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INTEGRATED DESIGN OPTIMIZATION OF FLEXIBLE PIEZOELECTRIC STRUCTURES FOR REQUIRED DEFORMATION

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ABSTRACT

This paper presents the formulation and numerical methods for integrated optimization of applied control voltage and material distribution of flexible planar piezoelectric structures for producing required deformation.

Piezoelectric materials can produce a mechanical strain when application of actuation voltage. Actuators using piezoelectric effect offer unique properties such as the capability of generating large strain and displacements in relatively compact sizes, high resolution within nanometer range and short response time. Piezo actuators have been utilized for generating actuation forces and attaining specified structural deformation in a wide range of intelligent structural systems. Particularly, flexible structures incorporating piezoelectric actuators have created many attractive opportunities for applications in micro mechatronic systems, bio-medical devices, aerospace and aeronautic structures and so on. For instance, using piezoelectric actuation, active flaps and adaptive wing provide an appealing means for maintaining the best overall aerodynamic performance of an aircraft. With the purpose of improving the efficiency of the piezoelectric actuation, design optimization problems of piezoelectric structures have drawn extensive interests.

Topology optimization of continuum structures aims to seek the best material layout of a structure under prescribed design constraints. Structural topology optimization methods, among which are the homogenization-based method, the SIMP approach and the Level Set-based method, have been applied to design of various engineering structures. Recently, the optimum distribution of conventional as well as piezoelectric material in smart structures using piezoelectric actuators has also been studied. However, in most existing formulations, the material layout is optimized under the presumed actuation voltage. Due to this limitation, efficient use of piezoelectric material in a smart structure can not be ensured. In order to overcome these shortcomings caused by separated design of control strategy and the actuator configuration, this paper proposes an integrated design optimization formulation for simultaneously determine the optimal distribution of the smart material and the control voltage. In this study, an artificial smart material model with penalized mechanical and piezoelectric properties is

suggested, and the elemental material densities are used for describing the structural topology. In the mathematical statement of the considered problem, both the actuating voltage and the material density values are taken as design variables. Constraints with regard to the energy consumption and the material volume are imposed to the optimization problem. The proposed optimization problem is solved with a gradient-based mathematical programming approach. For this purposed, the sensitivity analysis of the structural behaviours with respect to the design variables is also discussed.

In order to demonstrate the validity and applicability of the proposed methods, numerical examples will be presented. The optimal solution for a cantilever beam structure, which is to be activated by piezoelectric material for maximum tip deflection, is shown in Fig.1 and Fig. 2.

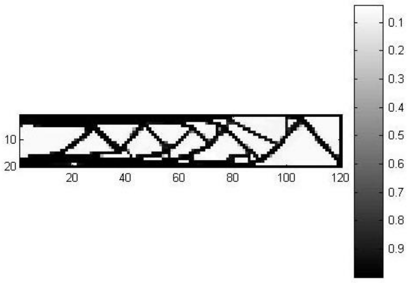
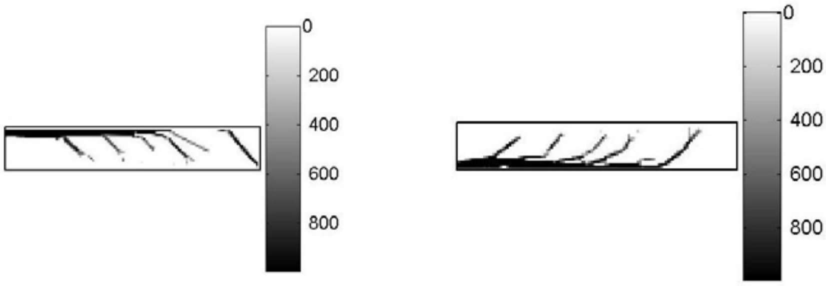


Fig1. Optimal distribution of piezoelectric material



a. Positive control voltage b. Negative control voltage

Fig2. Optimal distribution of control voltage

The proposed formulation and numerical techniques can be extended to the integrated design optimization of flexible smart structures using other types of induced-strain actuators.

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