NUMERICAL SYSTEM OF ACOUSTIC FIELD VISUALISATION

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Summary

This article presents the physical base of the numerical system for analyse and modelling acoustic fields by an acoustic head of arbitrary construction generated. The system allows to analyse the sending-receiving multielement ultrasound heads. Nowadays the system is being expanded to analyse the propagation of pressure wave through the acoustic media. The expansion of the system will allow to use it for investigation of biological tissues and for mechanical devices monitoring.

Keywords: ultrasound field of an acoustical head, numerical modelling, linear system, acoustical visualization

1. INTRODUCTION

The main aim of this work is the presentation of the possibility of the elaboration the tools (theoretical and numerical) for the analyse of acoustical head of arbitrary construction. The method allows to describe an acoustical pressure wave in real mediums generated by the acoustical head of this kind and a creation of the numerical model of spatial and time variation of the field behaviours [1, 2, 3, 4]. Then, such model will be developed to construct the numerical model which works in reverse direction. It means that the model should be able to recreate the state of the acoustical system basing on the signal which travel through the medium and on the changes of such signal in frequency domain.

2. PROJECTING SYSTEM

In present time the projecting system allows to analyse the acoustic fields produced by ultrasonic transducers. Basic analyse enable us to determine the pressure map in homogeneous medium for the far field condition. Additionally, there is a possibility to calculate the efficiency of power transfer between the transducer and surrounding medium. Some of calculations on Mason equations are based [5] and some there are the original achievement of the authors.

The elaborated system allows to analyse the generation of frequency-modulated wave packets. Those packets in e.g. pulse coding are used. Such option allows to check how the analysed head could work when a signal of its excitation has a wide spectrum of frequencies. For these cases, the spatial characteristics of the radiated acoustical field have been changing, because the acoustic properties of multielements head are as a rule a strong function of frequency its excitation [6, 7].

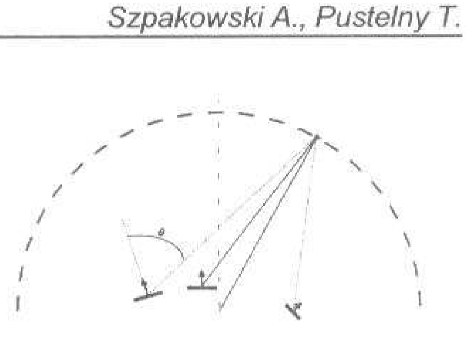

Figure 1: Idea of the geometrical analyse for multielement acoustical head

3. THEORETICAL BACKGROUND OF THE PROJECTING SYSTEM

The theory part of the projecting system is based on the assumption that any surface acoustical source can by approximated by a group of elementary point sources, vibrating in proper phases. This approach leads to modification of the Huyghen?s formula, that can by expressed us [8, 5]:

$$p(P) = \frac{j\rho\omega}{2\pi r_0} \exp\left[j(\omega t - kr_0)\right] \iint_S v_{n\,max}(S) \exp(-jk\Delta r)\, dS \tag{1}$$

Simplification of this approach can be achieved by assuming, that the pressure distribution is calculated in Fraunhoffer?s zone [8, 5, 9]. Those equations allow to calculate the pressure distribution in medium from the transducers, and enable to get a fix on transmitting and receiving directivity characteristics. More extensive description on theoretical and numerical background can be found in previous publications [6, 7, 10].

To calculate the propagation of energy through the acoustical system we use the linear representation of the system: sender-medium-receiver [11]. In this approach, the acoustic pressure distribution from transducer is found from the convolution between the acceleration of the surface of transducer and spatial impulse response. The impulse response depends on the relative position of the considered point in the field and the transducer. In most cases this kind of dependency makes impossible to analytically solve the problem and makes necessary to use models to numerically find the solution.

In general, such approach can be written in the equation [6]:

$$y(t) = h(t) \star x(t) = \int_{-\infty}^{+\infty} h(t')x(t-t')dt' \tag{2}$$

where, the h(t) is the transition function of a linear system of sender-medium-receiver for impulse excitation (sc. a spatial impulse response of acoustic linear system).

As a result of the analyse, the calculation of a spatial impulse response for an arbitrary shaped aperture of transducer might be determined. The pressure field for such aperture S mounted in an infinite rigid baffle can be found by the Rayleighs? integral [10]:

$$p(\overrightarrow{r_1},t) = \frac{\rho_0}{2\pi}\int_S \frac{\frac{\partial v_n(\overrightarrow{r_2},t-\frac{|\overrightarrow{r_1}-\overrightarrow{r_2}|}{c})}{\partial t}}{|\overrightarrow{r_1}-\overrightarrow{r_2}|}dS \tag{3}$$

where: v_n is the normal velocity of the elementary parts of a transducer surface. The above equation assumes, that according to the Huyghens? principle the radiated field can be found by integrating the contributions from all small areas on the surface of the transducer. This approach assumes also that the propagation occur in a homogenous medium and that no attenuation takes place. After converting this equation and introducing the velocity potential Ψ in a form of [10, 11]:

$$\vec{v}(\vec{r},t) = -\nabla\Psi(\vec{r},t) \tag{4}$$

and,

$$\overrightarrow{p_0}(\vec{r},t) = -\rho\frac{\partial\Psi(\vec{r},t)}{\partial t} \tag{5}$$

