CONTROLLED EXCHANGE OF CO-EXISTENT ATTRACTORS

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ABSTRACT

The idea of adaptable systems has been used on several applications, where the ability of a system to exchange between different attractors and configurations can bring a lot of versatility and expand its functionality. However, the control methods required to explore the different behaviours and configurations of these adaptable systems have not been fully investigated and just a few studies have focused on this matter [1]. Existent controllers also require the full knowledge of the attractors, the system model and the phase between response and excitation in non-autonomous systems, which bring several difficulties on real applications.

The time-delayed feedback control (TDF) [2] is the target of several studies and was designed to stabilize unstable periodic orbits (UPOs) inside chaotic attractors. Originally, it requires the knowledge of the system's model to calculate its gains and stabilize UPOs, however, when targeting stable orbits this calculation is not required and only a low amount of information, mainly the period of the target orbit, is needed. Recently, a new direct mass excited impact oscillator with high excitation accuracy [3] has been reported to present multi stability and the ability to be a platform for implementing and testing control methods.

This work introduces a new modification of the time-delayed feedback control to perform exchange between co-existing attractors and applies it numerically and experimentally to an impact oscillator to test its capabilities in various scenarios. Initially an analysis of the system dynamics is performed and four different scenarios are selected to test the control strategy. The TDF control is applied to each different scenario and successfully exchange the system response between each coexistent attractor in the first three cases. In the last case the TDF alone can not perform the exchange and the modification proposed is introduced by utilizing a fraction of the targets orbit period as the delay. The proposed controller is able to successfully perform the exchange which can be verified on Fig. 1.

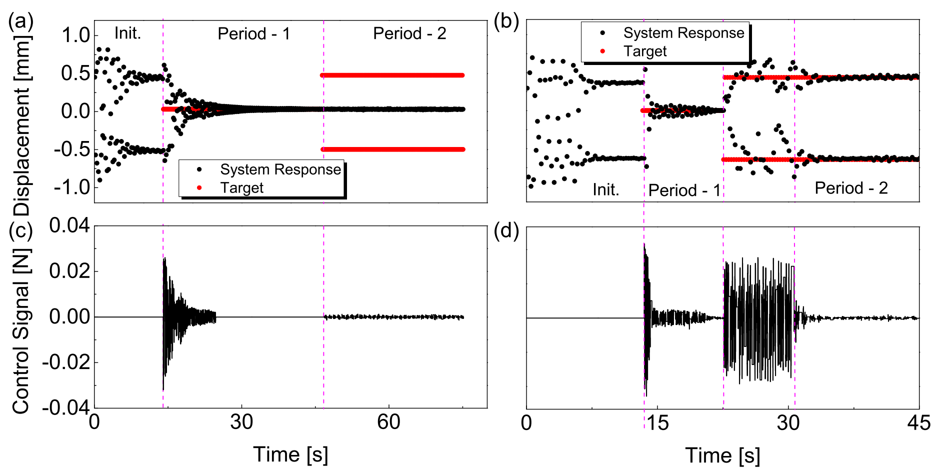

Figure 1: Experimental exchange control of coexisting attractors. Poincaré time series of position (a) for the TDF control and (b) for the new controller. Control signal for (c) the TDF control and (d) the proposed control. Dashed magenta lines indicate boundaries where the controller targets a period-1 or a period-2 orbit.

Keywords: Impact oscillator, Time-delayed feedback, Chaos control

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ANALYTICAL METHOD FOR PIECEWISE LINEAR OSCILLATORS

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ABSTRACT

Analysis of piecewise linear systems are of great importance for several engineering applications. Systems with motion-limiting constraints or clearances can be investigated using these non-smooth models. Determination of the response allows to prevent unwanted system wear or improper functioning and gives important knowledge useful for mechanical design. For this reason, piece-wise linear systems are extensively studied. Investigation including numerical integration (e.g. [1]), experimental analysis (e.g. [1]) and analytical studies (e.g. [3]) have been done for these systems. A generic and versatile system is analysed, with the ability to represent multiple parameter configurations. Mapping transformations and stability investigations will be presented. A validation of the method is done by comparison with brute-force numerical solutions for selected range of parameters (Figure 1). Finally, multiple system parameter settings are discussed, with particular focus in understanding the effect of stiffness and damping functions definition (e.g. Figure 2).The proposed method allows to predict the different bifurcation scenarios and analyze stable and unstable orbits. Typical hardening and softening behavior were reproduced by adequate variation of stiffness definition. A relation between the shape of the bifurcation diagram and the possibility of presence of chaotic behavior has been observed.

