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Nonlinear dynamics and bifurcation of a vibration absorber-harvester

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Abstract

Recently, harvesting of energy from vibrating systems has gained immense popularity. The harvested power depends on the amount of accessible kinetic energy and the efficiency of the harvester. It has been shown that under certain conditions, the presence of non-linearity in the device may cause an improvement of performance as compared to the standard linear systems [1]. In this paper we investigate an autoparametric system presented in Figure 1. It consists of the main system (oscillator) and the absorber (pendulum). Additionally, the ocillator's suspension is active, made up of the magnetorheological damper (MR) and the shape memory alloy spring (SMA). Usually, such device is used as the dynamic vibration absorber [2]. However, it has potential for energy harvesting [3].

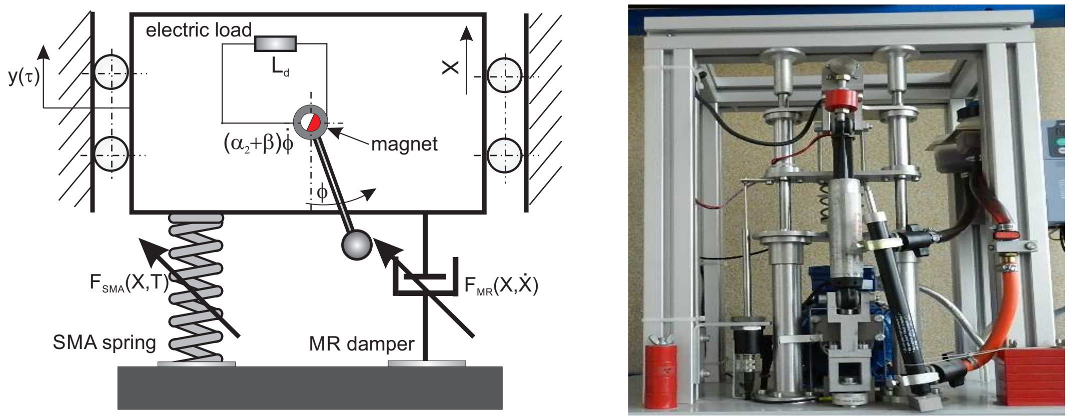

Figure 1: Scheme and real view of active pendulum system.

The system is described by two ODEs. Coupling between subsystems is nonlinear and ensures that the excited oscillator can be at rest while the pendulum is oscillating. Such a solution is called a semi-trivial (ST) solution. When ST solution is unstable, one can expect the non-trivial solutions can be initiated and both elements start to oscillate. The dimensionless movement equations describing the system are given by 1 and 2:

$$\ddot{X} + F_{SMA}(X,T) + F_{MR}(\dot{X},X) + \mu\lambda(\ddot{\phi}\sin\phi + \dot{\phi}^2\cos\phi) = y(\tau), \tag{1}$$

$$\ddot{\phi} + (\alpha_2+\beta)\dot{\phi} + \lambda(\ddot{X}+1)\sin\phi = 0, \tag{2}$$

where X and ϕ denote the vertical and angular displacement of the oscillator and the pendulum, respectively. The function F_{SMA} means the restoring force of SMA spring, depending on the displacement of the oscillator and temperature ($F_{SMA}(X,T) = (\theta-1)X - \beta_1 X^3 + \beta_2 X^5$). The parameters β_1, β_2 are material constants, θ is a temperature ratio. The F_{MR} is a magnetorheological damping force, depending on the velocity and displacement of the pendulum ($F_{MR}(\dot{X},X) = \alpha_1\dot{X} + \alpha_3\tanh(\delta_1\dot{X} + \delta_2 X)$). The parameter α_1 is a viscous damping coefficient, α_3 means dry friction, while δ_1 and δ_2 are coefficients which describe the hysteresis effect. The system is harmonically excited by $y(\tau) = q\cos(\vartheta\tau)$, where q and ϑ denote the amplitude and frequency of excitation, respectively. The damping in the pendulum pivot is marked as α_2, while β represents the portion, that can be converted to electricity. Note, that the electrical damping force with a damping coefficient β is equivalent to a total electromagnetic force. The parameters λ and μ characterize construction of the pendulum. The detailed derivation equations of motion can be found in [4]. This paper proposes use the vibration absorber for energy harvesting. The influence of the SMA spring and the MR damper on dynamics, bifurcations and stability is studied in detail. In Fig. 2 one can be see an frequency response curves, where displacement of the oscillator (Fig. 2a), and angular velocity of the pendulum (Fig. 2b) are presented.

