Developing ANSYS macro for solving Isothermal Reynolds Equation for OCOC boundary condition

Under the guidance of

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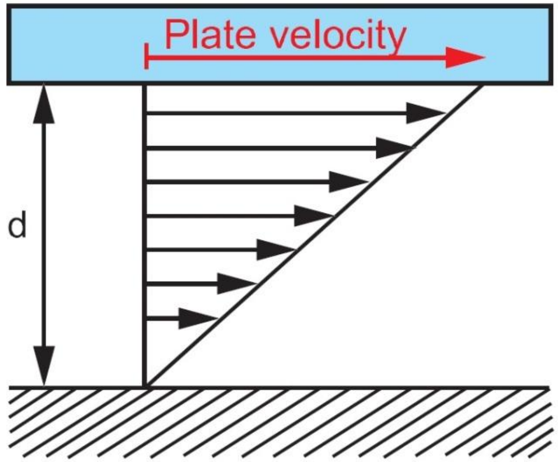
M.Tech (CeNSE)

Presentation Overview

- Introduction
- Governing Equation
- Solving in ANSYS
- Squeeze film analysis
- Modal projection method
- Results

INTRODUCTION

- Thin Film - Small gap of fluid between moving surfaces
  - Squeeze Film Effect
    - Important in accelerometers, micro-torsion mirrors, optical switches, resonators etc.
  - Slide Film Effect
    - Important in comb drives



Governing Equation

- Non Linear Reynolds Equation for compressible film

$$\frac{\partial}{\partial x}\left(\rho\frac{h^3}{\mu}\frac{\partial P}{\partial x}\right)+\frac{\partial}{\partial y}\left(\rho\frac{h^3}{\mu}\frac{\partial P}{\partial y}\right)$$
$$=6\left\{2\frac{\partial(h\rho)}{\partial t}+\frac{\partial}{\partial x}[\rho h(u_1+u_2)]+\frac{\partial}{\partial y}[\rho h(v_1+v_2)]\right\}$$

- In MEMS, $$\frac{\partial}{\partial x}\left(\rho\frac{h^3}{\mu}\frac{\partial P}{\partial x}\right)+\frac{\partial}{\partial y}\left(\rho\frac{h^3}{\mu}\frac{\partial P}{\partial y}\right)=12\frac{\partial(h\rho)}{\partial t}$$

- For Isothermal condition

$$\frac{\partial}{\partial x}\left(\frac{Ph^3}{\mu}\frac{\partial P}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{Ph^3}{\mu}\frac{\partial P}{\partial y}\right)=12\frac{\partial(hP)}{\partial t}$$

Contd..

- Non linear Reynolds Equation for squeeze film damping of parallel plates

$$\frac{\partial}{\partial x}\left(P\frac{\partial P}{\partial x}\right)+\frac{\partial}{\partial y}\left(P\frac{\partial P}{\partial y}\right)=\frac{12\mu}{h^3}\frac{\partial(hP)}{\partial t}$$

or

$$\frac{\partial^2}{\partial x^2}P^2+\frac{\partial^2}{\partial y^2}P^2=\frac{24\mu}{h^3}\frac{\partial(hP)}{\partial t}$$

Contd..

- Linearized Isothermal Reynolds Equation for compressible gas

$$p_a\left(\frac{\partial^2 p}{\partial x^2}+\frac{\partial^2 p}{\partial y^2}\right)-\frac{12\mu}{h_o{}^2}\frac{\partial p}{\partial t}=\frac{12\mu p_a}{h_o{}^3}\frac{\mathrm{d}h}{\mathrm{d}t}$$

- And finally in the non-dimensional form

$$\left(\frac{\partial^2 \tilde{p}}{\partial \tilde{x}^2}+\frac{\partial^2 \tilde{p}}{\partial \tilde{y}^2}\right)=\sigma\left(\frac{\partial \tilde{h}}{\partial \tau}+\frac{\partial \tilde{p}}{\partial \tau}\right)$$

Squeeze Number $\sigma=\frac{12\mu\omega l^2}{P_a h_o^2}$

Elements in ANSYS for modeling Thin Films

- FLUID 136 and FLUID 138 for squeeze film effects
- FLUID 139 for slide film effects

Conditions to be satisfied to use thin film elements to assess thin film effects

- The governing Reynolds equation limits the application of thin film analyses to structures with lateral dimensions much greater than the gap separation.
- The pressure change across the gap must be much smaller than the ambient (surrounding) pressure.
- Any viscous heating effects must be ignored.

