INSTITUTE OF PHYSICS PUBLISHING SMART MATERIALS AND STRUCTURES

Smart Mater. Struct. **13** (2004) 725–732 PII: S0964-1726(04)77132-3

Induced-strain multimorphs for microscale sensory actuation design

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Received 14 January 2004
Published 18 May 2004
Online at stacks.iop.org/SMS/13/725
DOI: 10.1088/0964-1726/13/4/010

Abstract

The paper proposes an analytic model that evaluates the levels of actuation and sensing by microbenders formed of several sandwiched layers (multimorphs) of active/sensitive materials such as piezoelectric (PZT) and shape memory alloys (SMA) interspersed with structural materials which only react to thermal variations. The model is generic, such that any type of induced strain can be incorporated into it, and its prediction gives the deformed (bent) shape, the corresponding tip bending moment, as well as the position of the neutral axis (NA) and the composite bending rigidity. The generic model reduces to the well-known Timoshenko 'bi-metal thermostat' model in the case of two layers of which one is thermally heated. Finite element simulation produces results that are very close to the analytic model predictions for a three-layer (trimorph) bender when all layers are heated. Concrete examples are further studied that can be encountered in small-scale (MEMS) applications, such as an antisymmetric PZT trimorph with either unilateral actuation and sensing or just antisymmetric actuation, a SMA-actuated bimorph and a hybrid PZT–SMA trimorph that can act as a simultaneous sensory actuator microdevice. Numerical simulations are performed for all examples in order to highlight trends in performance as a function of the microcantilever geometry.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

The authors are currently involved in modeling and designing microscale sensors/actuators that are sensitive to out-of-the-plane motion/deformation and that are built as multilayer sandwich cantilevers which incorporate active/smart materials, such as piezoelectric (PZT) ceramics and shape memory alloys (SMA). In addition to the type of transduction specific to a given active material, thermal effects of all layers and the subsequent deformations are also important factors in shaping the final bending response of these composite microcantilevers. A model is developed here that includes the various active material effects together with the thermally produced deformations and which is capable of describing the actuation, sensing, or both (sensory actuation) of such composite members.

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The problem of the bi-metallic strip and its associated thermal bending due to the difference in thermal expansion coefficient of the two materials was posed early and solved in the 1920s, when Timoshenko [1] formulated the curvature radius and the tip bending moment for what he called a 'bi-metal thermostat'. The literature is rich in examples of both theoretical modeling and applications of bimorphs (two layers composing the sandwich beam) and multimorphs (more than two layers forming the composite cantilever) actuated mostly thermally and/or piezoelectrically. Fuller and Elliott [2] presented several cases of benders actuated by means of piezoelectric patches. Smits and Choi [3] formulated the constituent equations of piezoelectric bimorphs by analyzing the electromechanical nature of this type of actuation and by deriving a tip bending moment, a tip force and a distributed force corresponding to the piezoelectric bender. Chu *et al* [4], following an

