Sensitivity of the Compression-Softening Effect to Mesh Imperfections in Compressed Flexures

S. Saha[1], A. Ramirez[1], C. DiBiasio[2], M. Culpepper[1]

[1]Massachusetts Institute of Technology, Cambridge, MA, USA
[2]Charles Stark Draper Laboratory Inc., Cambridge, MA, USA

Abstract

Introduction:
Flexures are low-cost bearings that are capable of providing motion guidance with high repeatability and low friction (Figure 1). However, applications of flexure bearings are often limited by their low range. This is because motion guidance in flexures is provided by bending/flexing of members; thus, range is limited by the bending stiffness. As the bending stiffness can be reduced by axial compression, this range limitation may be overcome by using compressed flexures. This compression-softening effect is especially significant at compressive loads that are close to the buckling limit. Theoretically, the expected reduction in the bending stiffness is about 1,000 times. However, real systems do not exhibit such drastic compression-softening effect due to the presence of geometric imperfections in the flexing members. The goal of this study is to (i) quantify the effect of initial geometric imperfections on the compression-softening effect and (ii) identify optimum operating conditions to maximize the effect.

Use of COMSOL Multiphysics® software:
The Structural Mechanics Module of COMOL Multiphysics was used to perform finite element simulations. Modeling was performed in two steps: (i) linear buckling analysis to predict the mode shapes, i.e., the shape of the initial imperfection and (ii) a nonlinear analysis to predict the deformed state (Figure 2). In this two-step process, (i) displacements of the 1st mode shape obtained from buckling analysis were extracted and then (ii) added as the initial imperfection to the mesh for the second step. LiveLink™ for MATLAB® was used to (i) extract the mode shape of the imperfections, (ii) generate the mesh with imperfections, and (iii) set up the nonlinear studies.

Results:
From the simulations it was observed that (i) the compression-softening effect decreases with an increase in the initial imperfection and (ii) the effect of initial imperfection depends on the preload displacement (Figure 3). At low preload displacements, imperfection does not have a significant effect on compression-softening. However, compression-softening is significantly affected by the imperfection when preload displacements are close to the buckling point. Close to buckling, the stiffness reduces by a factor of 7.9 for an imperfection of 1 um and by a factor of 1.7 for an imperfection of 100 um. Additionally, the increase in out-of-plane parasitic

displacement for the case of maximum compression-softening is limited to a factor of 5.5 (Figure 4). This verifies that the guiding behavior of the flexure bearings is preserved during compression-softening.

Conclusion:
This study quantifies the effect of mesh imperfections on the compression-softening effect in compressed flexures. This enables one to (i) predict the improvement in the range of a compressed flexure that has a predetermined initial imperfection and (ii) design and implement compressed flexure systems by selecting the optimum parameters. Additionally, the results of this study can be used to make engineering tradeoff decisions. For example, the fabrication cost of flexures and the performance enhancement decrease with the amount of imperfection. Thus, the quantitative data generated here can be used to make decisions based on cost versus performance tradeoff.

Figures used in the abstract

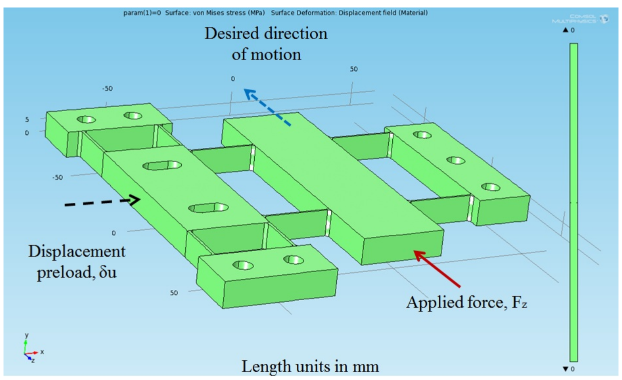

Figure 1: Initial configuration of the flexure.

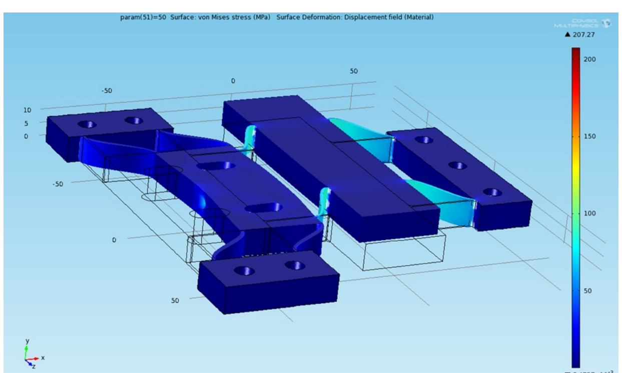

Figure 2: Deformed configuration of the flexure.

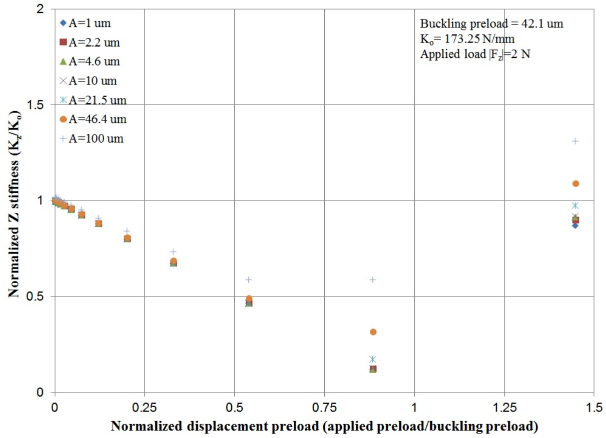

Figure 3: Compression-softening versus preload displacement for different imperfection values.

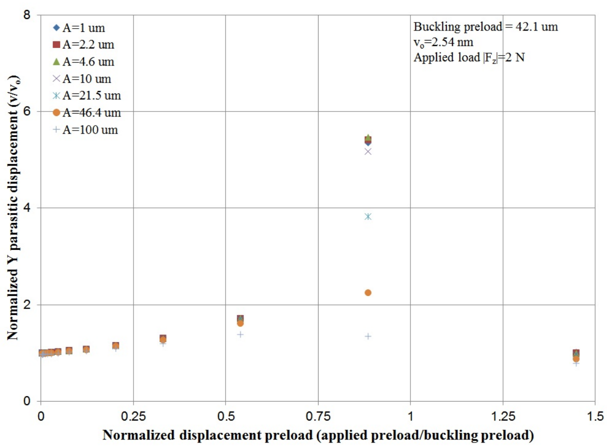

Figure 4: Out-of-plane parasitic displacement versus preload displacement for different imperfection values.