Squeeze Film Analysis

- The fluid film can add stiffening and/or damping to the system depending on the operating frequencies.
  - Static Analysis
  - Harmonic Analysis

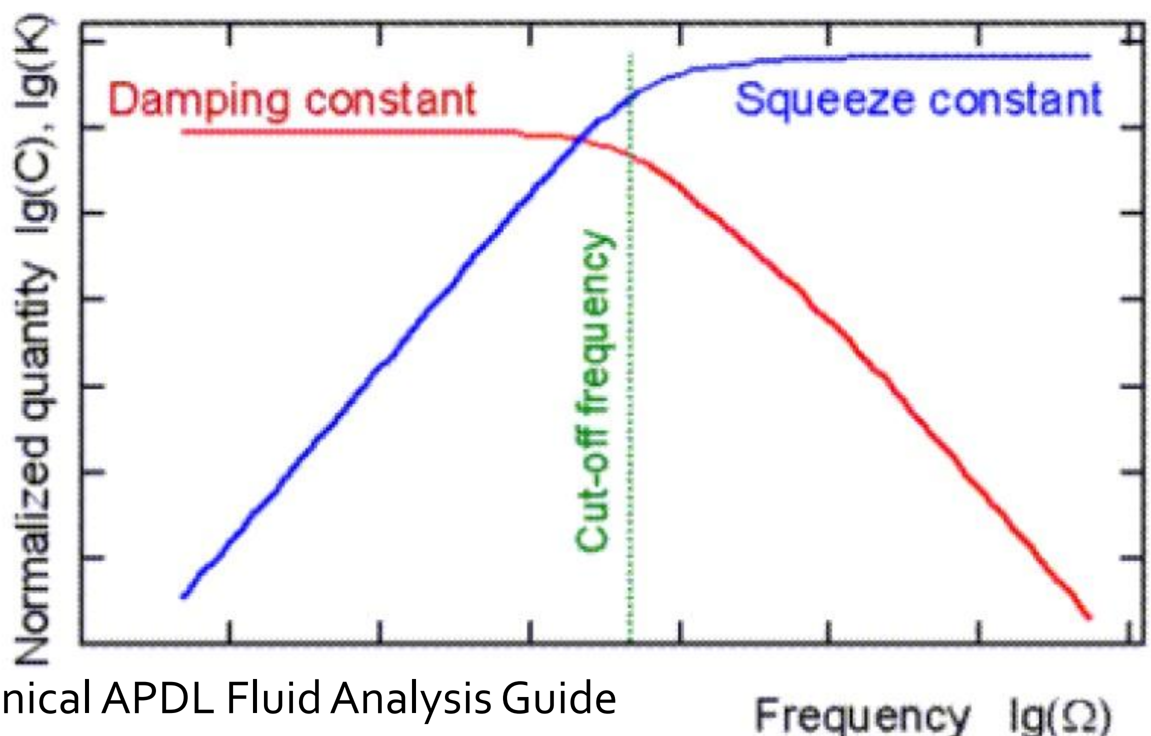


Image taken from ANSYS Mechanical APDL Fluid Analysis Guide

Modal Projection Method

- Fluid is excited by a velocity profile
- Element pressure integrated to compute the element nodal force vector
- Force Vector multiplied for each eigen vector to compute modal forces
- Real and Imaginary parts of modal forces used to compute damping and stiffness coefficients

$$C = \frac{F^{Re}}{v_z} \qquad K = \frac{F^{Im}\omega}{v_z}$$

- Repeated with next eigen mode

Steps in Computing Damping Parameters

- Build a structural and thin–film fluid model and mesh
- Perform a modal analysis on the structure
- Extract the desired mode eigenvectors
- Select the desired modes for damping parameter calculations
- Perform a harmonic analysis on the thin-film elements
- Compute the modal squeeze stiffness and damping parameters
- Compute modal damping ratio and squeeze stiffness coefficient
- Display the Results

Input Parameters in the ANSYS macro

- Length of the plate = 200 µm
- Width of the plate = 100 µm
- Thickness of the plate = 5 µm
- Air gap = 2 µm
- Ambient Pressure = 0.1 MPa
- Viscosity = 18.3 x 10^{-12} Kg/ (µm)(s)
- Reference Pressure = 0.1 MPa
- Mean Free Path = 64 x 10-3 µm
- Knudsen Number = Mean Free Path / Air Gap
- Young's Modulus of Silicon = 150 GPa
- Density of Silicon = 2330 x 10^{-18} Kg/$(\mu m)^3$
- Poisson's Ratio of Silicon = 0.17

Results – Damping Parameters

- Damping coefficient, Squeeze coefficient, Damping ratio, Stiffness ratio

dmpext.out

File

DMPEXT RESULTS

Frequency	Damping coeff	Squeeze coeff.	Damp. ratio	Stiffn. ratio
4621755.	13772.55	0.4082230E+13	0.2371361E-03	0.4840875E-02

dmpext.out

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DMPEXT RESULTS

Frequency	Damping coeff	Squeeze coeff.	Damp. ratio	Stiffn. ratio
5949912.	12906.78	0.4013414E+13	0.1726225E-03	0.2871661E-02

Thank You