AN EXPERIMENTAL STUDY ON TRANSDUCER FOR THE DDS TECHNOLOGY DEMONSTRATOR

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R&D MTC has began designing and building the next generation wideband Diver Detection Sonar (DDS, with cylindrical multielement piezocomposite transducer.

The paper will focus on key features of DDS technology demonstrator, with special attention on technologies of the transducer. The new transducer is designed at the cooperation with the producer of the transducer – Materials Systems Inc. (Littleton, USA), remainder hardware and software solutions are designed in R&D MTC.

In this article specific theoretical and technological principles of the wideband cylindrical piezocomposite transducer will be presented. The implementation of the transducer to the wideband Diver Detection Sonar (DDS) will be described. The results of transducer measurements, transmitter modules, matching circuits modeling and examples of application will be also presented.

INTRODUCTION

Piezocomposite 1–3 technology using shading technique shapes the transducer response (beampattern) without resort to complex electronics – it is possible due to ceramic rod is electrically isolated from its neighbour as well as due to ceramics rods are embedded in polymer matrix which significantly reduces coupling between the different modes in the ceramic that effectively provides a uni–modal response without unwanted resonances. Composites materials are inherently wideband because of damping provided by the polymer matrix and furthermore the introduction of specially designed matching layer between the outer electrode and the sea water.

The composite structures reduces the acoustic impedance closing it to impedance of the sea water – it means the higher power is transferred, so efficiency increases.

The electro-acoustic performance of these piezoelectric materials embedded in polymer matrix, sophisticated data processing and software solutions have enabled improvement in operational parameters of sonars, adaptation of sonar to specified protected object, propagation and environment condition. The designed technology demonstrator of DDS is a first attempt of our firm leading to next DDS generation intended to operate in shallow water. The new array has been created at the cooperation with Materials Systems Inc. (Littleton, USA), remainder hardware and software solutions are being formed by R&D MTC.

Technology demonstrator (TD) of DDS has been designed as two modules: underwater and above water [4]. Both modules connect by cable: power + data (ETHERNET). Underwater parts will be in cylinder form with possibility to be placed on the sea bottom or suspended in column water. In the further parts of the paper, we described in details only one of the most important sub–assembly: transducer.

The following assumptions for TD's transducer have been established:

- tranducer will be made as curved piezocomposite (piezoelectric ceramic rods in a polymer matrix) array – cylindrical array with 180^o aperture and 64 elements,
- tranducer will operate in shallow water (survival depth – 100 m),
- frequency range: 60 kHz ÷ 80 kHz,
- source level: $\geq$ 205 dB,
- vertical side lobe level: -21 dB*,
- diameter: $\leq$ 350 mm,
- transducer height: 120 mm,
- elements spacing of transducer: $< \frac{1}{2} \lambda$,

** – vertical side lobe level without shaping is 13.4 dB.*

1. DESIGN OF TRANSDUCER

Technology demonstrator (TD) of DDS utilizes piezoelectric materials in the transducer to generate and receive the acoustic signals. The transducer determines the performance limits of the sonar system. The use of piezocomposite improves transducer's performance.

Advantages of piezocomposite transducers for sonars:

- increased sensitivity,
- better resolution by broader bandwidth,
- improved image contrast by reduced side lobes,
- better efficiency (increased signal to noise ratio), by improved impedance matched to water,
- low interelement cross talk,
- greater element to element phase and amplitude uniformity,
- low cost construction.

Piezocomposite design goals:

- maximization of capacitance,
- electrical impedance match to system,
- acoustic impedance match to water,

– maximization of electromechanical coupling,
– electrical loss tangent minimization,
– mechanical loss (1/Qm) minimization.

Any composite design is a compromise among these parameters.
For environment condition of Baltic Sea: temperature 10^{o} C and salinity = 7 $^{o}/_{oo}$ sound speed is approx. 1450 m/s and element spacing of the transducer for 70 kHz is 10.36 mm and for 80 kHz is 9.06 mm. Calculated, at assumed transducer dimensions, spacing is:

$$d = \pi * 175/64 \approx 8.6 \text{ mm}$$

We assumed that developed transducer will have 64 elements with width = 7.8 mm and gap = 0.8 mm; assumed spacing (see Fig. 1) is less then theoretical spacing for 80 kHz by 5.1 %, which protects against spatial aliasing at lowest frequencies.
Average 3 dB beam width is:

$$\Theta_h \approx 50.7 * \lambda / L \approx 9^{o}$$

where: λ is wave length and L = 120 mm (see Fig. 1).
Beams spacing $\Theta_s \approx 3^{o}$.

