Decoupling control and trajectory tracking for a class of piezoelectric materials

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Keywords: piezoelectric materials, modelling, robotics, decoupling control, trajectory tracking.

Extended abstract

In many recent papers [1]-[6], [8], [10]-[15] different problems related to the piezoelectric materials, used as sensors and/or as actuators, have been analysed: the modelling of the structure by means of the finite element method and of the assumed modes method, the control of the structure by means of the classical PID control (known as *direct feedback control*), and the sliding mode control (known as *Lyapunov feedback control*), with an application to the suppression of vibrations, control of truss structures and of flexible robots.

A piezoelectric material has the property that when a stress is applied in some directions (e.g. a biaxial stress for planar structures), it responds in the same and/or different directions with a charge storage, whose entity is dependent, apart from the characteristics of the material, only on the applied stress. In a similar way, if an external electric potential is applied to a piezoelectric material, and so charges are stored in some directions, the structure responds with a deformation in the same and/or different directions, whose entity is dependent, apart from the characteristics of the material, only on the stored charges. The reversibility of the piezoelectric phenomenon makes these materials useful both for local force and/or deformation sensing and for distributed actuating.

In this paper an approximate linear, time-invariant, finite-dimensional dynamic model is proposed for a planar sandwich structure, by using the approach proposed in [7], [9], with reference to flexible robots. The sandwich structure is assumed to be constituted by two thin piezoelectric elements (one for local sensing and one for distributed actuating), mounted on a thin elastic support with known elastic characteristics.

In the above described dynamic model, a straightforward characterization of the piezoelectric and flexure phenomena is obtained by introducing the piezoelectric and flexure energy densities.

The approximate model of such a sandwich structure will be derived by using the Ritz-Kantorovich method to represent the kinematics of the structure in a polynomial form ensuring a certain approximation order, and by applying the integral Hamilton principle, in the Lagrangian form. Although the procedure proposed in the paper will be given with regard to an arbitrary approximation order, a second-order dynamic model will be explicitly derived for the case study.

For the sandwich structure we will state some important control problems — such as the decoupling control and the tracking of reference trajectories, under the assumption that all the position and velocity measurements are available — together with the asymptotic stabilization. The analytical solution of the above stated problems will be derived for the case study, taking advantage of the intrinsic properties of the structure, that can be viewed from the second-order dynamic model.

The paper will end with some simulation runs to show the effectiveness of the control algorithms that are designed with respect of the proposed model.

References

[1] H. Allik and T. J. Hughes, "Finite Element Method for Piezoelectric Vibration", *Int. J. of Numerical Methods*, 2, 151–168, 1979

[2] T. Bailey and J. E. Hubbard, "Distributed Piezoelectric-polymer Active Control of a Cantilever Beam", *J. of Guidance, Control and Dynamics*, 8(2), 605–611, 1985

[3] A. Baz and S. Poh, "Performance of an Active Control System with Piezoelectric Actuators", *J. Sound Vibration*, 126(2), 327–343, 1988

[4] S. A. Collins, C. E. Padilla, R. J. Notestine, A. H. von Flotow, E. Schmitz and M. Ramey, "Design, Manifacture and Application to Space Robotics of Distributed

Piezoelectric Film Sensors", *J. of Guidance. Control and Dynamics*, 15(2), 396–403, 1992

[5] P. Halevi, "Bimorph Piezoelectric Flexible Mirror: Grafical Solution and Comparison with Experiments", *J. Opt. Soc. of Am.*, 73, 110–113,1983

[6] M. Nailon, R. H. Coursant and F. Besnier, "Analysis of Piezoelectric Structures by a Finite Element Method", *ACTA Electronica*, 25(4), 341–362, 1983

[7] S. Nicosia, P. Tomei and A. Tornambè, "Hamiltonian Description and Dynamic Control of Flexible Robots", *Journal of Robotic Systems*, 6(4), 345–361, 1989

[8] A. Preumont, J. P. Dufour and C. Malekian, "Active Damping by a Local Force Feedback with Piezoelectric Actuators", *J. of Guidance, Control and Dynamics*, 15(2), 390–395, 1992

[9] P. Tomei and A. Tornambè, "Approximate Modeling of Robots having Elastic Links", *IEEE Trans. on Systems, Man and Cybernetics*, 18(5), 831–840, 1988

[10] H. S. Tzou, "Distributed Modal Identification and Vibration Control of Continua: Theory and Applications", *ASME J. Dynamic System, Measurements and Control*, 113, 494–499, 1991

[11] H. S. Tzou and C. I. Tseng, "Distributed Piezoelectric Sensor/Actuator Design for Dynamic Measurement/Control of Distributed Parameter System: a Finite Element Approach", *J. Sound Vibration*, 138(1), 17–34, 1990

[12] H. S. Tzou and C. I. Tseng, "Distributed Modal Identification and Vibration Control of Continua: Piezoelectric Finite Element Formulation and Analysis", *ASME J. Dynamic System, Measurements and Control*, 113, 500–505, 1991

[13] H. S. Tzou and C. I. Tseng, "Distributed Structural Identification and Control of Shell using Distributed Piezoelectrics: Theory and Finite Element Analysis", *Dynamics and Control*, 1, 279–320, 1991

[14] C. -K. Lee and F. C. Moon, "Modal Sensors/Actuators", *ASME J. Applied Mechanics*, 57, 434–441, 1990

[15] R. M. Jones, *Mechanics of Composite Materials*, McGraw–Hill, 1975