Using Nonlinear Energy Sink to Improve the Dynamic Behavior of Rectangular Plate under Supersonic Aerodynamic Flow at Different Angles

Hassan Asadigorji[1], Ardeshir Karami Mohammadi[2*]

[1] PhD Candidate, Shahrood University of Technology, Shahrood, Iran
[2] Associate professor, Shahrood University of Technology, Shahrood, Iran

ABSTRACT

In this paper, the effect of nonlinear energy sink on the dynamic behavior of a rectangular simply supported elastic plate at different azimuth angles is investigated. The plate under study is a thin rectangular plate to which a non-linear energy sink is connected and the supersonic flow of air passes over it. The aim of the research is to improve the behavior of the plate by changing the spatial parameters of the nonlinear energy sink. Classical plate theory is used to obtain plate equations, and Van-Carmen strain-displacement relations are used to consider the nonlinear geometric effect. Modeling of supersonic aerodynamic flow will be based on "first-order piston theory." The Kelvin-Voigt model is also used for non-linear energy sinks. The equations were extracted from Lagrange's method and then discretized by Rayleigh-Ritz method and solved by fourth-order Runge-Kutta method. In order to investigate the effects of nonlinear energy sink, the time history curves, phase portraits, Poincaré maps and bifurcation diagrams are used. The results show that using nonlinear energy sinks, the behavior of the plates, which in some cases is very complex, can be changed to a simpler behavior. In some cases, using a non-linear energy sink near the center of the plate is not appropriate.

KEYWORDS

supersonic flow, azimuth angle, nonlinear energy sink, dynamic behavior, Bifurcation diagram

* Corresponding Author: Email: username@EmailServer.com

1. Introduction

Many engineering structures, including in the aerospace industry, can be considered and modeled as plates. Because plates in the aerospace industry are subject to aerodynamic forces, they may exhibit complex nonlinear dynamic behaviors, which can also depend on different azimus angles.

Dowell investigated the behavior of flutter in plates due to airflow [1, 2]. Grover et al. [3] investigated the ultrasonic flutter of a composite plate. They concluded that flow stiffness and geometric parameters should be considered as the main factors in designing flutter velocities in mechanical structures.

Hosseini et al [4], have used numerical solution to analyze the flutter of a functionally graded continuous plate under supersonic flow with different azimus angles. The results show that the critical value of the azimus angle depends on the aspect ratio of the plate and geometric parameters such as thickness. Taleshi et al [5], have investigated the effect of nonlinear energy sinks to control plate vibrations. They considered a thin simply supported plate under harmonic excitation. The results show that nonlinear energy sinks designed for some excitation values show better behavior than adjusted TMD, but with increasing excitation force, nonlinear energy sinks have less effect than TMD. Chen et al [6], have studied composite plate and optimal design of nonlinear energy sinks.

In the present study, the effect of nonlinear energy sink on the dynamic behavior of simply supported rectangular plate under the effect of supersonic airflow at different azimus angles, with the occurrence of different types of movements such as periodic and chaotic movements, and its improvement to simpler behaviors has been considered. The aim of this research is to try to improve the behavior of the plate by changing the location of the nonlinear energy sink. Classical plate theory was used to obtain the plate equations and Van-Carmen strain-displacement relations were used to consider the geometric nonlinear effect. Aerodynamic flow modeling for supersonic flow was based on the "quasi-static first-order piston theory". The Kelvin-Voigt model is also used for nonlinear energy sink. The equations are extracted by the Lagrange method and then discretized by the Reyleigh-Ritz method and solved by the fourth-order Runge-Kutta method. In order to investigate the effects of nonlinear energy sink, time response and fuzzy diagrams, Poincaré maps and bifurcation diagrams were used.

2. Methodology

The square simply supported panel with a nonlinear energy sink connected to it, shown in Fig. 1.

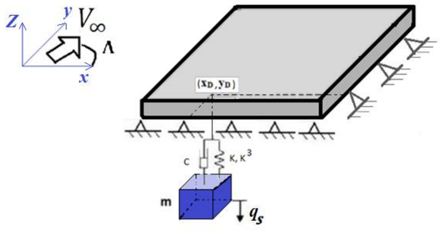

Figure 1. Schematic view of the simply supported plate equipped with nonlinear energy sink under aerodynamic flow with azimus angle.

The air flow is supposed to cross over upper surface of the plate in different angels. The plate is taken as homogeneous isotropic.

