SOUND FIELD MEASUREMENT IN THE BOUNDED PLAIN

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ABSTRACT: *Computer simulation, being one of the fastest and the most efficient ways of designing and checking, is commonly used nowadays. The correctness of mathematical interpretation used for simulation should be checked by measurements in field measurements or measurement on scaled models. Therefore, the simulation of sound field in bounded plane has been checked on scaled model. The level of sound pressure has been measured in a model, specially designed for this research, and it's characteristics are similar to bounded plain. The results of measurements achieved in this way have been compared with those achieved by computer simulation. The comparison of the results proves the quality of computer simulation of a sound filed. That is possible only in acoustically determined room and condition.*

Key words: *ultrasound, simulation, sound pressure level, scaled models*

1. INTRODUCTION

Knives used in neurosurgical dissection are both scalpels and "ultrasonic scalpels". The latter function using the effects of non-focused ultrasound of high energy level on brain tissue. The scalpel itself has the direct contact with the tissue and due to multifocal concavity and lack of symmetry of the cranium, considerable unhomogeneities and very high oscillations in the distribution of sound field in cranium occur. Therefore, the levels of ultrasound on some spots could rise much higher than when spreading in unbounded space. If it results in the level of sound higher than allowed, permanent damage of the neural tissue appears together with the unanticipated negative effects for the patient.

The simulation of the distribution of ultrasound field in human cranium is used in order to discover the most convenient access to the place of operation and in this way to reduce the unnecessary risk for the patient. In order to carry out successful simulation several things are necessary: to be thoroughly acquainted with the characteristics and the orientation of the ultrasound scalpel, to know the shape of the patient's inner cranium, to be familiar with the acoustic characteristics of human brain and cranium. Of no less importance is the determination of the spot where the neurosurgical operation is going to take place. As the mathematical model of such a simulation is very complex, it is necessary to check each and every detail and harmonize it with the results achieved by control measurement. [1-4]

Taking the human brain into consideration and due to ethical reasons, it is not possible to perform the control measurement in natural environment, but to make a model on which the necessary measurements could be done in order to check simulation model. The first model has been made with necessary simplification; but gradually more and more elements which can influence the level of ultrasound field on particular spots within human cranium will be taken into consideration. [5]

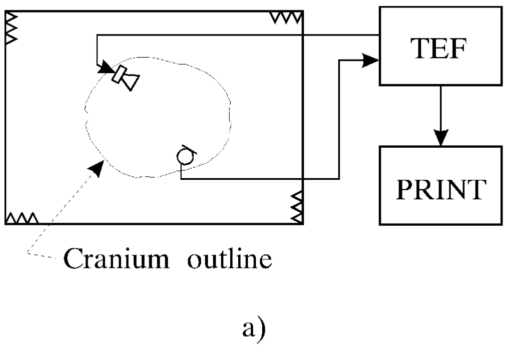
The initial hypotheses for the programming of computer model were based on the limitations that are present in defining the inner shape of human cranium. The exact shape of the inner cranium of the patient could be attained by computer thomography, given in the form of segments, which presents the two-dimensional picture of the head section at a particular altitude in relation to the base of brain. In consideration of that fact, the construction of the simulation model has been designed for the two-dimensional field. In order to check the correctness of the computer simulation, the measurements of the sound pressure distribution and the first reflections on the specially designed model have been done. All the measurements were carried out to the adequate scale.

2. SOUND FIELD MEASUREMENT IN THE BOUNDED PLAIN

2.1 Two-dimensional model and measurement

Neurosurgical ultrasound equipment usually works at a frequency near to 25 kHz. This refers to medium very similar to water by its acoustic characteristics. The measurements were done in the air due to practical reasons, but prior to that it was necessary to perform the transposition of the dimensions of the inner human cranium, as well as the frequency of sound field source. The magnified model of the inner human cranium section was made in scale 5:1 to the original CT picture and the source of the sound field with the frequency of 5 kHz was selected. The 10 mm height of the two-dimensional section was determined by the selected transferable scale and the height of the head section treated by CT. The smallest height of the section was selected; the one which is frequently seen by computer thomography nowadays. The real section dimensions are 2-4 mm. The model itself was made of an 8-millimetre-thin waterproof plywood which was cut into 10-millimetre-wide segments. These were stuck together according to the adequate scheme. The segments were perpendicularly fixed at the back side of the plywood. The plywood absorption coefficient α at a frequency of 5 kHz was equal to 0,15 (α=0,15). Crossword-like scheme was drawn on the model, which enabled the defining of the exact sound source position and orientation, as well as the position of the microphone during the measuring. The model was hung on a thin fishing line in the unechoic chamber, being fixed by side anchorage to prevent any moving. The measurements scheme is shown in Fig.1.

The high-quality dynamic microphone (AKG 80) was used as the sound source due to its both linear frequency characteristics and adequate directional characteristics. First reflections were measured by TDS (Time Delay Spectrometry) method, using the analyzer TEF 12+ (Techron) and the microphone B&K 4007 (1/4 inch). The sound pressure was measured by miniature (1/3 inch) condenser microphone B&K 4138 and analyzer B&K 2032 which had inbuilt quality sound source. The measurement was done in the anechoic chamber in order to get just the reflections caused by the model that simulated “two-dimensional segment”.