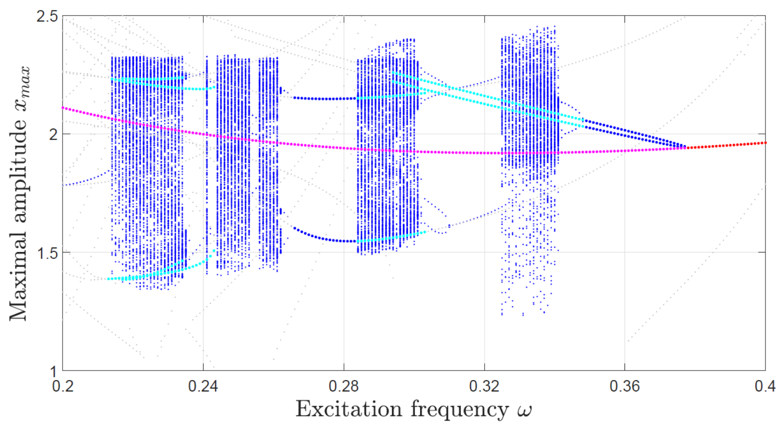

Figure 1: Simultaneous plots of brute-force numerical integration and proposed methodology results. Blue color is chosen for the numerical integration method. In red (symmetric stable), pink (symmetric unstable), blue (non-symmetric stable) and light blue (non-symmetric unstable) orbits obtain for the proposed methodology are presented.

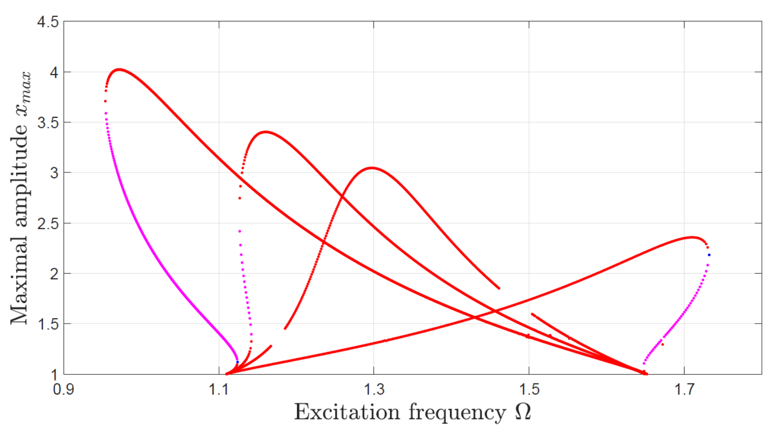

Figure 2: Different bifurcation scenarios obtained for multiple stiffness function definition. Typical softening and hardening behaviors are presented.

Keywords: Piecewise linear oscillator, impact, analytical method, numerical simulation.

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International Conference on Engineering Vibrations

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EFFECTS OF OSCILLATING PEGS IN A GALTON BOARD

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ABSTRACT

The Galton Board can be considered as an interesting dynamic toy which demonstrates how with a large sample size a binomial distribution approximates to a normal distribution. Researchers have investigated the Galton Board investigating irreversibility in it [1], a viscous attractor for it [2], along with its statistical structure [3]. This paper investigates the outcome of the distribution obtained from a Galton Board when the pegs are dynamic. In this regard, sinusoidal oscillations of the pegs are considered. We show how bi-modal distributions can be formed due to oscillating pegs in a Galton Board. It is expected that this result will lead to further investigation into the idea of dynamic Galton Boards and their characteristics in future.

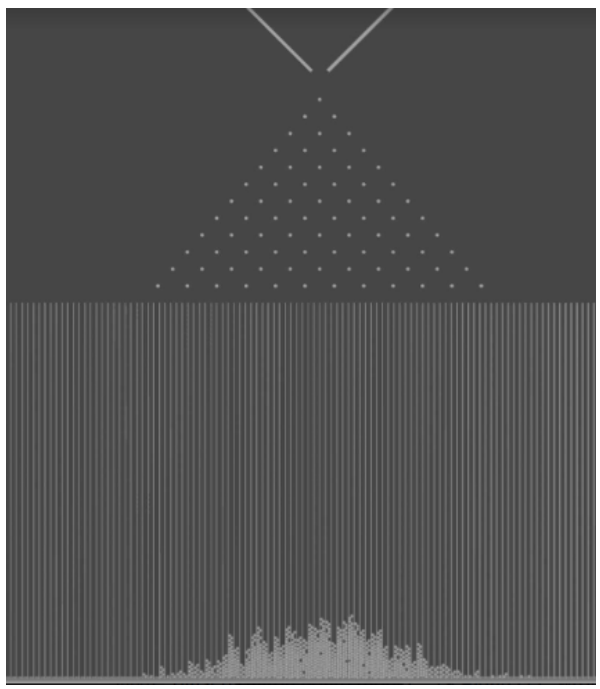

Figure 1: Output from a Galton Board simulation using Blender [4]