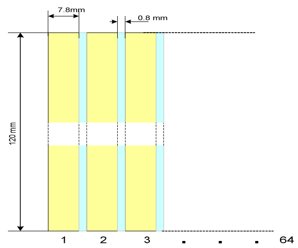

Fig.1. Elements shape and spacing

Transducer element is a piezocomposite block with ceramic rods embedded in polymer matrix; it should be noted, that for ceramic rods with height compared to their lateral dimensions prevail length mode of vibration resulting in improved electroacoustic efficiency, then sensor sensitivity and signal/noise ratio increased. Other benefits, related to applying piezocomposite transducer to sonars, are: better resolution due to broader bandwidth, reduced side lobes and moreover low cost construction [2].

2. FACTORY ACCEPTANCE TESTS

Materials Systems Inc. invited CTM representative to visit MSI facility and laboratory to carry out the factory acceptance test of the sonar transducer.
Tests conducted for following parameters:

– TVR (all elements),
– RVS (all elements),
– Impedance in water (all elements),
– Horizontal directivity with all other elements electrically shorted (all elements).

Tests were conducted in MSI tank for the transducer connected with all elements open circuited except for the element under test. It was determined that capacitive cross coupling between element's wire pairs within 5 meters cable adversely affected element's TVR, RVS and directivity. To eliminate the cross coupling and better simulate performance under actual operating condition (preamps and power amps located within 40 cm of the array), every element was retested for RVS and TVR with all other elements short circuited. This eliminated the performance irregularities.

Test results:

- One element's TVR (ref. 1μP/V for 1 m), predicted 125 dB and measured 144 dB,
- One element's RVS (ref. 1V/1μP), predicted – 188 dB and measured –176 dB,
- Transmit bandwidth (-3 dB), predicted 60 kHz to 80 kHz and measured 61 kHz to 82 kHz,
- Receive bandwidth (-3 dB), predicted 60 kHz to 80 kHz and measured 65 kHz to 81 kHz,
- One element's horizontal directivity, measured 80º,
- 24 elements segment beamwidth, measured 50º.

The summary impedance in water of piezocomposite transducer elements are presented in Fig. 2 and 3.

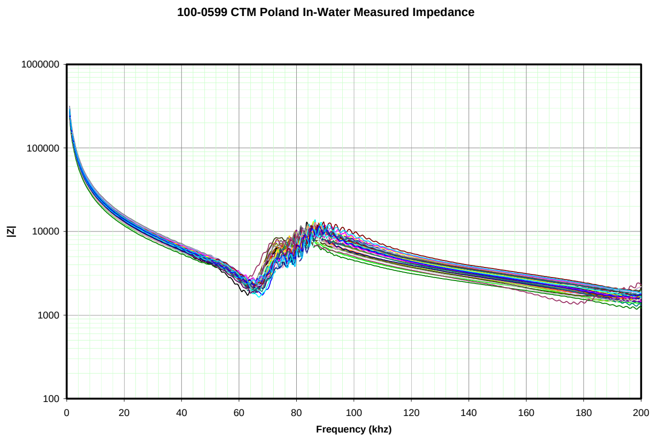

Fig.2. In water measured impedance module for 64 elements

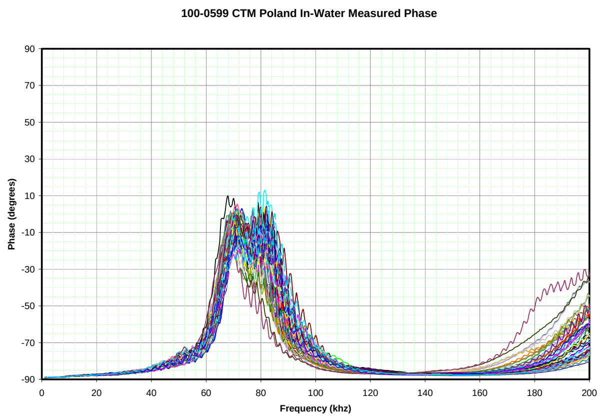

Fig.3. In water measured impedance phase for 64 elements

3. ARRAY VERTICAL BEAM PATTERN

During the design of the transducer, vertical beam pattern shading have been included, which theoretically provides -30 dB side lobes. Electrical and acoustic performance predictions are based on software models which have generally shown good correlation to typically measured performance, but do not predict secondary effects such as mounting and housing effects of manufacturing variation. Since prototypes are the first units built, according to new design, performance can not be predicted with complete accuracy. Therefore electrical and acoustic performance specifications for prototypes have been met on a best effort basis.