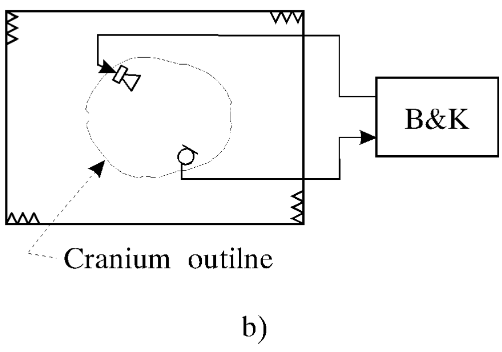


Fig.1 Block scheme of the measurements in the anechoic chamber: a) first reflections, b) sound pressure levels

The measurement of the sound field distribution took into account several characteristic positions of the source within the two-dimensional surface and different orientations of the sound source. The measuring spots of the microphone were selected with planning in advance to check the characteristic spots acquired by computer simulation. [6,7]

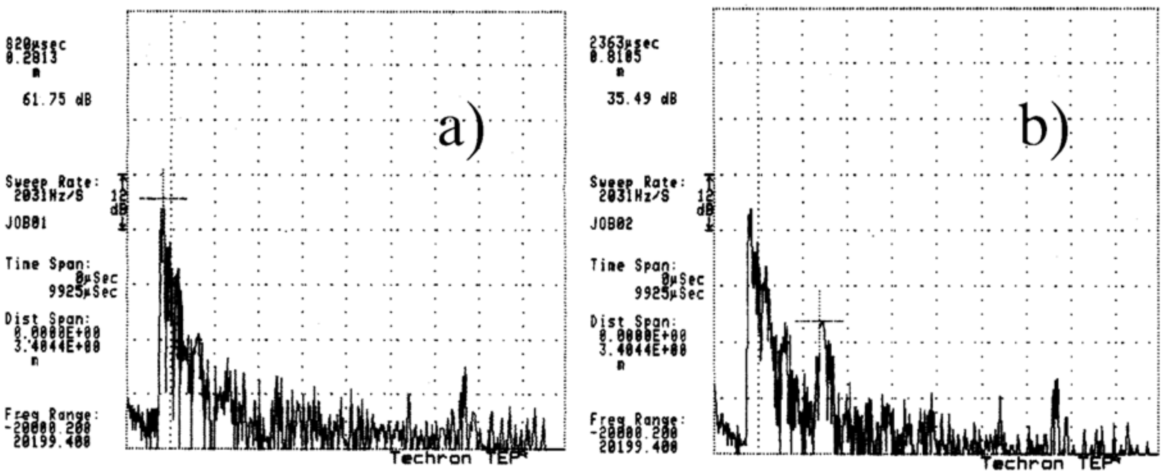


Fig.2 ETC a) for the unechoic chamber without the model b) within the model in the unechoic chamber

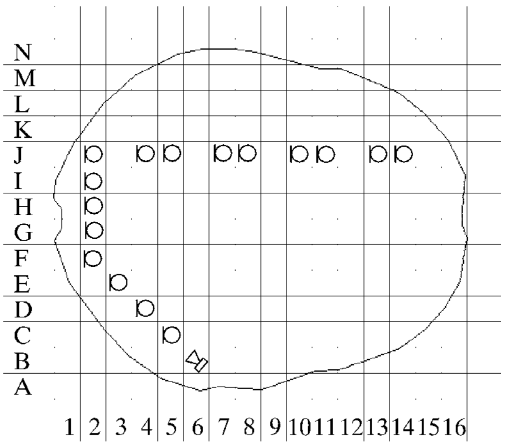


Fig.3 Drawing of the source position and the distribution of the characteristic control measurement spots

Each and every measuring spot was checked by all respects i.e. the presence of the first reflections, their time- and space-amplitude positioning. All first reflections appeared within the first 2.6 ms at the levels of at least 6 dB lower than the direct sound. This measurement was done by measuring ETC (Energy Time Curve) with TEF 12+ analyzer. Fig. 2.a shows ETC in unechoic chamber without the model, and Fig. 2.b shows ETC within the model, which is also in unechoic chamber.

During both measurings the source and the microphone were at the same position. The sound pressure was measured on each and every position where the ETC was measured. Fig. 3 shows the crossword-like scheme of the head-segment model. The model was divided into 167 squares. The sound source and the microphone were positioned in the middle of the "crossword" squares. That kind of division for the first stage of the model development was sufficient. For further measurements we plan to divide each square into smaller sections.