Keywords: Galton Board, Statistical Distributions, Dynamics

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MULTIMODAL PIZZA-SHAPED PIEZOELECTRIC VIBRATION-BASED ENERGY HARVESTERS

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ABSTRACT

Piezoelectric vibration-based energy harvesting systems receive increasing attention nowadays as an alternative to power sources like batteries that have a limited lifetime and need periodic recharge or replacement. One of the main challenges is to develop efficient devices capable of adapting to diverse sources of environmental excitation. In this regard, ambient vibration excitations may feature in a broadband frequency spectrum. Usually, devices presented in the literature are related to piezoelectric energy harvesting systems based on a cantilever beam, which cannot explore all energy potential available in the environment. This work proposes a novel multimodal piezoelectric energy harvesting design to harness energy from a wideband ambient vibration source. Circular-shaped and pizza-shaped configurations are employed as candidates for the device, comparing their performance with classical cantilever beam devices.

The most common vibration-based configurations studied in the literature of energy harvesting are the piezoelectric beams. Piezoelectric linear devices based on cantilever beam models have been investigated numerically and experimentally, showing that these systems have better performance under resonant conditions, losing efficiency when the excitation frequency is distributed over a wider spectrum [1,2]. Multimodal systems constitute an alternative to broaden the operational frequency range of linear energy harvesters. The multimodal system can be designed aiming at close resonant peaks, increasing the operational frequency range [3]. This work aims to develop novel configurations of multimodal piezoelectric energy harvesting devices to harness energy from a broadband vibration excitation. The classical cantilever beam configuration is established as a reference performance case to exploit other harvester designs. Different configurations, including circular-shaped and pizza-shaped, are modeled using finite element analysis to design, develop, optimize and investigate the system to establish suitable performance conditions under different types of vibration excitations.

Figure 1 presents a comparative analysis of the output power generated for all energy harvester configurations. It is noticeable that the pizza-shaped designs achieve wider frequency bandwidth compared to conventional energy harvesters. The resonant peaks are designed to align in the frequency range of 100 – 150 Hz, being spread enough to extend the frequency bandwidth but also sufficiently close in such a way that the valleys among them are mitigated. This is of special interest especially when the ambient excitation source is spread away from the resonant frequency of the system and the conventional cantilever energy harvester is less efficient. Therefore, the proposed multimodal piezoelectric pizza-shaped device shows potential to extract energy from ambient vibration sources with a broadband spectrum.

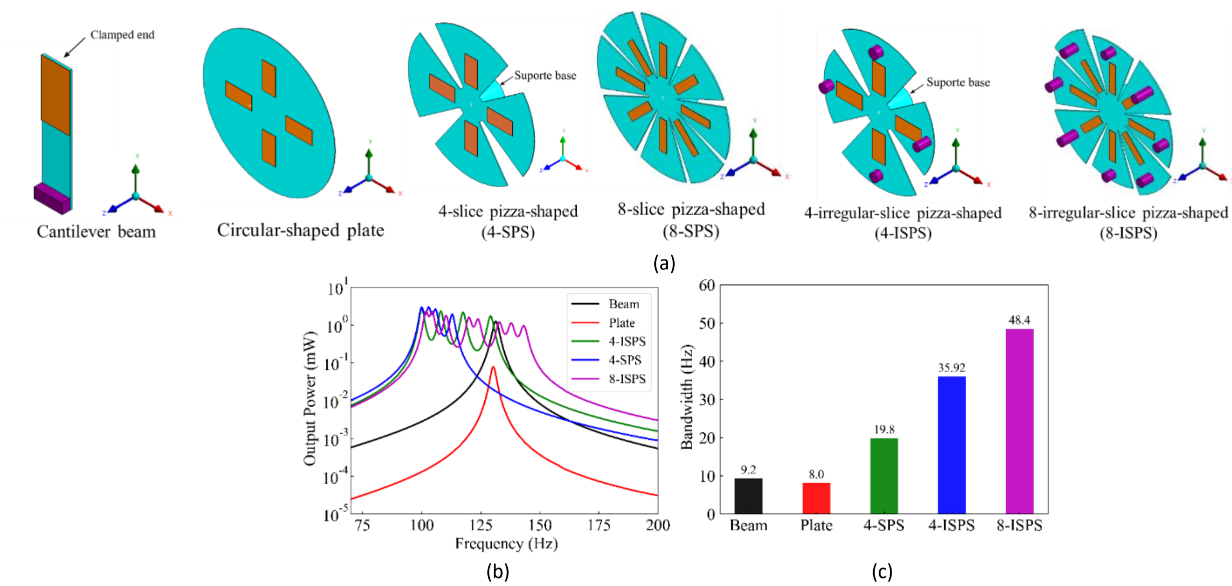

Figure 1: (a) Energy harvesters configurations, comparative of (b) output power spectrum curves and (c) frequency bandwidth.

