NONLINEAR MODELING AND DESIGN STRATEGY OF MAGNETO-RHEOLOGICAL FLUID BASED SQUEEZE FILM DAMPER

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ABSTRACT

The modeling and design strategy for Magneto-rheological fluid (MRF) based squeeze film damper (MR-SFD) is presented. The nonlinear modeling of MR-SFD is attempted by solving Reynolds equation for MRF with adoption of a new nonlinear fluid model instead of the Bingham model and numerically calculating the pressure distribution of MR-SFD. The stiffness variation in MR-SFD is taken into account by employing a frequency-dependent stiffness model. In order to verify the validity of the proposed model, the simulation and experiment results are compared. Based on the extensive experimental works performed under various conditions, the influences of important design parameters are analyzed and the design strategy for MR-SFD is established.

MOTIVATION / IDEA

The modern rotating machinery has a tendency of high operating speed, high load capacity and light weight in pursuit of the improved energy efficiency and mechanical performance. Thus it is becoming increasingly important that a rotating machine can have a capability of changing its dynamic characteristics so that excessive vibrations, occurring particularly when passing through critical speeds or unstable speed regions, can be avoided. Since the classical passive-type bearing cannot provide such capability, semi-active type squeeze film dampers (SFD) with controllable fluids have been studied in recent years. In this work, the lubricant of SFD is replaced by MRF, which is a controllable fluid and behaves as a Newtonian fluid without magnetic fields. With magnetic fields, the magnetized particles in the solution constitute numerous chains parallel to magnetic flux paths, and then MRF gains a resistance to the shear force or the flow of fluids. With the adoption of MRF as the lubricant of SFD, the entire supporting system can be made compact in size and insensitive to impurities.

MRF BASED SQUEEZE FILM DAMPER

In order to verify the feasibility of the proposed fluid model, a prototype of MR-SFD is designed and fabricated as shown in Figure 1. Magnetic circuit analysis is performed to avoid the magnetic saturation of MR-SFD and to determine the appropriate values of design parameters.

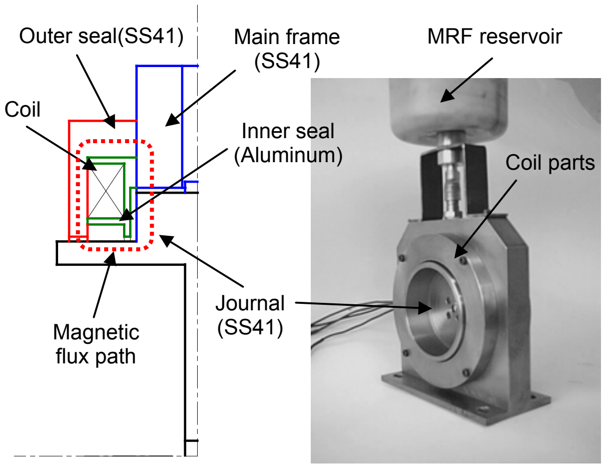


Figure.1 Cross-sectional and perspective view of MR-SFD

The adequacy of the selected design parameters is verified by the analysis program used for the magnetic field analysis. The perspective view of the assembled MR-SFD is shown in Figure 1.

MODELING OF MR-SFD

Accurate modeling of MR-SFD is most important in order to effectively design and control its dynamic characteristics. However, a majority of previous researches related to semi-active type SFD have only focused on vibration reduction problems. In this work, we propose new nonlinear fluid and frequency-dependent stiffness models from the analysis. In the frequency domain, the governing equation for MR-SFD can be expressed as

$$F_X(\omega)/X(\omega)=D_R(\omega)+j\omega D_I(\omega) \qquad (1)$$

where j is the imaginary number ($\sqrt{-1}$), and ω denotes the frequency, and $D_R(\omega)$, $D_I(\omega)$ are the real and imaginary part of a dynamic stiffness respectively. Real part of Eq.(1) explains the stiffness effect of MR-SFD and can be modeled by the frequency-dependent parameters. From the curve-fitting of the experimental results, the stiffness model is obtained as

$$D_R(\omega) = k_1(I) + k_2(I)\cdot\omega^2 \tag{2}$$

where I denotes the current. Damping force of MR-SFD is associated with the imaginary part of Eq.(1) and it can be predicted from the new fluid model given by

$$\dot{\gamma} = \nu(I)\cdot\tau^n \tag{3}$$

where γ is the shear rate ($\partial w/\partial y$), and ν, n are the experimental constants of MRF, and τ is the shear stress. Simulation results using Eqs.(2) and (3) are compared with experimental results in Figure 2, where both results are in good agreement.

