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► To cite this version:

Vincent Marre, Guilhem Michon, Vincent Manet. Performance of nonlinear targeted energy transfer under stochastic and deterministic excitations. ASME 2017 International Design Engineering Technical Conference & Computers and Information in Engineering Conference DETC/CIE 2017, Aug 2017, Cleveland, United States. hal-01851620

HAL Id: hal-01851620

<https://hal.science/hal-01851620>

Submitted on 9 Nov 2018

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DETC2017-67569

**PERFORMANCE OF NONLINEAR TARGETED ENERGY TRANSFER UNDER
STOCHASTIC AND DETERMINISTIC EXCITATIONS**

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INTRODUCTION

In this paper, a theoretical and experimental investigation of a linear oscillator coupled to a cubic Nonlinear Energy Sink (NES) is presented. During the past decades, NES have been studied extensively in a deterministic framework whereas in practice solicitations are mainly random. Indeed, it is widely recognized that most of engineering structures are submitted to random excitation. This is the case for example for earthquakes, environmental loads (wind, waves, etc ...) and also in service vibration on vehicles. The main idea of the presentation is to propose a simplified approach to estimate the stability threshold of NES under random excitation.

Historically, the principle of Targeted Energy Transfer (TET) was initiated by the work of Gendelman et al. [?] [?]. This allows to highlight the efficiency of a NES to mitigate the impact of vibration on structures. The theoretical analysis (Complexification Averaging, Fixed Point and Asymptotic Analysis) of the NES coupled to a linear oscillator presented herein are based on [?], [?] and [?]. The determination of the optimal parameters for the NES under deterministic excitation was based on the appearance of the detached resonance curve as discussed in [?].

On the basis of these results, the Extreme Response Spectrum (ERS) proposed by Lalanne [?] is investigated in order to evaluate its capability of defining an equivalent white noise able to trigger the instability on previously designed NES. In order to check that our case study lies in the range of application of the

ERS method a stochastic analysis is performed to estimate the steady-state joint probability density function governed by the Fokker-Planck equations. To conclude, experimental results for deterministic and stochastic excitations are presented in order to confirm the relevance of the method.

DETERMINISTIC ANALYSIS

The aim of this section is to determine the optimal characteristics for a NES dedicated to control the first natural frequency (around 350Hz) of our experimental setup. The excitation is supposed to be a 2g sine-sweep between 5Hz and 2kHz. The system is governed by the set of equation of motion and was modeled with Nastran software.

With the assumption that the first mode is uncoupled with each other and has a linear behavior, the full finite element model was reduced (Craig & Bampton) to a classical two DOF system. The equations of motion were then projected on the *Craig & Bampton* basis (with one component mode and one physical degree of freedom). And then, the equations are simplified and rewritten in a classical form. Finally, the steady-state response regimes and their stability are computed and the optimal characteristics of the NES are evaluated (see figure 1)

Thanks to that results a NES made of a lever pulling transversely on two stainless steel cables (cubic stiffness) was proposed.

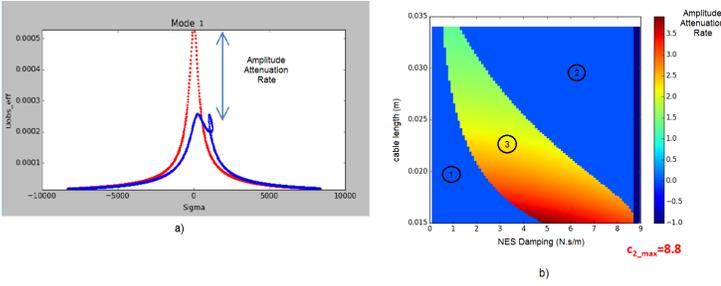


FIGURE 1: a) Fixed point response : dot line (...) denotes system response without NES and solid line (—) system response with NES b) zone 1 : The detached resonance, zone 2 : NES is not activated and zone 3 : NES is activated with Strong Modulated Response - optimal zone

STOCHASTIC ANALYSIS

The aim of this section is to evaluate a white noise excitation that could trigger the NES which has been defined previously. The idea is to propose a simplified and equivalent method to evaluate the random excitation associated to the NES thresholds.

