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Analytical stiffness model of a fluid-filled U-shaped bellows based three-parameter fluid damper for micro-vibration suppression

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Abstract: Bellows are widely employed to construct three-parameter fluid damper in application to on-orbit micro-vibration isolation thanks to its ability to provide accurate stiffness and deformation without dry friction. An analytical stiffness model is established to provide a designing method for a U-shaped bellows based three-parameter fluid damper, which considers coupling between bellows and fluid to account for fluid-structure interaction (FSI). Firstly, the stiffness and volume deformation for a U-shaped bellow under composite axial load and internal pressure are obtained based on the analytical model of a U-shaped bellow. Then, the FSI model of a three-parameter damper is established to obtain the output force and internal pressure under harmonic displacement input. The stiffness model employs expressions of volume deformation, the pressure equation and the continuity equation in the orifice to derive the coupling equation, and the force and pressure are obtained by solving the equation with the Laplace transform method. The stiffness model of the bellow is verified by a finite element model. The stiffness model of the U-shaped bellows based three-parameter damper is validated with a two-way FSI analysis carried out in ANSYS WORKBENCH. The results demonstrate that analytical prediction is in good agreement with numerical simulation with greatly enhanced efficiency.

Keywords: three-parameter fluid damper; U-shaped bellow; fluid-structure interaction; toroidal shell; stiffness

1. Introduction

In order to protect the high precision payloads from the micro-vibrations induced by attitude control equipment and actuating components, such as reaction wheels, control moment gyroscope