Keywords: Energy harvesting, multimodal harvester, finite element analysis, ANSYS, random vibration

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AN APPLICATION OF THE GLOBAL SENSITIVITY ANALYSIS ON A BISTABLE ENERGY HARVESTER

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ABSTRACT

Piezoelectric energy harvesting technologies are being explored by many researchers, due to their high potential to provide clean energy for low consumption devices. It consists of an electromechanical system capable of converting mechanical energy, dissipated in the environment, into electrical energy. Currently, one of the main challenges is to optimize the power harvesting over a wide frequency range and, according to [1], an alternative is the inclusion of non-linearities. Nonlinear systems require rigorous studies and analysis, as they can present chaotic behavior. This work presents an application of a global sensitivity analysis based on the Sobol indices, defined by [2], which consists of a decomposition of the total variation of the model's output, quantifying the individual and joint effect of each model's input variability. The piezo-magneto-elastic energy harvester (PMEH) system studied consists of a ferromagnetic cantilever beam attached in vertical to a rigid base excited by a harmonic force, a pair of magnets is placed at the rigid base in lower part, and two piezoelectric laminae are placed on beam's highest part, being also connected to an electrical circuit, as illustrated in Figure 1a. According to [3], the equation of motion is given by

$$\ddot{x} + 2\xi\,\dot{x} - 0.5x\,(1 - x^2) - \chi\,v = f\,\cos(\Omega t) \quad \text{and} \quad \dot{v} + \lambda\,v + \kappa\,\dot{x} = 0, \tag{1}$$

and the averaged power harvested, that is the quantity of interest, is given by

$$P \;=\; \frac{1}{T}\int_{t_i}^{t_f} \lambda\,v\,(t)^2\;dt. \tag{2}$$

The global sensitivity analysis based on Sobol' indices employs an orthogonal decomposition in terms of conditional variances, making it possible to measure the (individual and/or joint) effects of the model parameters variability on the average power (quantity of interest) [2]. In Figure 1b, it is possible to verify that the electric piezoelectric coupling (κ) and the frequency of the external force (Ω) have a higher degree of influence on the system's response, respectively. And in Figure 1c has the sensitivity of the joint effect that has less influence than first-order. Thus, this analysis becomes essential, since non-linear systems can have high sensitivity.

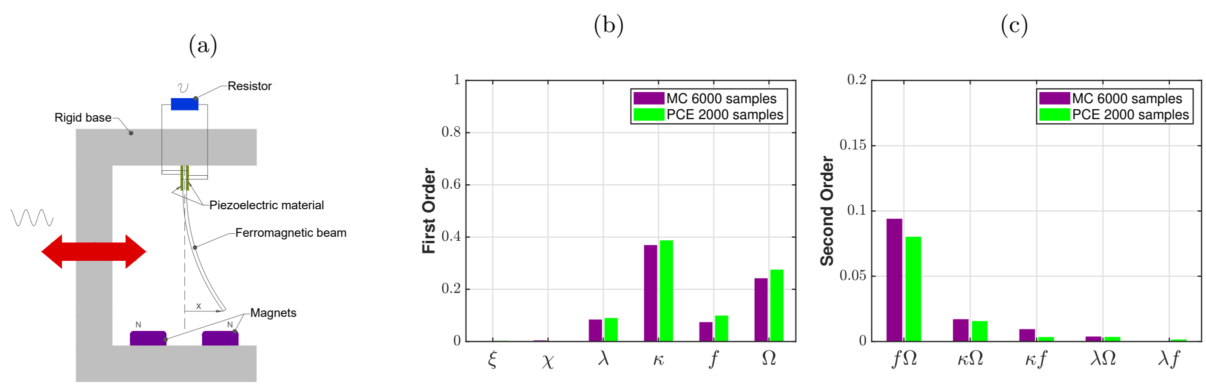

Figure 1: (a) PMEH schematic illustration (b) First-Order Sobol' Indices (c) Second-Order Sobol' Indices. System parameters: $\xi = 0.01$, $\chi = 0.05$, $\lambda = 0.05$, $\kappa = 0.5$, $\Omega = 0.8$, $f = 0.147$, $(x_0, \dot{x}_0, v_0) = (1, 0, 0)$, and $\sigma = 20\%$.

