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Control of deformation and transversal vibrations of a clamped beam by two discretely attached monolithic piezoelectric rods

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Abstract: Presently, most of the research on vibration and shape control of slim structures by piezoelectric actuation is restricted to the systems in which the actuator or actuators are embedded in or bonded to the substrate. In the present contribution, two monolithic piezoceramic actuators are attached to the beam at discrete points. In such implementation, the actuators possessing flexural stiffness bend together with the structure. The applied design enhances the static performance in relation to the standard architecture and influences the natural vibrations of the structure. For the system with curved members because of the electric field loading, the equations of motion are linearized about the curvilinear equilibrium state. The governing equations of motion and boundary conditions are derived using extended variational Hamiltonôs principle. Constitutive equations expressing the piezoelectric coupling between the electric and elastic fields, the von Kármán theory of moderately large rotations but small strains and the Eulerï Bernoulli beam theory are used in the formulation. Due to the nonlinearity of the governing equations, their solutions are attempted by a regular perturbation technique leading to asymptotic expansions of displacements, internal forces and the natural vibration frequency. Numerical examples are presented, including how the geometrical nonlinearity is incorporated in the structure static and dynamic responses as a function of two main variables, the actuators offset distance and the electric field application.

Keywords: piezoelectric actuation, shape control, nonlinear vibrations

1. Introduction

When an electric field having the opposite polarity and orientation in regard to the original polarization field is placed across the thickness of a uniform piezoceramic actuator, the piece expands in the transverse direction and, at same time contracts in the longitudinal direction, i.e. along the polarization axis. When the field is reversed, the motions are reversed, hence, as the piezo contractors are usually flat elements, their displacements, which occur perpendicularly to the polarization direction on the basis of the transverse piezoelectric effect, may be efficiently exploited for actuation purposes. This idea has been adopted for the shape and vibration control of a cantilevered beam shown in Fig. 1. The whole system that is composed of an aluminium beam and two contracting monolithic piezoceramic stripes with opposite polarity and voltage applied across the individual transducers, creates a compound bending actuator. Since the piezoceramics are discretely attached to the beam at its end, the static and dynamic response of such compound bender should be more evident than in the case when two layers of piezoceramic are bonded to a thin metal shim sandwiched in the middle. Piezoelectric ceramic transducers may be designed as multilayer elements. The multilayer elements, possessing larger cross-sectional area, generate higher forces and may be operated at a lower voltage. The enhanced control of beam's deflection with discretely attached piezoelectric strain actuator was studied by Chaudry and Rogers [1]. Przybylski and KuliŒski [2] observed the shape enhancement of an eccentrically loaded column using discretely mounted piezoelectric actuator.

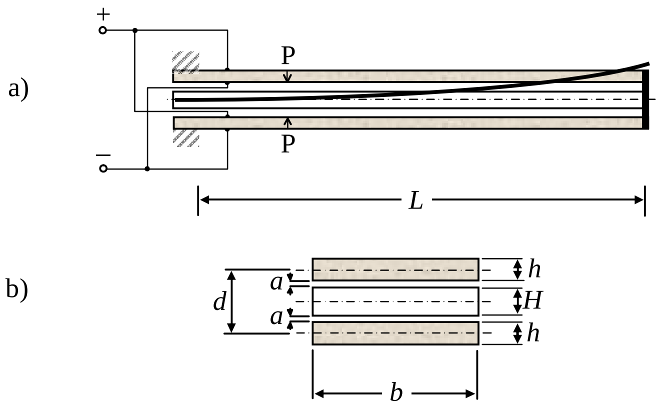

Fig. 1. Compound bending actuator (a) and its cross-section (b)

2. Problem statement

When the piezo contracting actuators are coupled to the beam as in Fig. 1, the driving voltage leads to contraction of the upper ceramic and expansion of the other one, what creates a bending moment. The bending moment converts the small change in length into a large bending displacement perpendicular to the beam's axis. To prevent tensile stresses in the piezoceramics that may appear as a result of the contraction, a mechanical preload is proposed. Such actuator may be applied as a precision positioner, or may operate as a piezoelectric bending motor when the driving voltage will be applied at frequencies much higher than the mechanical resonance. The piezoelectric devices allow continuous smooth motion for unlimited travel, while maintaining high resolution and positioning accuracy [3].

Hence, the main objective of this paper is to demonstrate how distance *d* between piezoelectric stripes and the voltage applied to them affect both the static performance and the natural vibration frequency of this compound structure. A nonlinear model based on the von Kármán and Eulerï Benoulli beam theories has been derived to provide numerical analysis for reasonable explanations of the studied phenomena.

The proposed design of compound piezoelectric bender may have a very wide area of applications. Comparing both the static and dynamic responses of the novel actuator and the classic bimorph, it has been proved, that application of smaller voltage is necessary to the former device to obtain demanded efficiency. The lack of bonding layer also improves the performance and reliability of the actuator.

References

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