However, because the piezocomposite is comprised of discrete piezoceramic pins, the effective pattern is determined by both the screen printed electrode pattern, which is quite precise, and the piezocomposite ceramic pin locations, which are more random. It is therefore not possible to implement a perfect pattern and side lobes should be higher than theoretical. We expect to come close to -21 dB side lobes, but can only commit to meeting the specification on a best effort basis.

MSI have been conducted additional modelling with 3 elements model of the transducer. Measurements of this model can give better information about vertical beam pattern side lobes. Vertical beam pattern tests of model were conducted in Technical University tank for selected frequencies.

Selected test results of vertical beam pattern are presented in Fig 4.

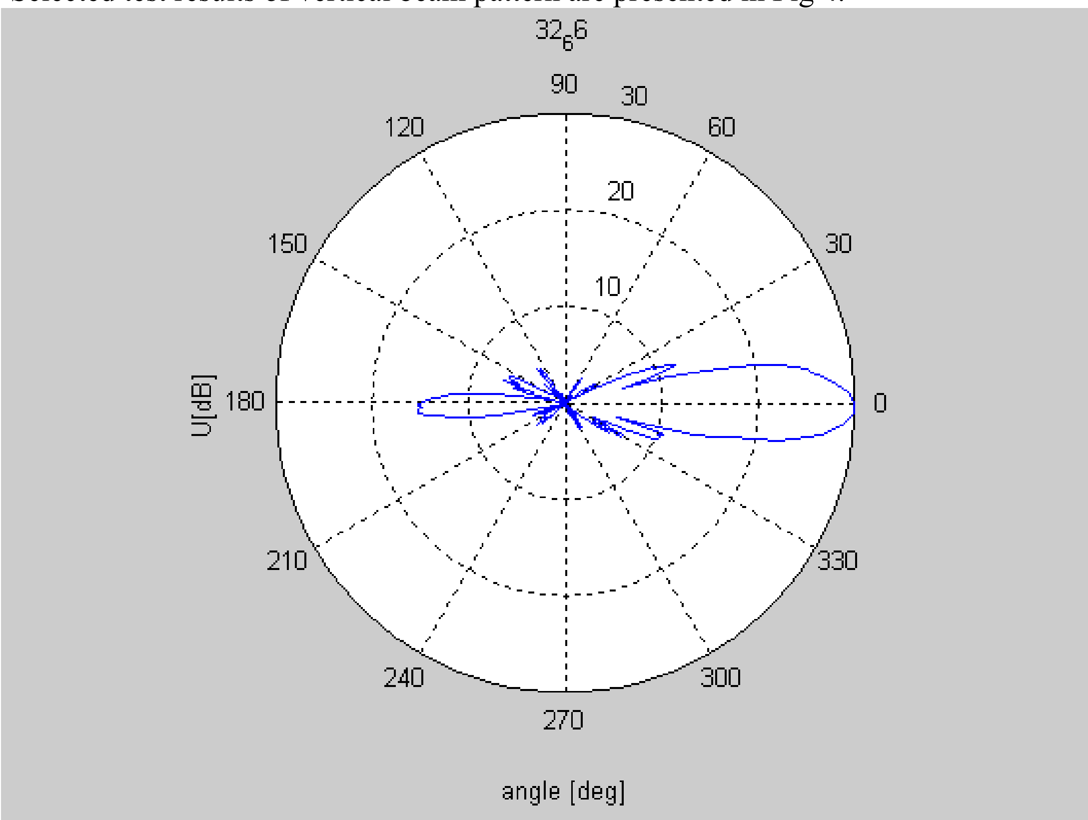

Fig.4. Single element vertical beam pattern for frequency 66 kHz

Side lobes for narrow band system with one selected frequency are on the level -18 dB and -20 dB. This result should be accepted because the distance between the composite pins is greater than the pattern resolution required to achieve -30 dB shading. We suspect that the results for wideband system will be -21 dB.

4. MEASUREMENT AND CALCULATION

The model of the transducer consisting of three composite elements was examined in detail. His electric impedance in the function of the frequency and the directivity pattern was measured. Results of the measurement of the impedance are confirming the advantages of composite technology. As a result of lowering the acoustic impedance, the transducer is better matched to the working environment. We can see as the influence of the radiation medium (the water) on the wheel shape of the impedance of the transducer -fig.5.