Keywords: energy harvesting, bistable system, global sensitivity analysis, Sobol' indices

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NONLINEAR ENERGY HARVESTING FROM A ROTATING SYSTEM

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ABSTRACT

A nonlinear electromagnetic energy harvester with the cubic nonlinear stiffness is proposed, and the characteristics of dynamic responses as well as the power harvested from the device are studied in this paper. The nonlinear electromagnetic vibration energy harvesting device is installed on the host base which is rotating at a constant speed and is vibrating vertically. The governing equation of the energy harvester is then derived. Owing to the combination of vertical and rotating frequency of the host base, the possible 1:1 primary resonance is investigated by using the multiple scale method. The dynamic characteristics of responses in terms of system parameters are studied and the bifurcation curves are derived. In addition to possessing the resonance characteristics, there some saddle-node bifurcations occur for the steady-state solutions under certain conditions due to the nonlinearity of the system. Moreover, the effects of parameters on the output average power are investigated as well. The results of analysis show that there are multiple frequency bands and parameter regions existing where the large power can be harvested because of the resonance and nonlinearity of the system. Introducing the nonlinearity not only can increase the value of the output power but also expand the frequency bands and parameter regions to harvest the large power. Suitable parameter selection could help to optimize the average power harvesting in the design.

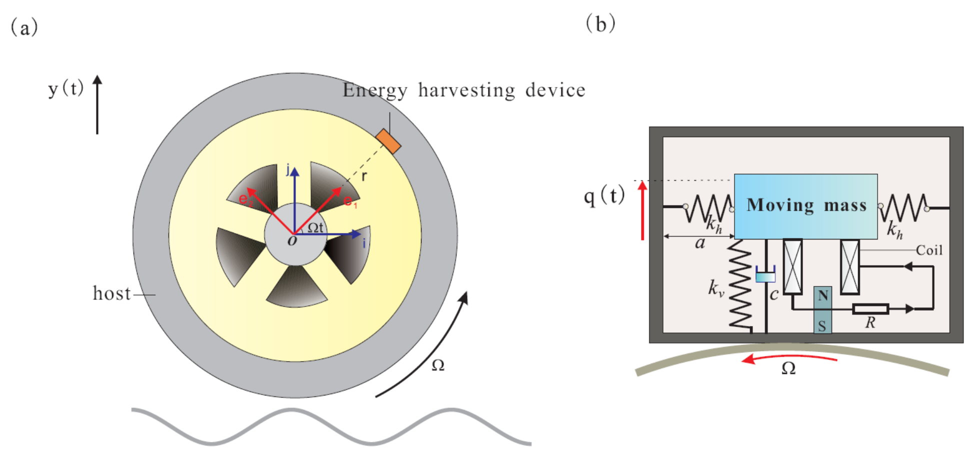

Figure 1: Schematic of a nonlinear energy harvester installed on a host system:(a) the host system; (b) the nonlinear energy harvester

Keywords: nonlinear electromagnetic energy harvester, multiple scale method, resonance, nonlinear responses, output power

BIOLOGICAL SENSORS FOR STRUCTURAL MONITORING

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ABSTRACT

The use of energy harvesters as structural health monitors in their own right has become popular in recent times. The use of such sensors for monitoring damage [1] or leakage [2] in pipes have far reaching impact. Despite the promises of energy harvesting for such detection [3], piezoelectric materials have environmental concerns and there is a need for investigating new materials [4-5] and develop sensors from them.

In this presentation, we show how biological sensors can be effective in terms of energy harvesting and subsequent detection of leakage in pipes. An experimental test rig carrying water is investigated in this regard. The results indicate the potential of extensive investigation of this concept in structural monitoring.

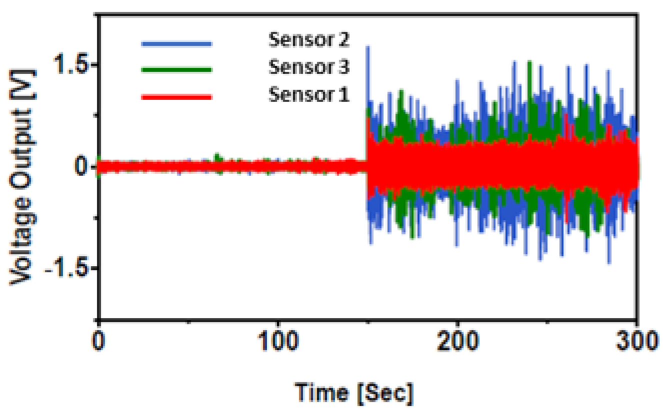

Figure 1: Detection of sudden leakage in water pipes.

