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Modelling Geometrically Nonlinear Flexure Mechanisms With Piezoelectric Vibration Damping

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1 Introduction

Flexure mechanisms are widely used in the industry when high accuracy and repeatability are required. However, the lack of friction or any other form of damping results in undamped parasitic dynamics, which can result in high transmissions of vibrations and difficulties with controller design. Traditional damping methods using viscous material can be difficult to implement and introduce unwanted behaviour such as creep and hysteresis. Alternatively, piezoelectric patches can be placed strategically on such flexure mechanisms. Damping can then be added to the mechanism by using the patches to actively suppress the vibrations, or by using passive shunt circuitry to dissipate energy.

2 Large deflection modelling

A variety of linear beam elements with piezoelectric layers is available, several simple models are given in [1]. This leads to a typical linear beam constitutive equations, relating beam strain, curvature and voltage to applied forces, moments and charge.
Similar to the method presented in [2], the linear beam constitutive equations can be used to formulate a geometrically nonlinear beam element with piezoelectric interaction. This element has been implemented in the multibody software SPACAR, which can be used to simulate transient responses of controlled flexure mechanisms. Furthermore, it can also be used to determine the frequency response of mechanisms in the deflected state.

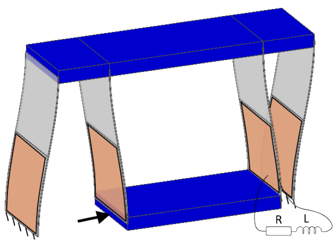

Figure 1: A double parallelogram flexure where voltages can be applied to the piezoelectric patches on the surface of the leaf springs. Force is applied and deformation is measured at the location of the black arrow. Each of the orange piezoelectric patches is attached to the surface of the leaf spring and is shunted with an RL-circuit.

3 Piezoelectric shunting

A double parallelogram flexure, as depicted in Figure 1, is considered. Piezoelectric patches are applied to the bottom half of the flexures and shunted with RL-cirucits. An RL-circuit in series with a piezoelectric patch forms an electric resonance circuit due to the inherent capacitance of the piezoelectric patch. At this resonance frequency mechanical energy is converted to the electric domain and dissipated there. In this case the resistances (R) and inductances (L) have been chosen to suppress resonance of the upper body. The frequency response of the shunted mechanism in the nominal and deflected position is shown in Figure 2. The frequency of the internal mode changes when the mechanism is deflected, making the piezoelectric shunting less effective.
The implemented geometrically nonlinear beam element allows investigation of piezoelectric damping in large stroke flexure mechanisms. This framework will be used for future investigation into alternative control techniques that will be able to robustly reject parasitic dynamics under large deflection.

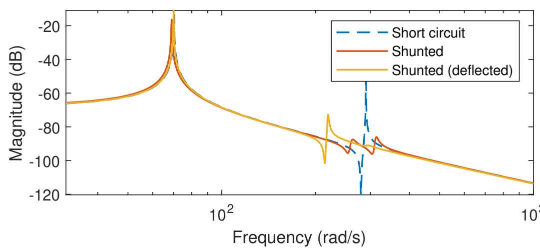

Figure 2: Frequency response function from applied force to displacement of the mechanism in actuation direction, for the nominal and deflected state.

References

[1] L. Luschi, G. Iannaccone, and F. Pieri, "A critical review of reduced one-dimensional beam models of piezoelectric composite beams," *Journal of Intelligent Material Systems and Structures*, vol. 30, no. 8, pp. 1148–1162, 2019.

[2] J. B. Jonker and J. P. Meijaard, "A geometrically nonlinear formulation of a three-dimensional beam element for solving large deflection multibody system problems," *International Journal of Non-Linear Mechanics*, vol. 53, pp. 63–74, 2013.