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SELECTED PROBLEMS OF THE DESIGN OF THE MULTI-ELEMENT SONAR ARRAYS

Zbigniew Wojan

Technical University of Gdańsk
Faculty of Electronics, Telecommutation and Informatics, Department of Acoustics
ul. Narutowicza 11/12, 80-958 Gdańsk, Poland
e-mail:szosia@pg.gda.pl

The paper discusses the design and technology problems of planar, large-scale sonar arrays. It covers the fundamental operating parameters that bring the original array design to the requirements of an actual sonar system and briefly discusses state of the art technology issues. The main part of the paper includes a description of array design using PU elastomers in the volumetric filling version. This material is used both for the internal framework, the casing, sealing housing and the coupling layer. The author highlights the limitations and risks of using polyurethane to manufacture planar sonar arrays, especially those for deep water operation. Examples of designs and technological problems are given and discussed. They are the result of many years of experience gathered in the designing and testing of arrays made for the various sonar systems at the Department of Acoustics and Department of Polymers of the Technical University of Gdansk.

INTRODUCTION

In practice, there are two stages to the process of designing multi-element transducer arrays for the various sonar systems. The first stage involves the creation, mainly using analysis and computation, of the conceptual design of an array. Its electroacoustic conversion and field functions parameters fully meet the system requirements in relation to the function and planned application [1], [2]. At this stage the general array geometry, its spatial form (plane, cylindrical), the shape of the active aperture (rectangular, circular) are defined. The type of piezoceramic material (its electrostrictive and mechanical properties), the quantity, shape and dimension of elemental transducers contained in the array, how they are divided and distributed in the functional sections (staves) and their relative position are established, as well. All this conditions the antenna's technical parameters: resonance frequency, bandwidth, transmission characteristics, transmitting efficiency and maximal power, voltage sensitivity, mutual and radiation impedance of the active elements as well as the beam patterns as the effect of combined properties [3], [4]. The question – how to make a adequate design using the available technologies and materials and taking into account the phenomena that have been either idealised or neglected – can be answered in the second stage of array design which involves the construction and technology.

The second stage should solve the issues listed below in the following sentences. Optimisation and full repeatability of electromechanical and field parameters of each of the elemental transducers in actual conditions. Optimal and repeatable coupling of the active apertures of all elemental transducers with the loading medium through the array housing. Full or controlled acoustic isolation between the antenna's elemental transducers. Isolation of elemental transducers from external acoustic interference carried by the array housing, especially the external mountings. The multi-element transducer matrix as well as the other array components (electronic parts, wiring, mounting) and their connections have to be waterproof because of the long periods of submergence (penetration and hydrolysis) and natural and polluting components of sea water (corrosive and galvanic processes). The array structure and especially the piezoceramic matrix have to be resistant to high and rapidly changing hydrostatic pressure.

1. LARGE-SCALE MULTI-ELEMENT ANTENNAS MADE OF PU ELASTOMERS

When analysing the conceptual design, the array designer has to choose the basic technology of manufacture. This decision determines two other design solutions: a) the external housing and mutual relations between array components (sealing, pressure resistance, coupling with the loading centre), b) the forming and mounting of piezoceramic profiles in the multi-element transducer matrix (optimisation and repeatability of the parameters of elemental transducers, acoustic isolation between the elements, support of the internal active surface of the profiles, resistance to deformation). There are several technologies for making large-scale arrays, such as: titanium boxes with oil filling, bonded multi-layer structures with rigid support, volumetric polyurethane fillings using elastomer for the housing and internal framework.

PU elastomer arrays have numerous functional advantages as well as some disadvantages, some of which are quite significant. The technology is difficult, involves many stages and expensive special equipment. It also means that some regimes have to be followed absolutely. However, once mastered, the technology proves reliable and relatively inexpensive [5]. Polyurethane materials have a number of fundamental functions to play in the array design. Due to the fact that ρc values of these materials are close to ρc of water and they have relatively low attenuation rate, they perform well as the layer that couples piezoceramic profiles with the centres [6]. When necessary, they can also separate the same profiles in the multi-element matrix from undesired vibrations that are carried, e.g. by array mountings and act as a flexible easily moved binder of rigid mechanical array elements. Thus, the otherwise destructive effect of changeable deepwater pressure, can be minimised. It also ensures a lasting and complete sealing where these elements come into contact, i.e. between the protective layer and exposed mounting and the protective layer and the external wiring in varying pressure.

To optimally use PU elastomers, especially in volumetric fillings of plane large-scale hydroacoustic antennas, the design of the antennas has to be tailored to the requirements of the technology. The design helps to counteract the specific risks to array durability caused by the material properties as follows:

1. In the case of multi-layer compact structures, the big temperature span ($\Delta t \cong 200°C$) in the process of elastomer thermal hardening causes periodical deformation due to distinctly varied thermal expansion coefficients. This effect is similar to the thermobimetalic phenomena and applies mainly to the support layer where even a slight deviation from the plane would permanently ruin the piezoceramic matrix and in some versions would destroy it altogether.

2. In the process of intermolecular chain binding, the high volume contraction coefficient of the elastomer may cause non-homogenous stresses of the housing towards the particular elemental transducers and distort the repeatability of the mechanical parameters. When particles of the coupling layer move (as a result of the contraction) along the surface of the active piezoceramic matrix, the external signal wires may be ripped off and the binder permanently separated. All this will destroy the array completely.

