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The linear theory of piezoelectric viscoelastic materials is incorporated into a finite element code. The code allows specification of general electrical and mechanical boundary conditions and loadings. Applications of the code to problems involving ferroelectric ceramics, ceramic/polymer composites and viscoelastic piezoelectric polymer films illustrate the utility of the method. A parametric design study of a ceramic-ploymer transducer reveals a strong dependence sensitivity to polymer Poisson's ratio values. The finite element method provides detailed information that can be used to advantage in component design.

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This report is a summary of the activities performed under Navy Contract N00014-84-0524. This contract was in existence from July 15, 1984 through July 14, 1986. Professor Eric Becker of the Aerospace Engineering and Engineering Mechanics was the principal investigator.

Scope

This research was concerned with the study of computational methods for the analysis of highly compliant piezoelectric components. Electrically polarized elastomeric materials, elastomers filled with finely divided ceramics and ceramic/elastomeric structures all fall within the class of materials studied. The special characteristics of such materials, to which our efforts were directed, are a) very low shear stiffness b) near incompressiblity (large ratio of bulk to shear stiffness) and c) viscoelastic mechanical response.

Present applications for the materials of interest are almost entirely in the transducer area. Potential applications could include active damping or combined sensing/active damping components in the control of structural or fluid/structural systems. Rational design of components for these applications will require methods of analysis not previously available.

The objective of this program has been the development and demonstration of a finite element method applicable to quite general combinations of elastic and viscoelastic materials, piezoelectric or inert, subject to a variety of electrical and mechanical excitation.

Summary of Work Accomplished

The equations of linear coupled viscoelastic piezoelectric material response, cast in variational form, have been incorporated in a finite element code. The code treats two dimensional (plane or axisymmetric) boundary value problems. Both mechanical and electrical loadings and boundary conditions are assumed to be harmonic in time but otherwise quite general forms are accommodated. Temperature dependent mechanical properties are treated. The formulation is suitable for nearly incompressible materials.

Analyses were performed, using the finite element code, of example problems involving three material classes. In each case a typical application was hypothesized.

In its first application, the finite element code was used to compute the frequency response of a piezolectric bimorph (PZT4 ceramic). The frequency response of the bimorph obtained from the finite element method was compared to experimental data. The comparison was good. A simple uncoupled beam theory also was employed to calculate the frequency response of the same bimorph. In this theory the electric field across the beam thickness is assumed to be constant. This assumption has been shown to produce an unrealistic result especially when the frequency of the forcing function approaches the resonant frequency of the bimorph. A coupled piezoelectric beam theory is proposed. In the newly proposed theory a linear electric field is assumed through the thickness of the beam, which has been verified from the results obtained by fully coupled analysis (finite element method) to produce more realistic results.

As an example of an axisymmetric case a piezoelectric mirror was treated. The center deflection of an aluminum mirror which is bonded to a piezoelectric ceramic plate with a hole in the middle was studied to determine the optimum size of the hole in the ceramic, and optimum ratio of thickness of the mirror to that of the ceramic, etc. The result showed that by controlling the hole size and the thickness of the ceramic (or aluminum) plate, significant improvement in the design could be accomplished.

The next application problem is a piezoelectric composite sensor (hydrophone). Piezoelectric ceramic-polymer composites are very popular for hydrophone applications. Using the finite element method, the deformed shape of the composite, stress state, and electric polarization in the ceramic phase were carefully studied. The study provided a close look at the mechanics involved in the sensor design. The results show that clever use of two different phases could improve the performance of the sensor.

The third piezoelectric material involved in the application is piezoelectric polymer film which exhibits strong relaxational behavior, electrically as well as mechanically. A bimorph constructed by bonding two thin PVDF polymer films together has been studied. The results show a noticeable difference in the phase shift of the bimorph in a certain frequency ranges when only mechanical losses are considered, neglecting the electrical losses if the material. Finally, the power dissipation density of the bimorph has been computed and shown to give an idea of the energy loss suffered by the PVDF bimorph.

Technical details regarding the finite element code and its applications are to be found in the Ph.D thesis by Dr. Sung-Kie Youn, The University of Texas, Austin, August 1987.

Technical Reports

The only technical report produced under this contract was in the form of a Ph.D thesis:

"A Finite Element Method for Dynamics of Piezoelectric Structural Components" by Dr. Sung-Kie Youn, The University of Texas at Austin, August 1987.

Technical Presentations and Publications

Three oral presentations of the work have been given by Dr. Eric Becker. These were:

1. "Formulation of Coupled Viscoelastic Piezoelectric Problems" ONR Workshop, Palo Alto, March 1985.
2. "Viscoelastic Stress Analysis" Adhesion Science Workshop, Blacksburg Va. April 1985.
3. "Finite Element Analysis of Viscoelastic Piezoelectric Structures" 10th U.S. National Congress of Applied Mechanics Austin, Texas June, 1985.