On the reliability of contact models in Vibro-Impact Nonlinear Energy Sinks

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Summary. The Vibro-Impact Nonlinear Energy Sinks (VI NES) is a highly nonlinear device employed for dissipating energy of a primary vibrating system. The simplest setup consists of a rigid container enclosing a spherical particle, which slips along the container and impacts against its walls under vibrations. This study assesses the sensibility of the VI NES dynamics to the impact velocity and the contact force estimation.

Introduction

Over the past few years, the use of vibro-impact dampers as vibration absorbers aroused the interest of the research community. Potentially, vibrational energy may be dissipated by the impacts that occur between a particle and one or more rigid barriers linked to a primary structure. Several configurations of vibro-impact systems were proposed, including single-sided VI NES [1, 2], symmetric single-sided VI NES [3] and double-sided VI NES [4, 5].
Refs. [6, 7] verified the efficiency of the VI NES for a primary system subjected to a seismic excitation. The greater part of the vibrational energy is dissipated at the beginning of the ground motion, when the primary structure is highly stressed. Notably, analytical and experimental studies revealed the existence of various dynamical regimes of the VI NES and their effect on the energy dissipation capability [8, 9].
This study focuses on the dynamics of a double-side Vibro-Impact Nonlinear Energy Sink (VI NES) shown in Fig. 1. Since the VI NES performs well in the vicinity of the 1:1 resonance, numerical simulations should be able to calculate as accurately as possible the rebound velocity and instant. We will show the effect of slight delays in the kinetic energy estimation and we will suggest some solutions to improve accuracy of the contact computation.

Instantaneous contact

In the framework of contact mechanics, instantaneous collisions between two rigid bodies lead to a change of direction and velocity depending on the value of the coefficient of restitution (COR) ϵ, which is defined as:

$$\epsilon = \frac{v_1(t_c) - v_2(t_c)}{v_2(0) - v_1(0)}, \tag{1}$$

with $0 \leq \epsilon \leq 1$. $\epsilon = 0$ for perfectly inelastic collisions and $\epsilon = 1$ for perfectly elastic collisions. The COR can be estimated by measuring experimentally the contact duration and the flight time of a bouncing ball [10]. $v_{1,2}(0)$ and $v_{1,2}(t_c)$ are the velocities of the particles before and after the collision, respectively, and t_c the contact duration. When the VI NES is coupled to a primary system for the passive vibration control, the contact duration t_c is generally very small with respect to the dominant time scale and the contact may be approximated as an instantaneous phenomenon. To solve numerically this problem, an event driven scheme may be used. At first, the simulation solves separately the free flight of the particle and the dynamics of the primary system. Then, when the particle collides with a barrier, the particle and primary system initial conditions (IC) are updated with new positions and velocities obtained from the law of conservation of momentum. The numerical integration scheme goes on until the end of the simulation.
Previous studies shown the close link between the VI NES damping capability and its dynamical regime, which ranges from periodic collisions to chaos. Hence, numerical resolution of this non-smooth numerical problem requires very high accuracy in the estimation of the impact velocities. Indeed, a small variation may lead to a huge change in the system

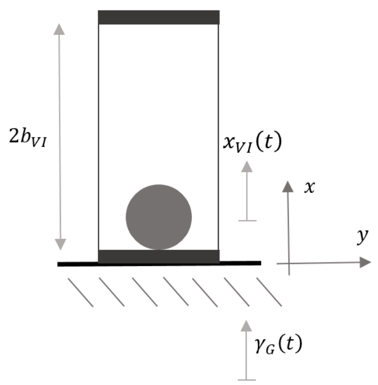

Figure 1: Schematic representation of a VI NES.

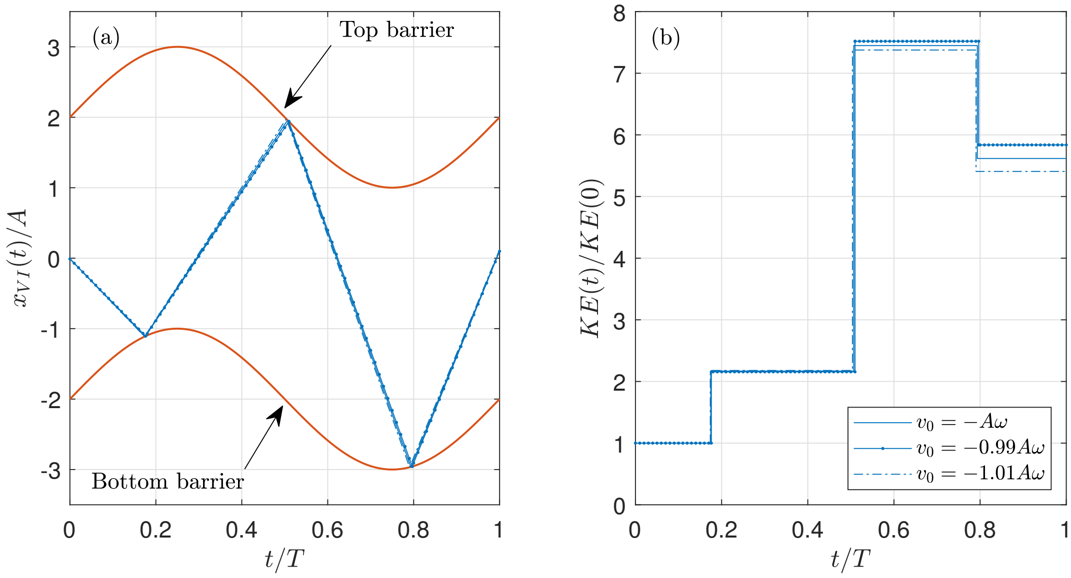

Figure 2: Simulated motion of the VI NES shown in Fig. 1. VI NES is shaken kinematically at $f = 1/T = \omega/2\pi = 100$ Hz with an amplitude $A = 10$ cm (see the red curves). The initial velocity of the particle is $v_0 = -62.8$ m/s. For the sake of clarity, the particle is considered as a point mass interacting with the inner walls of the container. (a) Position and (b) kinetic energy of the particle for $\epsilon = 0.7$ and by varying its initial velocity.

dynamics. As an example, we show in Fig. 2(a-b) the trajectory and the kinetic energy, respectively, of a steel spherical particle impacting against two rigid walls kinematically shaken at $\gamma_G(t) = -A\omega^2 sin(\omega t)$. Here, we implement the instantaneous contact model defined in Eq. 1, such that the contact duration $t_c = 0$ is infinitely small compared to the period of oscillation T and the VI NES dynamics is solved for one period for different initial velocities. As it can be seen, a variation of the order of the 1% of initial velocity leads to a difference of the about the 4% in the kinetic energy after only one period. This bias leads to different energy transfers and thus of energy dissipation. Moreover, this delay can cause an error in the simulation of the system dynamics by falling into one dynamical regime in preference to another.

Conclusions

The capability of a VI NES to damp vibrations of a primary system depends on its dynamical regime. For this reason, much attention must be paid on the numerical computation of the impacts in terms of relative velocity and time. One solution that prevents to increase computational costs, is to enrich the contact model by computing the contact force and using a finite duration continuous interaction potential. Notably, it is possible to demonstrate that the contact duration has a considerable effect on the estimation of the dissipated energy, even for very fast collisions. Another benefit of finite contact modeling is that it allows to evaluate the accelerations and the repulsive forces, which are not provided by the instantaneous contact model.

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