Keywords: Piezoelectricity, Experimental Methods, Damage Detection

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ENERGY HARVESTING USING A NON-LINEAR VIBRATION ABSORBER WITH A PIEZOELECTRIC ELEMENT: A CONCEPTUAL CASE STUDY

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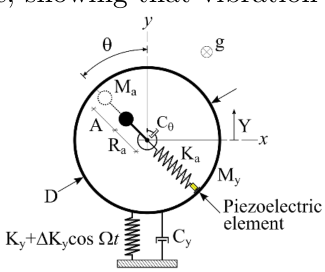
ABSTRACT

The use of auxiliary devices for passive suppression of structural vibrations is not a novelty. It is the case of *non-linear vibration absorbers* (NVAs), which have been addressed by many authors in recent years. Franzini *et al* [1], using reduced-order modelling (ROM), studied the parametric excitation of a rigid cylinder, to which a NVA was internally attached. It was seen that the NVA can effectively suppress the cylinder's vibrations, even in scenarios of principal parametric resonance. In [2], we proposed a NVA with variable radius, by attaching a spring to the NVA's mass. Enhancement of the bounded-response region in the control parameter space has been achieved. The same NVA of [2] is recast, this time aiming not only at vibration control, but also at *energy harvesting*. For this sake, a piezoelectric element is attached in series with the NVA, introducing a new degree of freedom to the assemblage: the voltage across the electrical circuit. Figure 1 depicts the model with some relevant parameters. Figure 2 depicts the system's behaviour in function of γ and δ, which are related to the excitation frequency Ω and to the system's natural frequencies (ω_s for the structure and ω_c for the circuit). Figure 2a shows that the average power p_{rms} uniformly varies with γ, and for nearly all values of δ there is little influence of Ω on p_{rms}; however, around $\delta = 0.55$ a power lift occurs. This is also where $a_{\max}$ is the highest, as seen in Fig. 2b. Notice that $a_{\max} < 1$ for every δ and γ_2, which means that, within the regarded parameter range, the internal mass does not impact against the walls of the cylinder. Finally, $y_{\max}$ is reported in Fig. 2c, showing that vibration control and energy harvesting can be simultaneously achieved.



$$a_{\max} = \frac{A}{D\left(\frac{1}{2} - r\right)} \qquad y_{\max} = \frac{Y_{\max}}{D} \qquad r = \frac{R_a}{D}$$

$$\tau = \omega_s t \qquad \delta = 4\left(\frac{\omega_s}{\Omega}\right)^2 \qquad \gamma = \frac{\omega_c}{\omega_s}$$

Figure 1: ROM of a NVA attached to a rigid cylinder

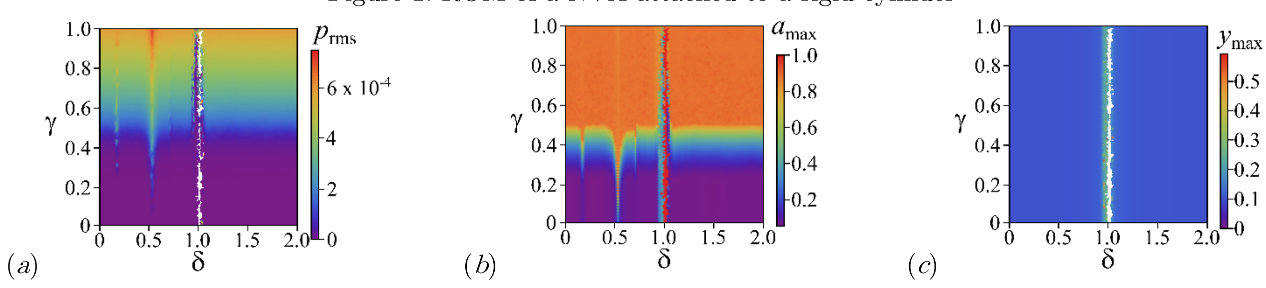


Figure 2: Parameter maps

Keywords: non-linear vibration absorber, parametric instability, piezoelectricity, energy harvesting.