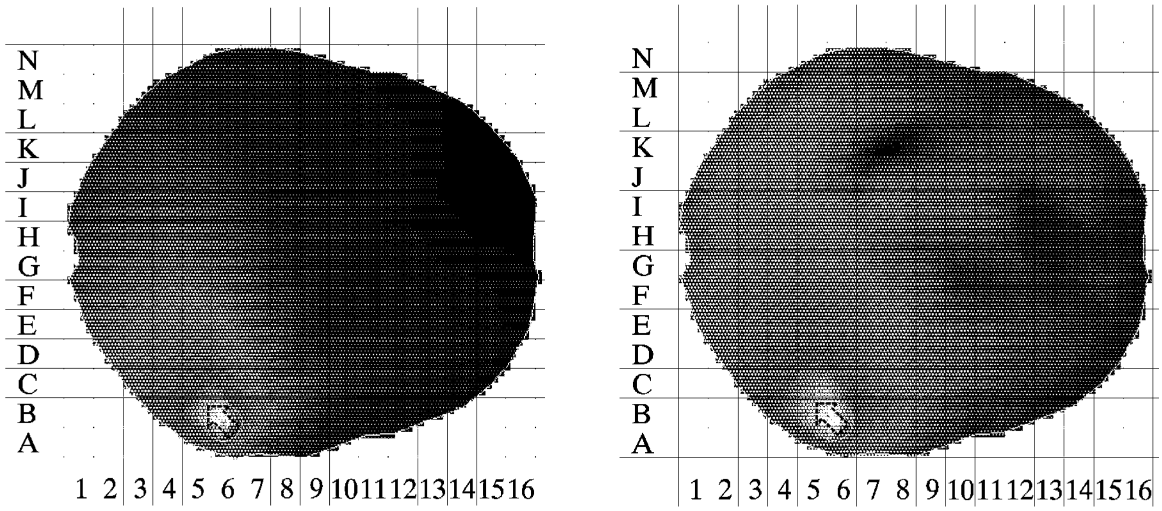
2.2 The results of measurement and computer simulation programme

Due to limited time, the measurements and calculations attained by computer simulation were divided into several groups of measurements. The measurements in the first group were done for a limited number of spots marked in Fig. 3. The results of measurements and calculation are given in Table 1.

Table 1. Results of SPL in dB achieved by both simulation and measurement for the spots marked in Fig. 3.

spot	C5	D4	E3	F2	G2	H2	I2	J2
simulation	-16.4	-23.2	-27.6	-30.4	-31.2	-31.8	-31.7	-32.5
measurement	-15.8	-23.0	-26.7	-30.1	-32.4	-32.8	-34.9	-33.9
Δ	-0.6	-0.2	-0.9	-0.3	1.3	1.0	3.3	1.4
spot	J4	J5	J7	J8	J10	J11	J13	J14
simulation	-33.7	-34.8	-38.5	-38.0	-38.3	-39.4	-41.6	-41.3
measurement	-35.5	-34.6	-36.9	-38.2	-39.4	-41.3	-42.1	-45.8
Δ	1.9	-0.2	-1.6	0.2	1.1	2.0	0.6	4.6

Sound pressure level visualisation of bounded plane calculated by computer programme is given in Figure 4. Figure 4a. shows sound pressure level for calculated bounded field without reflection from boundary. Figure 4b. shows sound pressure level with first reflection from the boundary. The influence of the first reflection is obvious. Darker areas show lower levels of sound pressure level. The arrows within segments present the position and the direction of sound source. Sound source level and directional characteristic are identical in both cases..



a)

b)

Fig.4. Visualisation of simulated sound pressure level a) without reflection from boundary b) with first reflection from boundary

3. DISCUSSIONS

The used two-dimensional model of the ultrasound field simulation applied for cranium section enables the estimation of the sound field pressure level in that section. The possibility of visualisation enables localisation of characteristic spots, and then, for the corresponding spots on the model, it is possible to carry out control measurements in an unechoic chamber. Taking into consideration the results got both by simulation and model measurement in an unechoic chamber, the following facts are easily noticeable: a) the differences in sound pressure level of the selected spots are within ± 2dB with exception for the spots I2 and J14; b) spots I2 and J14 are situated closely to the boundary where first reflections have the strongest influence. All said and done sets the need for considering more parameters in order to undertake the simulation as close as possible to the real condition of inner cranium bounded plain.

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MJERENJE RASPODJELE ZVU^NOG POLJA U OME\ENOJ RAVNINI

Simulacija ra~unalom kao najbr`i i najefikasniji na~in projektiranja i provjere sve se ~e{}e koristi. Ispravnost modela koji se koriste za simulaciju potrebno je potvrditi mjerenjima na konkretnim objektima ili na njihovim modelima. S toga je obavljena provjera simulacije raspodjele zvu~nog polja u ome|enoj ravnini mjerenjima na modelu. Mjeren je zvu~ni tlak na modelu, posebno izra|enom za tu namjenu, koji je imao svojstva pribli`na ome|enoj ravnini. Rezultati dobiveni mjerenjem uspore|eni su s kompjuterskom simulacijom. Usporedba rezultata ukazuje na postignutu kvalitetu kompjutorske simulacije raspodjele zvu~nog polja u bilo kakvom prostoru, pod uvjetom da je on akusti~ki odre|en.

Klju~ne rije~i: *ultrazvuk, simulacija, razina zvu~nog tlaka, model u mjerilu,*