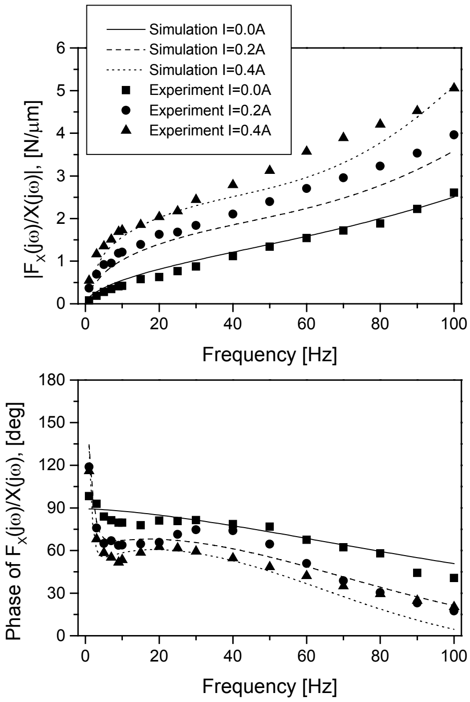


Figure.2 Comparison of simulation and experimental results

DESIGN STRATEGY FOR MR-SFD

In the design of MR-SFD, magnetic saturation of main material must be avoided. Therefore, design parameters must be determined through magnetic circuit analysis and the feasibility needs to be checked.

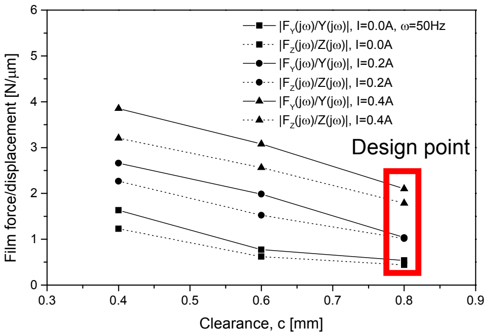
In order to maximize the control bandwidth of MR-SFD, design parameters must also be optimized. In this work, influences of crucial parameters such as clearance and seal width are tested extensively under various conditions.

Typical experimental results are shown in Figure 3. Note that larger clearance and wider seal width are required to broaden the control bandwidth of MR-SFD.

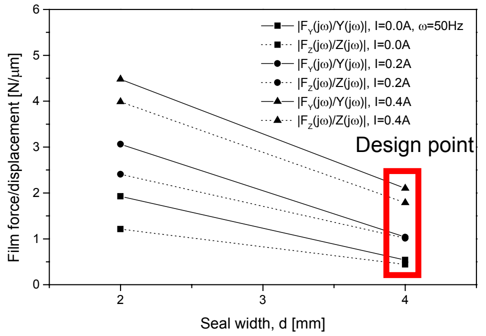
CONCLUSION

The modeling and design strategy for MR-SFD is described in this work. The nonlinear modeling of MR-SFD with adoption of a new nonlinear fluid model and the frequency-dependent parameters is found to well predict the experimental results. The influences of important design parameters are tested and the design strategy for MR-SFD is established.

In the future, MR-SFD-rotor system will be analyzed and tested to show its effectiveness for vibration control of rotating machinery.



(a) Clearance effects



(b) Sealing effects

Figure.3 Effects of design parameters for MR-SFD

ACKNOWLEDGMENT

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REFERENCES

1. C.W. Lee, *Vibration Analysis of Rotors*, pp.99~131, Kluwer Academic Publishers.
2. J.H. Kim, C.W. Lee, and S.K. Lee, “Modeling of Magneto-Rheological Fluid Based Semi-Active Mount,” MoViC, 1996.
3. C.H. Kim, N.S. Lee, and Y.B. Lee, “Vibration Control of a Pressurized, Sealed, Electro-Rheological Fluid Squeeze Film Damper Supported Rotor,” ISROMAC, 1998
4. S.W. Hong and C.W. Lee, “Frequency and Time Domain Analysis of Linear Systems with Frequency Dependent Parameters,” Journal of Sound and Vibration, Vol.127, No.2, pp.365~378, 1988.