

Torsional stiffness of several variable rectangular cross-section flexure hinges for macro-scale and MEMS applications

Nicolae Lobontiu^{1,3}, Ephraim Garcia¹ and Steven Canfield²

¹ Cornell University, Sibley School of Mechanical and Aerospace Engineering, Ithaca, NY 14853, USA

² Tennessee Technological University, Cookeville, TN 38505, USA

E-mail: nl73@cornell.edu

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Abstract

The paper develops approximate closed-form equations for the torsional stiffness of several variable rectangular cross-section flexure hinges for macro-scale and MEMS applications. Specifically, corner-filletted, elliptic, parabolic and hyperbolic flexure configurations, either longitudinally symmetric or non-symmetric, are studied. The model gives the tools for a preliminary assessment of the static/modal response of flexure-based devices that deform torsionally. Several numerical simulations are conducted based on the model, which indicate that, for similar values of the geometric parameters, the hyperbolic flexure is the stiffest, followed by the parabolic, corner-filletted and elliptic configurations. The modal response is studied for a two-flexure torsional micro-mirror by sequentially considering four different pairs of longitudinally symmetric flexure designs. The results of the simulation confirm the stiffness predictions and are also in agreement with finite element analysis results.

1. Introduction

Macro- and micro-scale compliant mechanisms, such as MEMS, gain mobility by means of their flexible parts that, through elastic deformation, displace the adjoining quasi-rigid members to positions and orientations that are necessary to achieve the functional role of the whole mechanism. In most applications, the flexible members are monolithically built with the rest of the device, and are usually designed to enable deformation about one or two sensitive axes, while preventing deformation about the other axes. In compliant micro-mechanisms, for instance, the flexible part (the flexure hinge) is realized by removing regions of the silicon substrate in order to yield a slim portion in the form of a monolithic hinge connecting two relatively massive parts. Generally, the hinge is designed to deform in bending and produce limited relative rotation between the adjoining members. In macro-scale applications, such as precision stages, the

hinges are exclusively aimed at bending (although ‘parasitic’ deformations produced through torsion, axial loading and shearing cannot be completely eliminated) and are usually known as ‘flexure hinges’. In many MEMS applications, however, the flexure hinges can accommodate torsion in addition to bending or are implemented to only deform torsionally. Such applications where the flexures are mainly subject to torsional loading include an entire host of micro-mirrors, (RF) micro-switches, tunable capacitors, mechanical filters/resonators, micro-actuators, optical data storage/reading devices, micro-gyroscopes and angular rate sensors. Maluf [1] presented examples of angular rate sensors and digital micro-mirror devices (DMDs) that incorporate torsional flexure hinges. Plotz *et al* [2] and Sattler *et al* [3] studied the application of torsional flexure hinges into RF microswitches by comparing the experimental results with electromechanical simulation data. Sampsel [4] gave an overview of the design and performance of DMDs that are utilized in digital projection display systems. Zhang *et al* [5] analyzed the static response and characteristics of a torsional micro-mirror by

³ Author to whom any correspondence should be addressed.