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Research paper

Nonlinear global resonance analysis of an embedded plate interacting with outside subsonic airflow

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ABSTRACT

The nonlinear global resonances of a viscous damper supported embedded plate interacting with outside axial subsonic potential airflow are investigated. The nonlinear equation of motion of the plate is derived based on the Burger's nonlinear plate model and discretized into nonlinear ordinary differential equations with multiple degrees of freedom by using the assumed mode method. The perturbation aerodynamic pressure caused by the coupling of the plate and the outside subsonic airflow is modeled by the linear potential flow theory. The amplitude–frequency curves of the steady state responses of the plate are obtained by numerical computations. The global nonlinear primary resonance properties of the plate are analyzed. The effects of the flow velocity, the excitation amplitude and the viscous damping coefficient on the steady state response properties of the plate are discussed. From the numerical simulations, some novel nonlinear dynamic phenomena of the vibration modes are observed and some dynamic properties of the plate are drawn.

1. Introduction

Plates interacting with outside airflow are commonly seen in many engineering applications such as the surfaces of the high speed trains, aviation aircraft and marine ships. The subject of the plates interacting with outside flow was firstly investigated in the 1950s and still receives much attention in recent years [1–7]. In previous researches, the stability of the plate interacting with outside airflow was frequently mentioned in most studies. It is known that with the flow velocity increasing, the inertia, the gyroscopic and the centrifugal forces generated by the coupled vibration of the plate and the axial airflow may lead to divergence or flutter instabilities [8,9].

For the plates in divergence and flutter types of instability states, the nonlinear vibrations such as the limit circle oscillation and chaos may be generated. The nonlinear limit cycle oscillations of a plate in subsonic airflow was studied by Tang and Dowell [10] and Tang and Païdoussis [11]. Their studies showed that when the flow velocity exceeds the critical velocity, the cantilevered plates will exhibit flutter type of nonlinearity and the amplitude of the flutter increases with the flow velocity increasing. Yao and Li [12] investigated the chaotic motion of a simply supported composite laminated plate in divergence state in the subsonic airflow. The criterions for the chaotic motion of the plate were obtained by using the Melnikov's method. Tubaldi and Amabili [13] researched the stability and critical velocity of a periodically simply supported plate in channel axial airflow. The effects of the expansion modes and the channel height on the critical divergence velocity

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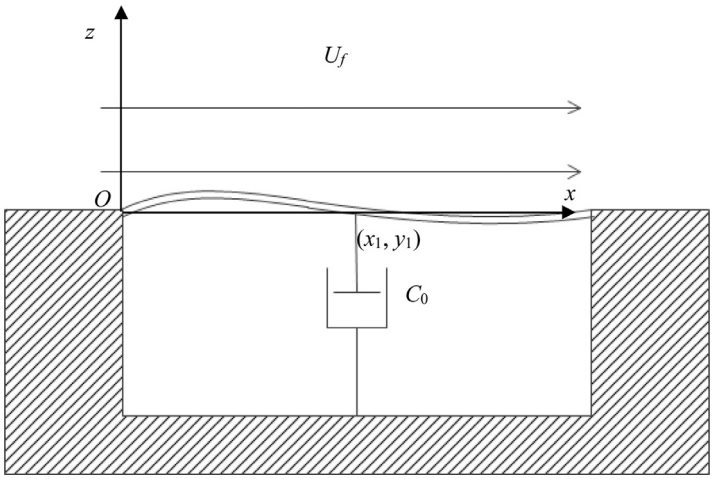

Fig. 1. Diagram of an embedded plate interacting with outside airflow.

Nomenclature

a, b, h	dimensions of plate in the x, y, and z directions
C_0	damping coefficient of the viscous damper
U_f	velocity of the airflow
ρ_f	mass density of the airflow
$w(x, y, t)$	deflection of the plate
ε_x, ε_y, γ_{xy}	normal and shear strains of the plate
σ_x, σ_y, τ_{xy}	normal and shear stresses
U	strain energy of the plate
T	kinetic energy of the plate
W	external work
F_0	force amplitude
ω	external excitation frequency
(x_0, y_0)	position of the external force
(x_1, y_1)	position of the viscous damper
Δp	perturbation aerodynamic force

of the plate were discussed. Yao and Li [14] considered the effects of the compressibility of the subsonic airflow on the stability and nonlinear vibration properties of the composite laminated plate. They found that the critical divergence velocity of the plate decreases when the plate is in compressible flow. Yao and Zhang [15] studied the aeroelastic stability of an axially moving plate. The coupled stability regions of the plate with respect to the moving velocity and the surrounding flow velocity were obtained by solving a generalized eigenvalue problem. Yao et al. [16] also investigated the thermal effects on the stability of the plate in potential flow. Their investigations showed that the threshold for divergence of the plate was a continuous surface relating to the flow velocity, the moving velocity and the temperature changing.

It can be seen from the existing investigations that the mechanism of the plate interacting with potential airflow is very complicated. So in the modeling of the plate interacting with potential airflow, the resonance characteristics of higher modes of the plate should be considered to obtain intact vibration properties of the system. However, to our best knowledge, very limited investigations on the nonlinear vibration properties of the plate including higher modes have been reported. This motivates us to carry out the present study. In this paper, the equation of motion of the plate is discretized into a nonlinear ordinary differential equation with multiple degrees of freedom and the global nonlinear vibration properties of the plate interacting with potential subsonic airflow are investigated. The amplitude-frequency curves of the steady state responses are obtained by numerical simulations. The effects of the flow velocity, the excitation amplitude, and the viscous damping coefficient on the nonlinear resonance properties of plates are discussed.

2. Structural modeling

An embedded rectangular plate as shown in Fig. 1 is considered. The length, width and thickness of the plate are a, b and h. The x-axis of the rectangular coordinates is along the length of the plate. The deflection of the plate at (x, y) at time