Mechanical Systems and Signal Processing xx (xxxx) xxxx–xxxx

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/ymssp

Nonlinear vibratory interactions between a linear and a non-smooth forced oscillator in the gravitational field

C.-H. Lamarque[a], A. Ture Savadkoohi[a,*], S. Charlemagne[a], P. Abdoulhadi[b]

[a] Univ Lyon, ENTPE, LTDS UMR CNRS 5513, Rue Maurice Audin, F-69518 Vaulx-en-Velin Cedex, France
[b] Univ Lyon, ENTPE, LGCB, Rue Maurice Audin, F-69518 Vaulx-en-Velin Cedex, France

ARTICLE INFO

Keywords:
Fast dynamics
Slow dynamics
Non-smooth
Gravitational field
Control
Energy harvesting

ABSTRACT

Nonlinear interactions of two coupled forced oscillators in the gravitational field are studied. The first oscillator that is supposed to be linear is coupled to a system which possesses multi-phase non-smooth non-conservative and restoring forces. The mass ratio of two oscillators is very small. Studying the system at fast time scale reveals an invariant manifold which depends on the amplitude of applied force on the non-smooth oscillator while slow dynamics of the system around its invariant demonstrates its equilibrium and singular points. Detected time multi-scale dynamics of the system can be endowed for designing proper controller and/or harvester non-smooth oscillators which presents final desirable periodic and/or strongly modulated responses.

1. Introduction

There are several ways of the vibratory energy control/harvesting. We categorize them into two major groups namely, linear and nonlinear ones. The most well-known linear controller/harvester system is Frahm device or tuned mass damper [1]. Linear systems modify frequency of the host oscillator while they are efficient for a narrow frequency width. There are many types of nonlinear controller/harvester systems or mechanisms [2]. One of the recently developed nonlinear guest oscillators which is very light (compared to the mass of the host oscillator) is named as nonlinear energy sink (NES) [3,4]. Most of the studies on NES-controlled/harvested systems are based on the essential cubic nonlinearity of the NES [5,6]. Some works have been carried out which consider other types of nonlinearities for the NES: the NES with non-polynomial nonlinearity [7], vibro-impact NES [8–11] and non-smooth NES [12,13] from which some of them take into account the effects of gravitational field or pre-stressed systems [14,15]. Localization and control process of main linear oscillators by NES with smooth cubic restoring behavior and hysteresis response [16] and a NES with local and global nonlinear potentials [17] are also studied. Recently, the nonlinear interactions between a linear oscillator which is coupled to a multi-phase non-smooth oscillator has been studied by authors [18]. In the current paper we expand that work to trace different possible scenarios for the overall system during extreme energy exchanges between two oscillators and to prepare design tools for passive control of main structures by such multi-phase non-smooth oscillators. In detail, we consider two coupled forced oscillators in the gravitational field: one of them is linear which is coupled to a light system with multi-phase potential function and non-conservative force. The paper traces fast and slow dynamics of the system which lead to the detection of its equilibrium and singular points corresponding to periodic and strongly modulated regimes. The article is structured as it follows: the academic model of the suggested system, treatments of its equations which contain introducing the center of the mass and relative displacement of two oscillators, complexification of system variables and keeping constant and first harmonics of the system are presented in Section 2. Fast and slow dynamics of the system are traced in Section 3. These studies reveals the slow invariant

* Corresponding author.
E-mail address: alireza.turesavadkoohi@entpe.fr (A. Ture Savadkoohi).

http://dx.doi.org/10.1016/j.ymssp.2016.09.043
Received 29 March 2016; Received in revised form 6 September 2016; Accepted 30 September 2016
Available online xxxx
0888-3270/

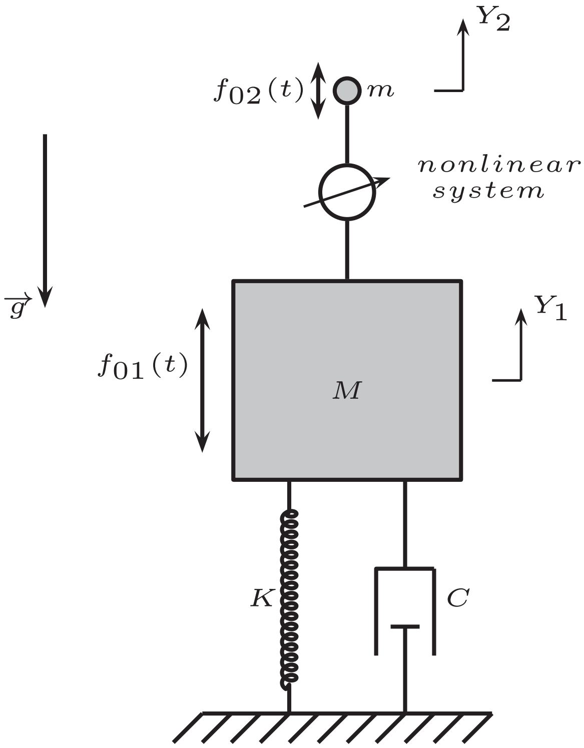

Fig. 1. Academic model of the system: the linear forced oscillator with the mass M is coupled to a non-smooth forced oscillator with the very light mass m. The overall system is in the gravitational field g.

manifold and its stable zones, equilibrium and singular points of the system. Two examples are presented in Section 4 where numerical results (obtained from direct integration of system equations) are compared with analytical predictions. Finally, conclusions are collected in Section 5.

2. The system under consideration and its preliminary treatments

The academic model of the system in the gravitational field is depicted in Fig. 1: a linear oscillator with mass, rigidity, damping and forcing terms as M, K, C and $f_{01}\sin(\Omega t)$ hosts a multi-phase non-smooth oscillator with the very light mass as m and external excitation as $f_{02}\sin(\Omega t)$. The non-smooth restoring force of the guest oscillator ($\widetilde{F}$) is illustrated in Fig. 2 which is defined as follows:

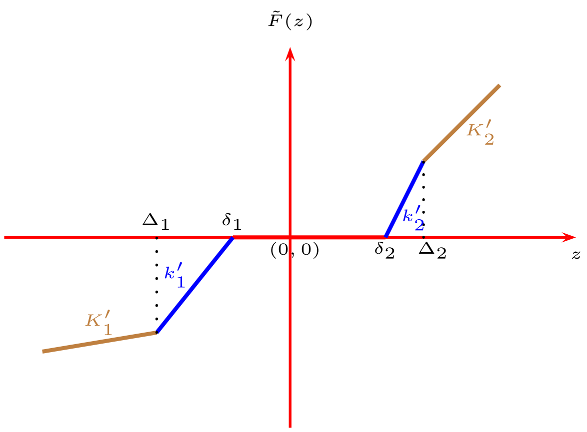

Fig. 2. The schematic of the multi-phase non-smooth behavior of the guest oscillator: restoring force $\widetilde{F}(z)$ versus the generalized displacement z.