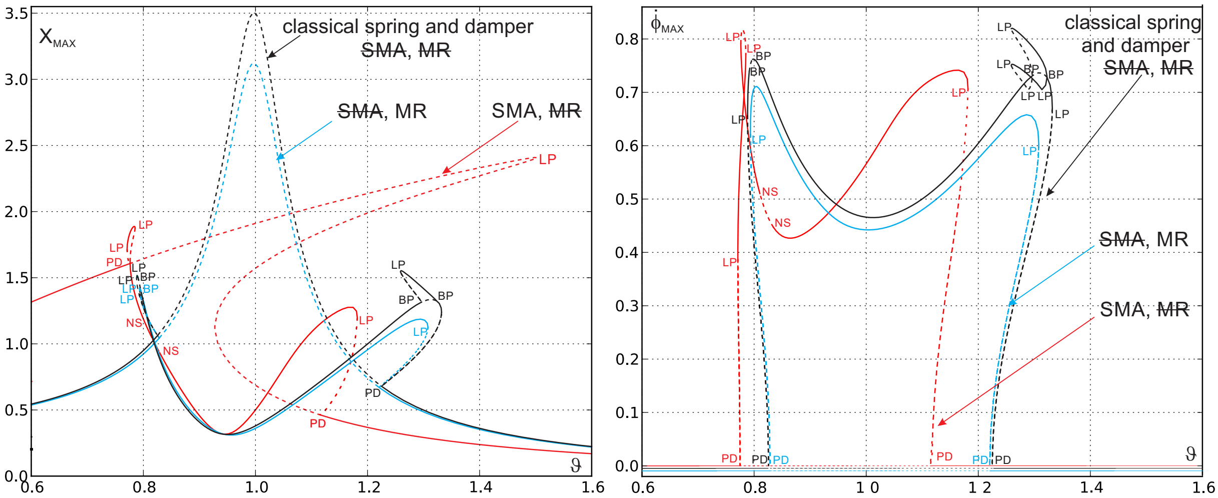

Figure 2: Frequency response for the oscillator (a) and the pendulum (b), for $\alpha_1 = 0.1, \alpha_2 = 0.069, \beta = 0.001, \alpha_3 = 0.03, \lambda = 0.25, \mu = 6, q = 0.35, \beta_1 = 0.04, \beta_2 = 0.1, \delta_1 = 100$ and $\delta_2 = 1$.

It is shown, that with a proper choice of the suspension parameters, the angular velocity of the pendulum increases (then increases energy harvesting), simultaneously reducing displacement of the primary system. Additionally, the smarts elements can be used to elimination or move the unstable regions. However, an active elements can introduce a new bifurcations: branch point (BP), period doubling (PD) or Neimark-Sacker (NS).

The main aim of this paper is to propose a method of control the vibration of the host structure and to harvest energy out of the dynamic vibration absorber simultaneously. To control is introduced via the active suspension. Some results of numerical studies were validated with experimental measurements.

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References

[1] M. Tian-Wei, Z. Hui, X. Ning-Shou. A novel parametrically excited non-linear energy harvester. Mechanical Systems and Signal Processing, Vol. 28, pp.323–332, 2012.

[2] K. Kecik, M. Kapitaniak. Parametric Analysis of Magnetorheologically Damped Pendulum Vibration Absorber. International Journal of Structural Stability and Dynamics, Vol. 14, No. (8), 1440015, 2014.

[3] K.Kecik, M. Borowiec. An autoparametric energy harvester. The European Physical Journal Special Topics, Vol. 222, No. 7, pp. 1597–1605, 2013.

[4] J. Warminski, K. Kecik. Autoparametric Vibrations of a Nonlinear System with a Pendulum and Magnetorheological Damping In J. Warminski, S. Lenci, M.P. Cartmell, G. Rega, M. Wiercigroch (Eds.) Nonlinear Dynamic Phenomena in Mechanics, pp. 1–61, Springer, 2012.