Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1998**	2. REPORT TYPE	3. DATES COVERED **00-00-1998 to 00-00-1998**

4. TITLE AND SUBTITLE **Performance Models For Underwater Transducers**	5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Massachusetts Institute of Technology,77 Massachusetts Avenue,Cambridge,MA,02139**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM002252.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**2**	

Performance Models For Underwater Transducers

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LONG TERM GOALS

Develop advanced energy-dense electrostrictive ceramic materials which will enable major reductions in the size, weight, and cost of acoustic projectors for active sonars.

OBJECTIVES

Improve the performance of underwater transducers through effective use of the nonlinear response of active materials. To accomplish this, develop a modeling capability that incorporates the nonlinearities present in the response of the material. Compile experimental data and update the nonlinear material model in the nonlinear regime under various loading and thermal conditions. Propose improved transducer designs based on the new modeling capabilities and develop a systems approach to unified transducer-electronics design.

APPROACH

Develop a modeling capability by the formulation and implementation of finite element equations and computer code with fully coupled acoustic and nonlinear electroelastic finite elements incorporating system dynamics. Base the nonlinear constitutive relations of the model on a 3D hysteretic energy expansion for general electroelastic materials developed by Ghandi and Hagood. Utilize solutions to compute performance metrics relevant to underwater transducer designs (i.e., electroacoustic efficiency). With the completed model, evaluate the design of a slotted cylinder transducer and determine its performance metrics.

WORK COMPLETED

The completed work included the formulation and computer implementation of dynamic and fully coupled 2D (and 3D) acoustic-nonlinear electroelastic finite element equations.

TECHNICAL RESULTS

The formulation of a dynamic and fully coupled nonlinear finite element code involved implementation using 3-node triangular and 4-node tetrahedral elements with a nonlinear piezoelectric material model and mixed electroelastic finite element equations. System dynamics solutions were realized with an implicit time integration scheme and a nonlinear solution algorithm, specifically a fully coupled Newton method with predictor integration steps. Post processing of a solution output provides performance metric calculations for simple 2D acoustic loaded nonlinear-electroelastic models. Performance models considered were ratios of electrical drive power to both wetted surface radiated power and acoustic mesh edge radiated power. Formulation of the hysteretic heat generation and heat conduction problem was started as an extension of the acoustic loaded nonlinear-electroelastic finite element work just described. A nonlinear characterization of PZT-5H in the nonlinear loading regime has been completed (as part of a Army Research Office effort) allowing analysis of PZT-5H underwater transducers driven in the nonlinear regime. A similar nonlinear characterization of PZT-5A has been in development in combination with an Active Composite Consortium effort. As a means to extend testing and characterization capabilities to include thermal loading effects, a thermal test chamber was acquired and is being set up for load testing compatability with an Instron test machine.

SYSTEMS APPLICATIONS

The development of models to analyze electrostrictive ceramic materials will impact smart skins, actuators, and sensors both in the military and in the commercial sector. High energy density transduction technology may lead to a 13 to 18 dB increase in source level over conventional low frequency source technology enabling revolutionary new shallow-water, broad bandwidth sonars. New high-power, multi-octave, high-frequency source array technology will impact submarine mine avoidance, weapon homing, and unmanned underwater vehicle sonars by diminishing the traditional transducer bandwidth and source level constraint on system design. Implicit and integral to this material and transducer development is the ability to predict and evaluate performance using analytical models. Systems currently being affected by this technology include the Lightweight Broadband Variable Depth Sonar (LBVDS) being developed by PEO (USW) ASTO and the Compact LFA Transmit Subsystem (CLTS) being developed by SPAWAR PD18.

TRANSITIONS

As the model (and its components) become available they will passed on to the scientists designing the transducer arrays.

RELATED PROJECTS

In past years, ONR has sponsored research in the development of new material and transducer models to permit the evaluation of emerging new high energy density drive materials. This work has been undertaken at NUWC, SSC-SD, NPS, and various defense contractors and academic institutions. The models developed will be used to design high energy density materials, transducers, and eventually the arrays used in new sonars.

PUBLICATIONS

None

PATENTS

None