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A SIMPLE AND VERSATILE ELECTROMAGNETIC ACTUATOR

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ABSTRACT

This study proposes a promising design of a versatile electromagnetic actuator, which is comprised of a permanent magnet and a single or a pair of identical solenoids (see Fig 1(a)). Specially, the twin-solenoid actuator (see Fig 1(b)) can provide constant force by passing a constant current (see Fig 2), hence it can produce an arbitrarily desired excitation depending upon the input current [1,2]. The modelling of the actuator is presented and an optimization procedure are implemented to obtain a wide effectively available range. Two basic applications in nonlinear vibrations are verified, which indicates the new design can be utilised widely as stable forcing sources and vibration controllers in vibration engineering. This study is motivated by the new electromagnetic actuator developed in CADR of the University of Aberdeen and the understanding of nonlinear mechanical systems [3,4]. MEMS and nonlinear exploitation are two fast-growing research interests in academic and engineering fields. It is worthy of noting that the actuator is an essential part in MEMS and the potential well is an important characteristic of the nonlinear mechanical vibration system, which can appear to be mono, double, triple, or multiple. Inspired by above-mentioned issues, this study will give a new idea of developing versatile electromagnetic actuators by utilising the solenoid and the magnet. The driven force of a single-solenoid actuator displays apparent dependence on the position of a magnet in the solenoid. Hence, the mathematical model of the electromagnetic actuator is firstly built for the magnetic flux density of the solenoid and the driven force. Then a new design of twin-solenoid actuator is proposed.

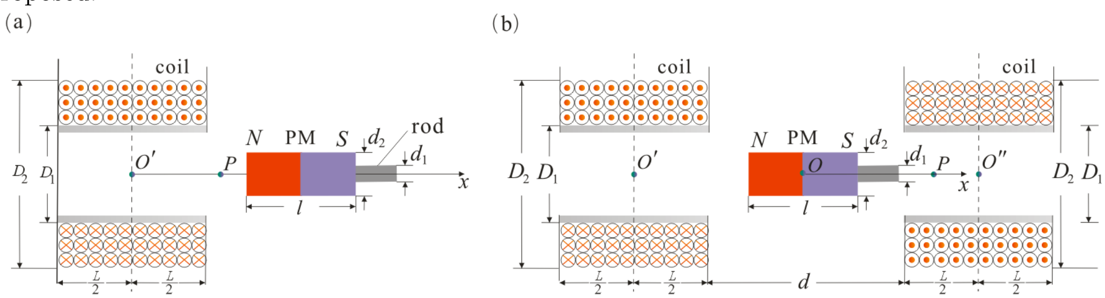

Figure 1: Schematic of the single- and twin- solenoid actuator in (a) and (b).

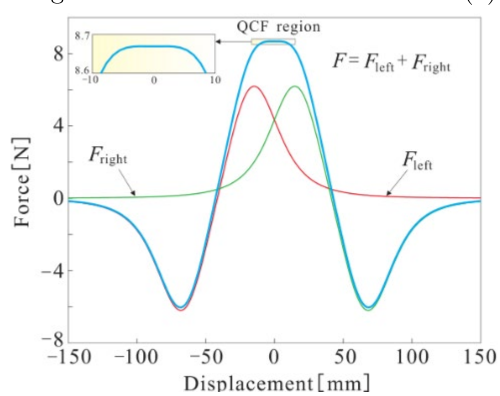

Figure 2: The quasi-constant force mechanism.

Keywords: Electromagnetic actuator, Solenoid, Quasi-constant force.

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DETERMINATION OF MATERIAL DEPENDENT PARAMETERS AND FRICTION IN ULTRASONIC-VIBRATION ASSISTED TURNING BY INVERSE MODELLING

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ABSTRACT

Ultrasonic-vibration assisted turning (UAT) is one of the most efficient processes among non-conventional machining methods for difficult-to-machine materials. In this paper, the normal and friction forces in ultrasonic-vibration assisted turning are estimated using an inverse method to evaluate the material parameters and friction. The inverse method requires the measurement of normal force, friction force and tool-chip contact length in conventional turning. The analytical expressions are used to estimate the normal and frictions. The inverse model predictions are in reasonable agreement with the experimental results available in the literature. The proposed methodology can be used for online determination of material dependent parameters and friction in ultrasonic-vibration assisted turning.

Figure 1 shows the comparison of the inversely estimated averaged normal and friction forces at different cutting speeds with the experimental results keeping other machining parameters constant. It is observed that the normal force matches with the experimental results of Jamshidi and Nategh [1] at higher cutting speeds whereas at low cutting speed the results of inverse model differ by 20%. The averaged friction forces estimated with inverse model were also compared with the experimental results of Jamshidi and Nategh [1] at different cutting speeds (Fig. 1b). It was found that the value of friction forces was in good agreement at low cutting speeds.

