Magnetoelastic nonlinear natural vibration analysis of an annular plate in induced non-uniform magnetic field

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Abstract. The magnetoelastic nonlinear free vibration of a conductive thin annular plate in non-uniform magnetic field generated by the long straight current-carrying wire is presented. Based on electromagnetic theory, expressions of the non-uniform magnetic field and electromagnetic force are derived. According to the Hamilton principle, magnetoelastic nonlinear vibration equation of plate is derived. The Galerkin integral method is used to derive axisymmetric vibration differential equation. By method of multiple scales, natural frequency is then obtained. In numerical calculation, the nonlinear natural vibration characteristic curves show influence of different control parameters, e.g., current intensity, plate size and time, on natural frequency, electromagnetic force, and system singular point stability. Natural frequency decreases first and then stabilizes with current, increases significantly with plate internal radius and thickness. Magnetic induction intensity and electromagnetic force shows different changing rules along radial direction. Additionally, the equilibrium point is center, when wire current is off, and stable focus, when current on.

Introduction

As basic components, annular plate structure is widely used in aerospace, computer storage, e.g., gyroscopes, and mechanical hard disks. Plate may emerge deformation, instability and damage due to electromagnetic effect and external disturbance, especially considering nonlinearity, coupling effect of plate and non-uniform magnetic field will lead to different change in natural frequency and dynamic characteristics. Magnetoelastic study on plate in non-uniform magnetic field is still less, the study is of theoretical and practical significance. Chonan et al. [1] modeled rotating saw blade as annular plate structure, solved displacement functions, and then achieved critical speed of saw blade under working condition. Hu et al. [2] modeled the circular plate rotating in air–magnetic fields, for magneto-aeroelastic forced oscillation issues, which illustrates bifurcation, chaotic motion characteristic and interaction between multiple modes. By bifurcation diagram, the maximum Lyapunov exponent and dynamic behaviours of system under different parameters was studied.

Numerical results and discussion

Fig. 1 shows three-dimensional diagram of electromagnetic force F_z varying with time t and radial position r. It is noted that F_z decays with time, and along radial direction, F_z increases from zero at inner radius to the global maximum at stagnation point $r = 0.6870R_a$ with increasing slower rate, then it reduces to zero at outer radius edge with acceleration. Fig. 2 indicates characteristic curves of natural frequency ω varying with current I at different initial amplitudes, which shows ω decreases with current. When current increases to a certain degree, ω tends to be stable with current. Under the same current, the larger a_0, the smaller ω, which means the system exhibits hard characteristics. Natural frequency is affected by initial condition, which reflects the typical nonlinear characteristics of system. However, when current increases to a certain degree, ω tends to be stable, and the effect of a_0 becomes less obvious.

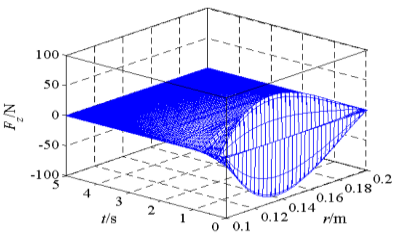

Figure 1: Diagram of. $F_z - t - r$

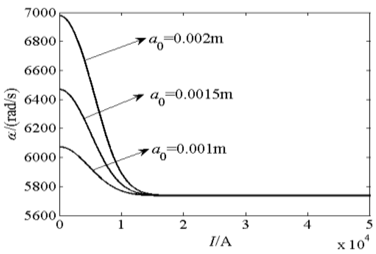

Figure 2: Curves of $\omega - I$ (different a_0)

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References

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