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RESEARCH PAPER

Limits of linearity in squeeze film behavior of a single degree of freedom microsystem

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Abstract This paper presents a theoretical investigation of squeeze film flow in systems employing microplates parallel to a substrate and undergoing large amplitude normal vibration. Most previous models of squeeze film damping assume small oscillation amplitude with linear system behavior, but it is often unclear how small the vibrations must be to actually elicit this response. In addition, fluid inertia effects are usually overlooked. This study provides a compact nonlinear solution for the incompressible hydrodynamic forces with specific terms describing fluid inertia and viscous damping. Numerical analysis (the explicit Runge-Kutta method) is applied to solve the nonlinear governing equation. The effects of frequency, oscillation amplitude, aspect ratio (of gap to length), and Reynolds number on the dynamic response of the system are investigated. The overall system response depends strongly on the actuation frequency and system properties. It is found that a simple criterion of validity for the linear system assumption is not possible. Near resonance, the vibration input amplitude (relative to the initial gap) must be very small indeed for linearity ($\sim$0.001), while in other cases the relative amplitude can be greater than one.

Keywords Hydrodynamic lubrication · Squeeze film damping · Nonlinear · Large oscillation · Fluid inertia · MEMS

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1 Introduction

Squeeze film damping is a common phenomenon which occurs in many devices that involves a surface moving in a normal direction in close proximity to another solid surface. The relative motion alternately squeezes out and draws in fluid between the two surfaces. This causes a pressure field to arise within the fluid, which may affect the movement of the surfaces. If the fluid film thickness is small enough compared to the wall width, such a phenomenon plays a significant role in energy loss and often dominates the dynamic motion of the system (Williams 2005).

Derived from integrated circuit fabrication technology, microelectromechanical systems (MEMS) have driven a great amount of research and number of applications, due to their potential of performing sensing and actuation at unprecedented levels of miniaturization (Hsu 2008). The study of a fluid film squeezed between two solid surfaces is important in many MEMS applications that involve the out-of-plane vibration of beams or plates in the proximity of a surface, such as accelerometers (Houlihan and Kraft 2005), resonators (Zhang et al. 2004), optical switches (Horsley et al. 2005), microtorsion mirrors (Pan et al. 1998), and others. As size shrinks, the volume forces such as gravity become less important, while surface forces like those due to hydrodynamics often comprise the largest source of parasitic losses (Bao and Yang 2007).

Depending on the design criteria and operating conditions, squeeze film damping influences the behavior of MEMS in different ways. For instance, in a resonant sensor, to achieve a high Q-factor, the damping should be reduced as much as possible for the best resolution (Homentcovschi and Miles 2010). On the other hand, system damping may provide stability to certain devices

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