Dynamics and performance analysis of a nonlinear energy sink with geometric nonlinear damping

Rony Philip*, B.Santhosh* and Bipin Balaram *

*Department of Mechanical Engineering, Amrita School of Engineering, Amrita Vishwa Vidyapeetham, Coimbatore, India

Abstract. Nonlinear energy sink (NES) is a passive method to achieve vibration absorption through the targeted energy transfer (TET). NES generally have a small mass, an essentially nonlinear element, and a damper to dissipate the energy. In this study, a nonlinear damping mechanism obtained by the geometric configuration effect is implemented on a two degree of freedom system with the primary system excited harmonically. The dynamics of the system is investigated using the complex averaging method (CX-A) to identify the slow and fast modulations along with the regions of strongly modulated resonance (SMR). Periodic solutions of the system are obtained using the multi-harmonic balance method (MHBM). It is found that the NES with geometric nonlinear damping performs better compared to the one with linear viscous damping. This study provides insight into the use of nonlinear damping mechanisms in NES and helps to develop efficient passive vibration absorption systems based on NES.

Introduction

NES is an essentially nonlinear element when attached to a vibrating system that can provide unidirectional flow of vibration energy through TET. The irreversible transfer of energy concept is effectively used in several practical applications to reduce the vibration of externally excited systems. Previous studies[1] considered the dynamics of an impulsively-excited system with NES and restricted the nonlinear coupling terms only to the stiffness element. In this study, a velocity displacement dependent nonlinear damping mechanism obtained by the geometric configuration of a linear viscous damper is considered. NES with geometric nonlinear damping is implemented on a two degree of freedom system with the primary system excited harmonically as shown in Fig.1. The non-dimensional equations of motion for the system is given by

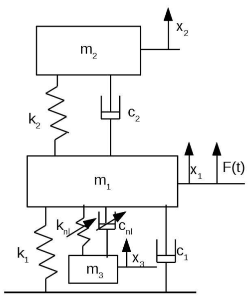

Figure 1: Two degree-of-freedom system with essentially nonlinear stiffness and nonlinear damping

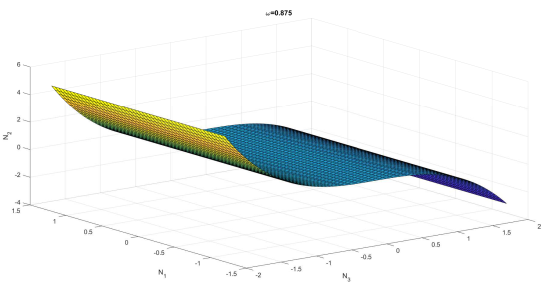

Figure 2: Strongly modulated resonance regime

$$\ddot{x}_1 + x_1 + \zeta_1\dot{x}_1 + \beta_2(x_1 - x_2) + \zeta_2(\dot{x}_1 - \dot{x}_2) + \beta_n(x_1 - x_3)^3 + \zeta_n(\dot{x}_1 - \dot{x}_3)(x_1 - x_3)^2 = f\cos\omega\tau \quad (1)$$

$$\mu_2\ddot{x}_2 + \beta_2(x_2 - x_1) + \zeta_2(\dot{x}_2 - \dot{x}_1) = 0 \quad (2)$$

$$\mu_3\ddot{x}_3 + \zeta_n(\dot{x}_3 - \dot{x}_1)(x_3 - x_1)^2 + \beta_n(x_3 - x_1)^3 = 0 \quad (3)$$

where $\mu_i = \frac{m_i}{m_1}, \beta_i = \frac{k_i}{k_1}, \zeta_i = \frac{c_i}{c_1\omega_1}, \beta_n = \beta_3 X_{st}^3, \zeta_n = \zeta_3 X_{st}^2$ and $f = \frac{F}{k_1 X_{st}}$ are nondimensional parameters. The complex dynamics of the system are analyzed using CX-A method [2, 3] to identify the slow and fast modulations, which help to investigate transience caused due to bifurcation of resonance capture. Periodic solutions of the system are obtained using MHBM. Parametric continuation is performed to obtain the frequency response plots. The design for NES can maximize energy transfer. It is found that even without very large excitation force the NES with geometric nonlinear damping performs better compared to the one with linear viscous damping. Fig.2 shows the regions of strongly modulated response (SMR), which are identified by numerical simulations and CX-A. This study provides insight into the use of nonlinear damping mechanisms in NES and helps to develop an efficient passive vibration absorption systems based on NES.

References

[1] Kong, X., Li, H. and Wu, C. (2018). Dynamics of 1-dof and 2-dof energy sink with geometrically nonlinear damping: application to vibration suppression. Nonlinear Dynamics, 91(1), 733-754.

[2] Qiu, D., Li, T., Seguy, S., and Paredes, M. (2018). Efficient targeted energy transfer of bistable nonlinear energy sink: application to optimal design. Nonlinear Dynamics, 92(2), 443-461

[3] Tripathi, A., Grover, P., and Kalmár-Nagy, T. (2017). On optimal performance of nonlinear energy sinks in multiple-degree-of-freedom systems. Journal of Sound and Vibration, 388, 272-297.