So, after assuming that the surface normal velocity is uniform on an entire transducer one can write down the velocity potential as:

$$\Psi(\overrightarrow{r_1},t) = v_n(t)\star\int_S \frac{\delta(t-\frac{|\overrightarrow{r_1}-\overrightarrow{r_2}|}{c})}{2\pi|\overrightarrow{r_1}-\overrightarrow{r_2}|}dS \tag{6}$$

where, the integral is the spatial impulse response of the system:

$$h(\overrightarrow{r_1},t) = \int_S \frac{\delta(t-\frac{|\overrightarrow{r_1}-\overrightarrow{r_2}|}{c})}{2\pi|\overrightarrow{r_1}-\overrightarrow{r_2}|}dS \tag{7}$$

This approach was proposed by P. Stepanishen [10] and later used by J.A. Jensen in the papers [11, 12]. The authors of this work propose the expansion of this approach and treat entire acoustic system as a set of elementary elements. Each element represents one physical phenomenon, e.g. reflection from some obstacle or radiation of a pressure wave by a transducer. Each phenomenon is characterize by its impulse response (the transfer function). Such approach facilitates the numerical analyse and makes possible to track an energy propagation in the system.

4. VISUALISATIONS

The important part of the elaborated numerical system is its visualisation module. There is great emphasis on proper visualisations of calculated data of analysed acoustic field [6, 13]. In case of diverse, three-dimensional characteristics, special methods has to be used. In the system there are several means of the date presentation. They encapsulate:

- classical two dimensional directivity characteristics in polar coordinates,
- three dimensional directivity characteristics in spherical coordinates,

- two and three dimensional intensity map,
- dynamic visualisations which allows tracking of acoustic field changes

In the Fig.2, as an example the spatial characteristic of acoustic field (acoustic pressure), generated by the head, composed of six round transducers.

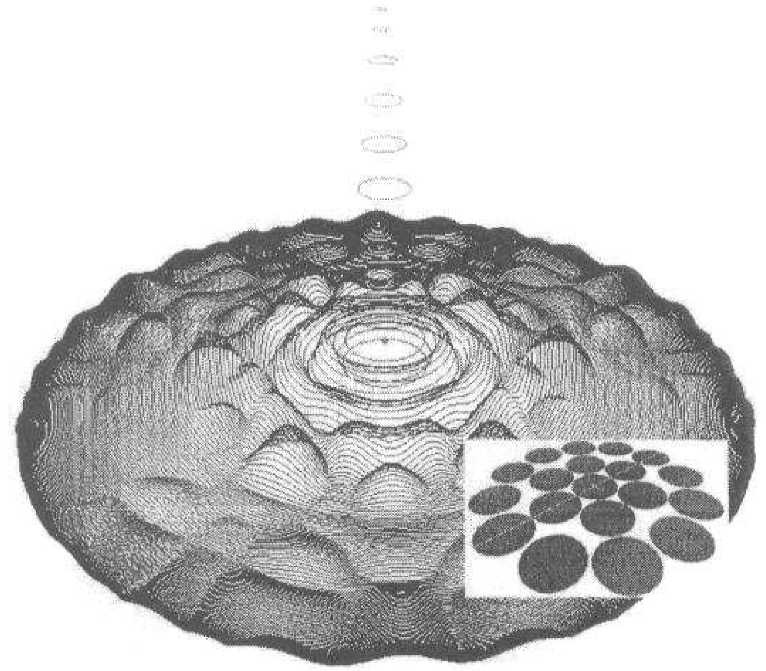

Figure 2: The acoustic field generated by the head, composed of nineteen round transducers

5. FEATURES OF THE NUMERICAL PROJECTION SYSTEM

The system is now expanded and focused on calculation of the acoustic waves propagation. Our aim is a system which allow us to analyse the propagation of acoustic wave in complex set. The basic parts of the system allows, (or will allow in near future), the following calculations:

- translating the electrical excitation into mechanical vibrations for the acoustical head which consists of simply transducers for their arbitrary configuration,
- describing mechanical vibrations considering apodization and other than piston movements,
- excitation of energy into surrounding medium with proper directivity characteristic,
- propagation of the wave in homogeneous, linear medium,
- refraction and reflection of the wave on the different acoustical impedances
- recording of the acoustical field by a transducer and the transformation of acoustical signal in the voltage response

Those features of the analysing numerical system will be applied in projecting of the self-adopting ultrasound head. The main target of this investigation is elaboration the numerical model of such acoustical heads as well as elaboration of a prototype of the ultrasound system which could be able to determine the properties of sending-receiving elements react currently on random disturbances in an acoustical system.

6. Experimental verification

The experimental verification, which has been partially fulfilled, will enclose:

1. measurements of the acoustical signals in a stable, well described and known environment in the configuration of:
   - direct transmission,
   - indirect with reflection from well described and simple obstacle,
   - indirect with several reflection elements
2. measurements of the signal in floating environment concentrated on:
   - stability of the model in various mediums and under different physical conditions,
   - repeatability of calculated and gatered data
3. verification of the correlation of experimental results with the data obtained from the numerical model
4. measurements in biological structures oriented on:
   - imaging of physical parameters of biological tissues,
   - localisation of the areas with properties important for medical diagnostic.

7. Conclusion

The main aim of the first part of this work was the creation of system that will be able to theoretically calculate the distribution of acoustic pressure caused by ultrasound multielement head. This kind of analyses allow us to estimate the directivity characteristics of the ultrasound head under consideration and its effectiveness.

The system, which main guidelines in this work were presented, it has been expanding and developing. Nowadays the system is being expanded to analyse of the propagation of pressure waves in various media. It allows to simulate the behaviour of acoustic waves for complex acoustic systems (sender-medium-receiver). The system will be applied for solving real problems such us biological tissues and mechanical devices monitoring, in near future. The next results of theoretical and experimental investigation will be published.

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