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Nonlinear Vibration Analysis of Fluid Conveying Microtube under Parametric Magnetic Excitation

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1. Introduction

Fluid conveying microtubes have extensive applications in micro fluidic circuits, biomechanical equipment and microelectromechanical systems. Therefore, modeling and analysis of their dynamic behavior and stability are important. In this research, effects of various system parameters on nonlinear response of transverse vibrations of beam-like fluid conveying microtube with fixed simply supported boundary conditions under axial magnetic parametric resonance condition is investigated; the issue has not been fully addressed in previous research works.

2. Modeling

Schematic view of a microtube with length L, radius R, and thickness h conveying a fluid with velocity V_f with fixed simply supported boundary conditions is depicted in Figure 1. The deformation field is assumed as

$$U(x,z,t) = u(x,t) + z\phi_x(x,t) \\ W(x,z,t) = w(x,t) \quad (1)$$

in which, u and w are axial and transverse displacements of the points located on the neutral axis of magnetized microtube and ϕ_x is rotation angle of the normal vector of transverse section around y axis. We use Reddy's first order shear deformation theory and Eringen nonlocal elasticity theory considering nonlinear geometric terms of von-Karmanand we derive microtube nonlinear equations of axial, transverse and rotational motion as three second order partial differential equations. Then dimensionless parameters are used for nondimensionalization of the equations.

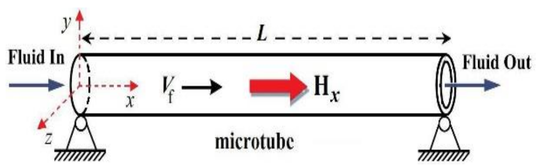

Figure 1. Schematic view of fluid conveying microtube

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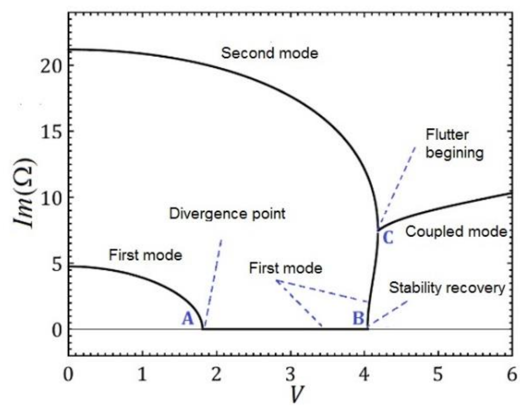
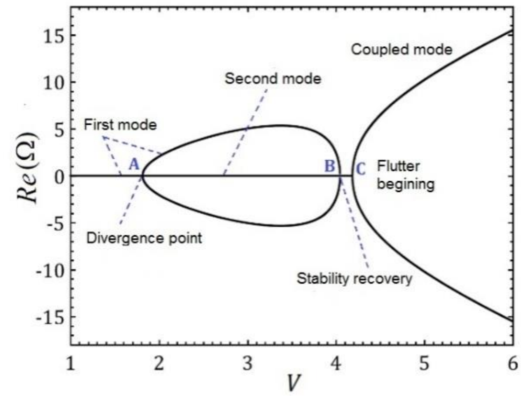
3. Influence of nonlocal stress parameter on flutter critical velocity

Using two first mode shapes of transverse displacements and neglecting nonlinear terms effect, we derive approximate solutions of axial and rotational displacements. According to Figure 2, second mode is stable at velocities less than V_B. At velocities more than V_C, the first and second natural modes are mixed and create an unstable coupled mode shape that is flutter instability.



(a)



(b)

Figure 2. Variation of (a) imaginary part and (b) real part of first and second mode eigenvalues versus dimensionless velocity of fluid

4. Nonlinear analysis of the problem and quantitative study of the stability

For fluid flow velocities more than flutter critical velocity, we study behavior of 2 DoF nonlinear system under parametric magnetic resonance condition. In Figure 3, variation curves of resonance amplitude versus magnetic excitation amplitude parameter for four values of frequency regulator parameter $\sigma = 0, 0.007, 0.01, 0.013$ are plotted. According to this figure, with an axial fluid flow with turbulent velocity of $\Lambda = 15$, the microtube is resonated all the time and increasing parameter σ causes moving bifurcation saddle and subcritical points of the curves towards right direction and decreases resonance zone width. Therefore, an increase of frequency regulator parameter has stabilizing effect on response. In addition, it is observable that increasing frequency regulator parameter decreases resonant amplitude.