By using the quasi-steady first-order piston theory, the aerodynamic pressure at supersonic velocity can be derived as follow

$$\Delta P = \frac{2q}{\beta}\left[w_{,x}\cos(\Lambda)+w_{,y}\sin(\Lambda)+\frac{M_\infty^2-2}{M_\infty^2-1}\frac{1}{V_\infty}w_{,t}\right] \quad (1)$$

The Kelvin-Voigt model is used for NES. m, C, K^1 and K^3 denote the mass, damping coefficient, linear stiffness, and cubic nonlinear stiffness, respectively.

Therefore, kinetic and potential energies can be written as follows.

$$T = \frac{1}{2}m\dot{q}_S^2 \quad (2)$$

$$U = \frac{1}{2}K^1[w(x_D,y_D,t)-q_s(t)]^2+\frac{1}{4}K^3[w(x_D,y_D,t)-q_s(t)]^4$$

$$Q_{ec} = \frac{1}{2}C[w_{,t}(x_D,y_D,t)-q_{s,t}(t)]^2$$

The Lagrange method is used to drive equations of motion. The equations are then discretized by the Reyleigh-Ritz method consists of assuming the form of the solution in terms of admissible functions and generalized coordinates. The required admissible functions satisfy the geometric boundary conditions of the plate. Then the dimensionless equation of motion for plate in according to classical plate theory is given Lagrange equations:

$$\begin{cases} \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{a}_{ij}}\right) - \frac{\partial L}{\partial a_{ij}} = 0 \\ \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{b}_{rs}}\right) - \frac{\partial L}{\partial b_{rs}} = 0 \\ \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_{mn}}\right) - \frac{\partial L}{\partial q_{mn}} + Q_{mn} = 0 \\ \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_{ec}}\right) - \frac{\partial L}{\partial q_{ec}} + Q_{ec} = 0 \end{cases} \quad (3)$$

3. Discussion and Results

Then nonlinear behaviors of aeroelastic plates in the presence of NES are studied.

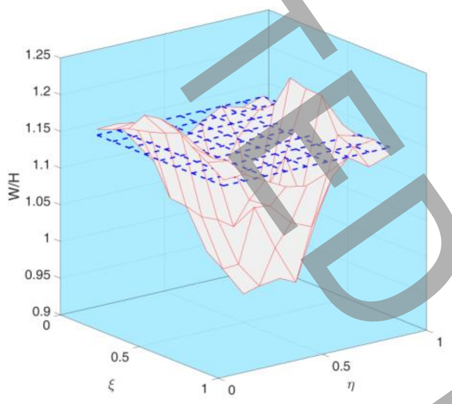

Figure 2. Dimensionless limit cycle oscilation amplitude of simply supported square plate with and without NES, in dimensionless aerodynamic load a) $\lambda = 900, \Lambda = 0$

First choosing the best location is the important issue. In Fig.2 dimensionless transverse limit cycle oscillation amplitude in dimensionless aerodynamic load $\lambda = 900$ for different NES locations are plotted. It is observed that placing NES near the middle of the plate has a greater effect on reducing the oscillation of the limit cycle oscillation than a plate without NES..

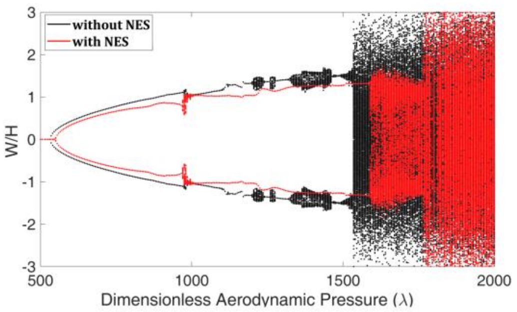

Figure 3. Bifurcation diagram for simply supported square plate with and without NES in location [0.6,0.4] with $\delta = 0.05, \varphi = 1, \Lambda = 30$

In Fig.3 by considering NES location in [0.6,0.4] the bifurcation diagram is plotted. As it shown using NES in plate can postpone the flutter and it may change complex behaviors to simple motions, so in this paper different aspect ratios and different flow directions are considered. Also by using time history, phase portrait, Poincare section and power spectra we investigate some changes in plate's behavior.

4. Conclusions

The effect of nonlinear energy sink on the dynamic behavior of a rectangular simply supported elastic plate under the effect of supersonic airflow at different azimuth angles is investigated. Results show that by selecting NES in locations around the middle of the plate, there is a significant change in its behavior for the aspect ratios 1 and 2, but these changes are insignificant for the aspect ratio 4. Changing the azimus angle has a great effect on the dynamic behavior of the plate so that the periodic motion range decreases with increasing azimus angle. The NES has the ability to absorb vibrational energy due to its damping and ability to act as a dynamic absorber, and it has been observed that if installed in the right place, it can transform complex nonlinear behaviors such as chaotic motion into simpler behaviors such as periodic motion.

5. References

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