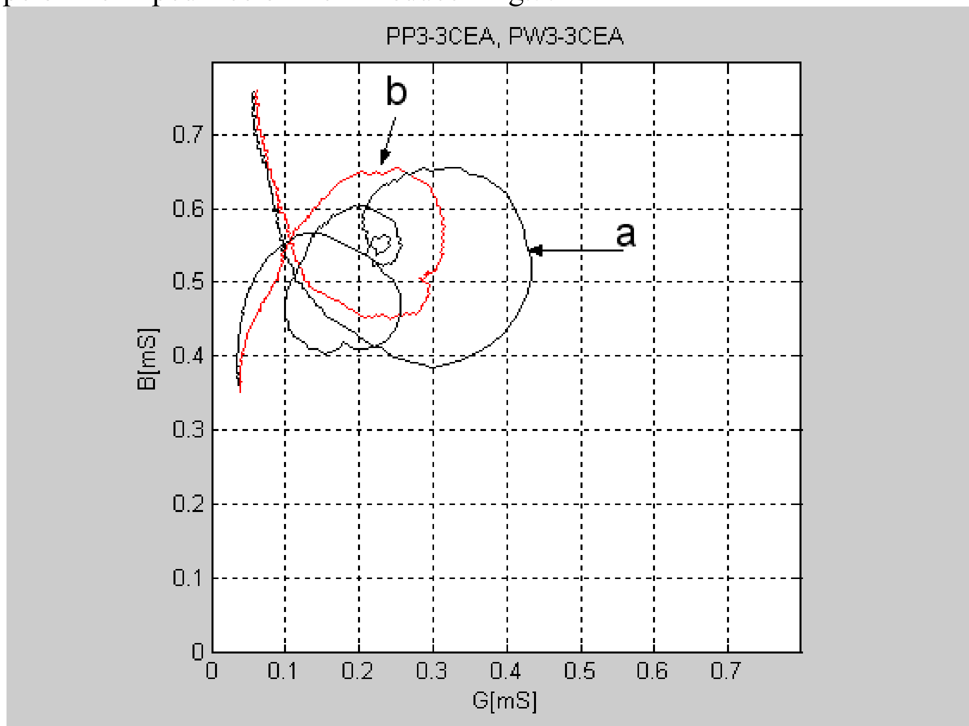

Fig.5. Electric admitance of transducer in: a) air, b) water

Through the application of composite technology, the dielectric coefficient of ceramic material falls down. Because of that, the static capacity is smaller and it is easier to compensate the imaginary part of the transducer.

Next pictures fig.6 and 7 are showing the shape of real and imaginary part of admittance of the transducer. On this basis it is possible to conclude, that irregularities in shape's characteristic of not-loaded transducer becomes regular after immersing the transducer in water. In this case, when the transducer is loaded, it has one mode of vibration. It is possible to explain it with the fact that such a phenomenon is appearing when the transducer is heavy loaded, which in the case of composite technology is taking place here. Different modes of vibrations disappear.