This method is based on the Extreme Response Spectrum (ERS) method (see Ref. [?]).

$$ERS_{accel}(f) = \sqrt{\pi f Q G_z(f) \ln(f.T)} \quad (1)$$

Where f is the frequency (Hz), Q the amplification factor, T the duration (in seconds) and G_z is the spectrum in g/Hz .

Then considering the ERS of a 2g harmonic excitation we can estimate an equivalent white noise with a PSD amplitude of 0.031 g/Hz .

The validity of the ERS method was verified by calculating the steady-state joint probability density function governed by the Fokker-Planck Kolmogorov (FPK) equations.

EXPERIMENTAL RESULTS

The setup was tested experimentally with and without the NES in order to estimate its efficiency to mitigate vibration for both type of excitation. The response of the system with the NES under 2g sine sweep between 5Hz and 2kHz is depicted in figure 2 when the excitation frequency approach 350Hz. We can observe a Strong Modulated response that occurs for this forcing amplitude. This figure presents the velocity measured on the main oscillator and on the NES. In each case, a Hilbert Transform is performed to obtain the instantaneous frequency (bottom view) to illustrate the resonance capture.

In the same way, figure 3 presents the experimental results for a white noise (0.031 g/Hz). As observed previously for the harmonic excitation, a strong modulated response appears on the secondary oscillator. That leads to a relevant attenuation on the amplitude response of the main oscillator.

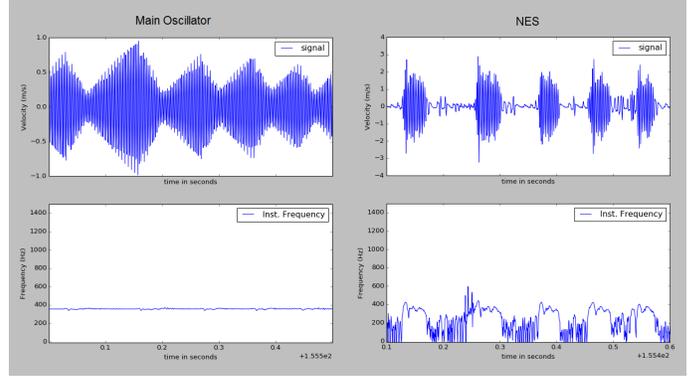


FIGURE 2: Deterministic excitation : Response on main oscillator (left) and NES (right)- Transient response (Top view) and Instantaneous Frequency (Bottom view)

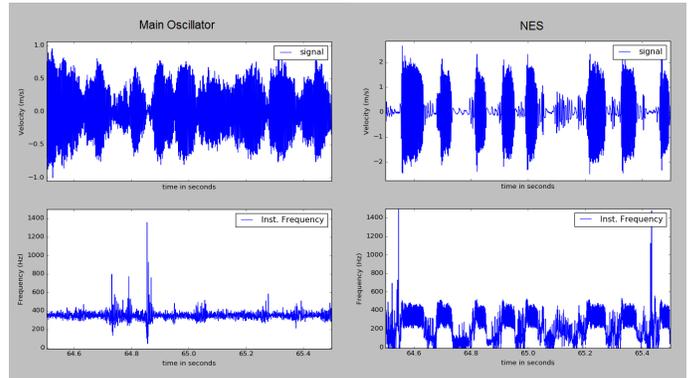


FIGURE 3: Stochastic excitation : Response on main oscillator (left) and NES (right)- Transient response (Top view) and Instantaneous Frequency (Bottom view)

Globally, the experimental results shows the relevance of the ERS method to easily estimate the NES thresholds.

CONCLUSION

In this presentation, the behavior of a linear oscillator with an embedded NES under deterministic and stochastic excitation was investigated theoretically and experimentally. At first a NES was designed to control our experimental setup and to exhibit a strong modulated response under 2g harmonic excitation using a classical approach. In a second time, the Extreme Response Spectrum method allowed us to estimate the NES threshold and to determine a white noise excitation able to trigger an instability on the NES. Despite some discrepancies, the experimental results show a good agreement with the theory for harmonic as well as random excitation. That confirms that the ERS method is relevant for designing a NES under Random Excitation.