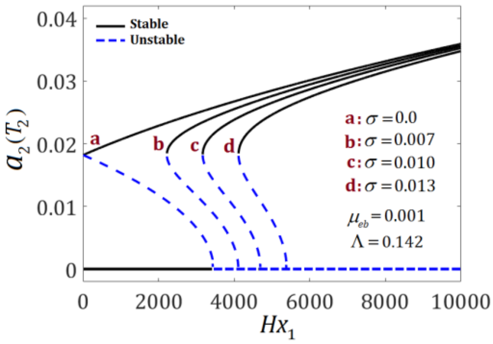


Figure 3. Magnetic resonance amplitude variation curves for four different values of the frequency regulator parameter

Figure 4 depicts characteristic curves of frequency response for four different values of the axial magnetic excitation amplitude $H_{x1} = 2860, 3475, 3900, 4400$ for the microtube beyond flutter beginning point (corresponding to the critical velocity V_{cr}) with turbulent velocity of $\Lambda = 0.142$. This figure shows that an increase of magnetic excitation amplitude has destabilizing effect that increases width of parametric magnetic resonance zone. Moreover, increasing excitation amplitude increases nonlinear response amplitude, that is, resonant amplitude.

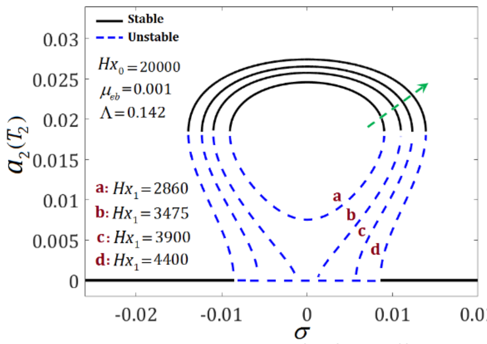


Figure 4. Frequency response curves for four different values of the magnetic excitation amplitude of microtube

Figure 5 illustrates frequency response characteristic curves for three different values of the non-local stress parameter (scale characteristic parameter) $en = 0, 0.07, 0.1$ by keeping other parameters $H_{x0} = 20000$, $H_{x1} = 20000$, $\mu_{eb} = 0.001$ and $\Lambda = 0.142$ constant. According to this figure, increasing non-local stress characteristic parameter has destabilizing effect and increases width of magnetic parametric resonance zone. On the other hand, increasing the non-local stress parameter increases nonlinear response amplitude or resonant amplitude.

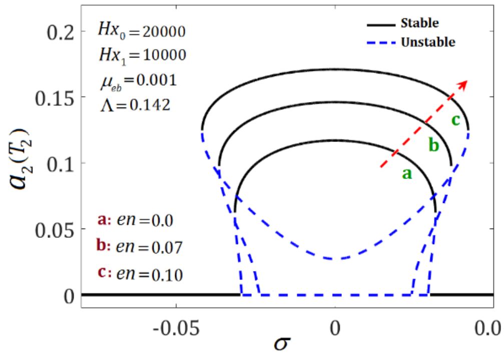


Figure 5. Comparison of frequency response curves for three different values of the non-local stress parameter

5. Conclusion

In this research, governing differential equations for axial, rotational and transverse movements of a magnetizing fluid conveying microtube was extracted using first order Reddy beam model and multiple scales method with consideration of nonlinear geometric terms, fluid viscosity effects and centrifugal acceleration effects, and stability of zero and nonzero solutions of the equations were analyzed in steady condition. Instability problem of nonlinear nonlocal vibrations of the microtube under parametric magnetic excitation of the axial flowing fluid beyond flutter instability was investigated. By deriving nonlinear response curves, effects of various parameters including magnetic excitation amplitude, parameter of excitation frequency and nonlocal stress parameter on resonance amplitude was studied and discussed. It was shown that increase of non-local stress characteristic parameterand magnetic excitation amplitude has destabilizing effects and increases the width of magnetic parametric resonance zone and increases nonlinear response amplitude. Also an increase of frequency regulating parameter has stabilizing effect and decreases resonance zone width and resonance amplitude.