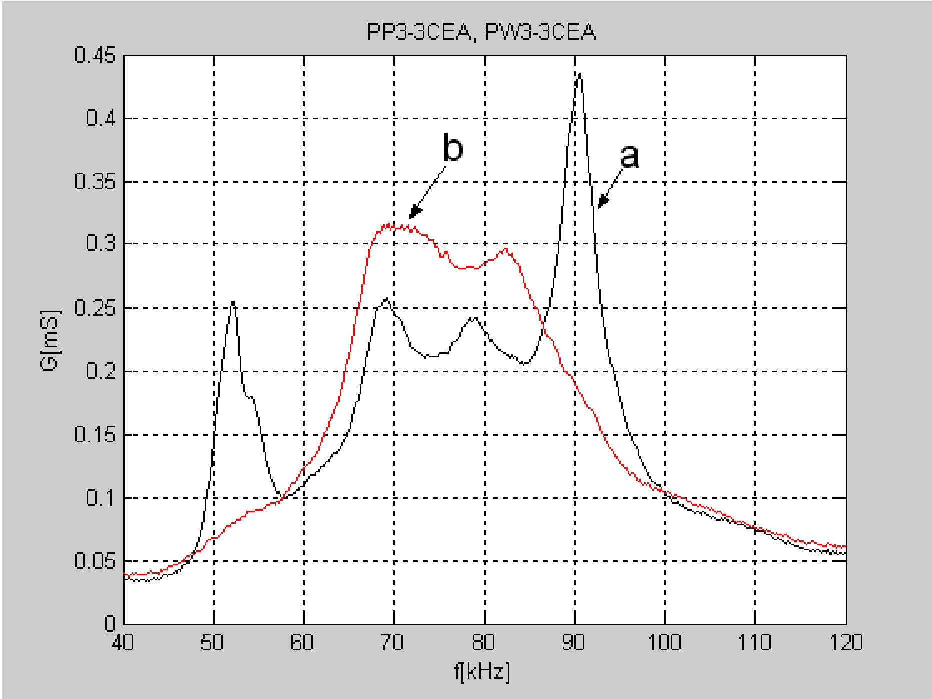

Fig.6. Conductance of transducer in: a) - air, b) - water

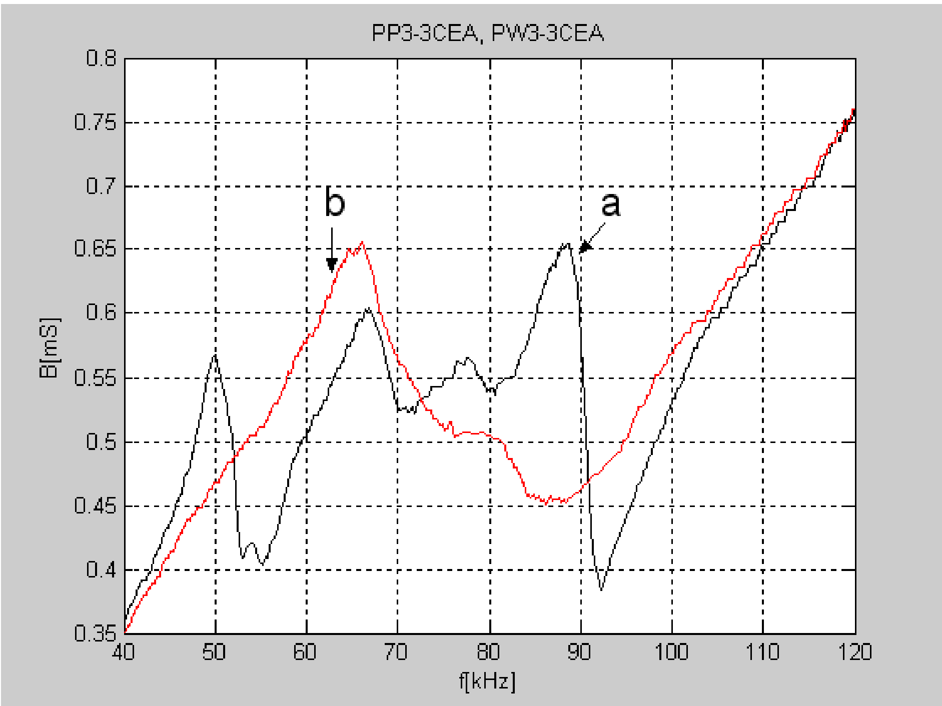

Fig.7. Susceptance of transducer in: a) - air, b) - water

5. CONCLUSIONS

1. Technology demonstrator of DDS is the good opportunity for check new technologies in piezocomposite transducers leading to new generation of sonars intended for detection of smaller targets in difficult littoral condition.
2. We anticipate the transducer which is being built using Piezocomposite 1–3 technology will fulfil our requirements and we would gather experience which will enable us to design transducers with other technical parameters (sector, number of elements, source level, etc.).
3. Performance achieved during FAT was generally very good and in the case of RVS and TVR levels much better than predicted.
4. For measured transducer there are a few elements with atypical response. Element-to-element variability should be reduced in future transducers by using more refined and extensive fixture's production.

ACKNOWLEDGMENT

This work is financed by fund dedicated for research and development project realized during 2007-2010 years. Research and development project No R 00 000 11/3.

REFERENCES

[1] A. Elminowicz, M. Okuniewski, E. Porosińska, L. Zajączkowski, Diver Detection Active Sonar, TEHOSS, Gdańsk 2005.
[2] Brochure: Piezocomposite_Transducer_Design, www.matsysinc.com.
[3] T.Janowski, A.Elminowicz, K.Szworski, Data Processing of Broad–Band Signals Received by Multielement Cylindrical Transducer, 7th EEA International Symposium on Hydroacoustic, Jastrzębia Góra, 2008.
[4] A. Elminowicz, L. Zajączkowski DDS technology demonstrator, 55 OSA Wrocław – Piechowice 2008.