITU-T Recommendation P.57: Artificial ears (2002)