3. Known polyurethane elasticity causes the plastic to move within the array volume under the influence of hydrostatic pressure which puts the array at risk in two ways: a) the ceramics – coupling layer binder may become separated for reasons similar to contraction, however, in this case it will be water pressure on the housing in the piezoceramic matrix surface that will be responsible for the shift, b) the pressure on the piezoceramic matrix surface may not be equal and may cause it to deflect given the elastic support (similarly to temperature changes in the elastomer hardening process). As a result, elemental transducers will no longer be bound with the coupling and support layers.

4. Increase in elastomer temperature during crosslinking (after prior coating to seal all parts of the array) excludes any gaseous content in the array volume. Air rests, gasified solvents and glue components which increase in volume as the temperature rises, may trigger destructive mini explosions in the structures of array elements, tear away the coupling layer from the ceramics and make the housing no longer hermetic by producing extensive micro channels.

2. SUGGESTED SOLUTIONS

The Department of Acoustics at the Technical University of Gdansk has succ essfully made plane and cylindrical arrays consisting of hundreds of elements. This was made possible thanks to the Department's own design solutions and specialised modifications of the general polyurethane technology.

Sample construction solutions are shown in Fig.1 and Fig.2. Some important parts are described below in the paper and marked with numbers.

These accomplishments have lead to the elimination of the difficulties and risks listed above:

1. The support layer (1) of the piezoceramic matrix (2) neutralise the vibrations of the internal active surface of elemental transducers, whose opposite surface is under the influence of high hydrostatic pressure that pushes the profiles against the support. This difficult task is achieved using several layers of materials each having a different function i.e. attenuation, scattering, absorption of vibrations and also maintaining high crushing strength and rigidity of large circular and especially rectangular surfaces. As a result, the parameters of layers are highly differentiated. The support of the matrix is made as a loosely riveted sandwich made of functional layers that can easily move on elastic and sealing inter-layers (required by the lack of air in array structures).

2. The negative effects of contraction in volume of the PU elastomer on the array can be prevented by putting the layers several times and by using a metal truss or a grid to limit the areas of free movement of the material by introducing local shrinking stresses.

3. Resistance to high hydrostatic pressure is obtained by designating zones of absolute rigidity and the controlled movement zone in the array volume. The piezoceramic matrix including the support layer and metal cover with the coupling layer, make a rigid package that will not deflect and move within the elastomer volume depending on the value and direction of external pressure. The elastomer space contained between the rigidity zones should be selected individually depending on the size and shape of active aperture and the predicted array operation depth.

4. Undesired gases can be eliminated by making compact and fully complete antenna elements, separated with cavities provided with deaeration ducts using gravitational casting, complex, porous and non-homogenous structures are coated with elastomers in exsiccators using the controlled vacuum technique.

The basic disadvantage of arrays made of polyurethane is that once mechanically damaged, the multi-element matrixes cannot be repaired. Special array covers should be used during transportation and installation. It may not be sufficient to discharge heat from the volume of the cast in the case of non-pulse operation of powerful transmitting transducers.

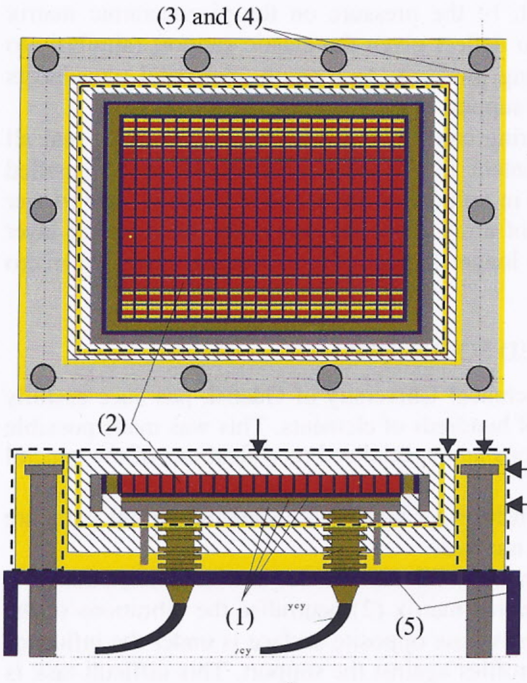

Fig.1.

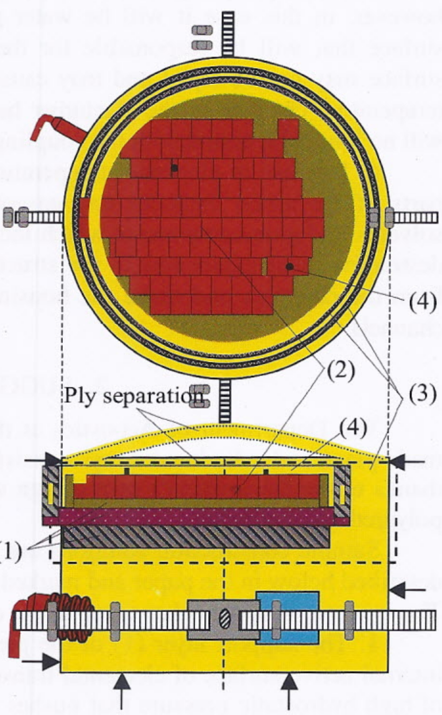

Fig.2

Fig.1. The construction of the array with two stiffness zones, supported by stiff housing (5).
Fig.2. The construction of the array with a single stiffness zone, without stiff support.

← Hydrostatic pressure | Elastomer PU
Zone of displacement | Zone of stiffness

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