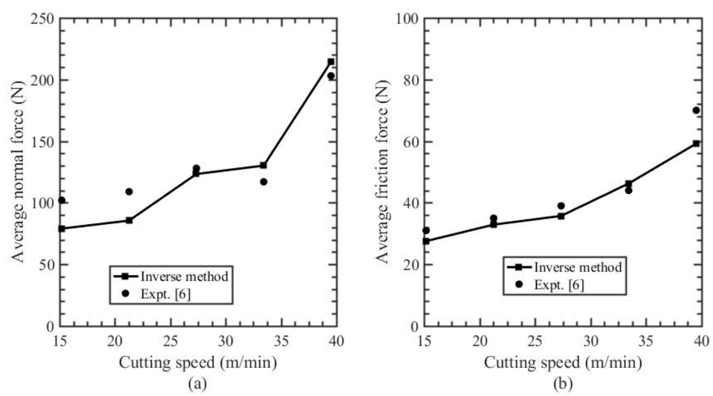

Figure 1: Validation of inversely estimated normal (a) and friction (b) forces with the experimental results of the different cutting speeds (*depth of cut* (d_0)=2.25 mm, feed rate (f)=10 m/min, frequency (f) =20 kHz and amplitude (a)=6 μm)

Keywords: material-dependent parameters; friction; ultrasonic-vibration assisted turning; inverse method; orthogonal cutting

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Performance analysis of a active coil-magnet vibration actuator using a numerical methodology

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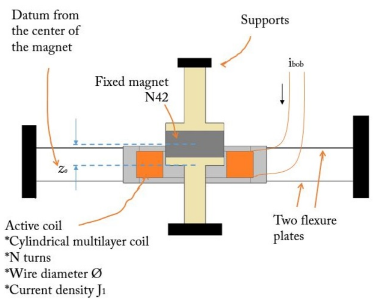
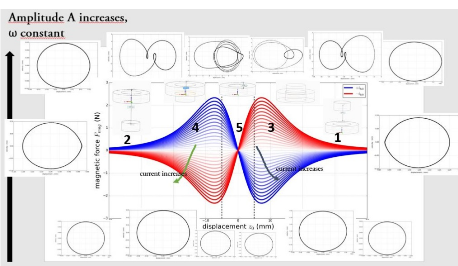
ABSTRACT

This work presents a performance analyses of a electromagnetic actuator for mechanical vibrations. The main goal of this actuator is to generate sinusoidal harmonic vibrations via the excitation produced by an electric sinusoidal harmonic signal. The performance is evaluated changing values of three important paramaters and solving a full coupled equarions system using numerical techniques, such as linear static FEA and magnetostatics analysis by FEM.



(a) Arragment of the magnet- active coil selected.



(b) Magnetic force F_{mag} as a function of z_0 and i_{bob}. Multiple phase trajectories for the complete solutions for different values of z_0.

Figure 1: Visual description of the arragment for the actuator and his possible solutions.

In [1], is presented a list of posibles arrangement of magnet-coil for energy harvesting devices. Adjusting this analyses for this work, it is selected an arrangement of an active coil moving through an fixed permanent magnet, as is shown in Figure 1a. The parameter z_0 is the distance between the datum located in the center of a fixed permament magnet and the center of an active coil at the equilibrium position. The coil and the flexures plates represented by a spring-mass-damper equivalent system, excitated with a magnetic force F_{mag}. This force is related to the position of the coil $z + z_0$, where z is the displacement of coil in vibration, and the current in the coil i_{bob} supplied for an external electric circuit with a main voltage v_{pwm}. This kind of system are well modelled and studied as a general full system with coupled electric, magnetic and mechanical subsystems. An example of this is described in shaker design analysis in [2].

First for the mechanical subsystem, an equivalent mass m and stiffness k, are obtained by a linear statics analysis, while firsts modes and natural frequencies of the structure, are estimated by a numerical modal analysis. For other hand, the damping value used has concordance with standard damping ratios presented in reference books, as [3]. Then, using a numerical model for the magneto statics problems is calculated the force F_{mag} for different values of z_0 and i_{bob}. The implementation in this part is done using an interface for python of the free software $femm4.2$, in the way that allows to perform a build and re-build magneto statics FEM models for differents conditions in the simulations. Also it is obtain here the induced voltage e_{mag} in the active coil, as is presented in [1]. The full complete coupled systems is expressed as a system of ordinary differential equations and a solution of this is found using a code in *python* with the library *scipy* and the function *integrate.ode*.

Analyzing the solutions of z,$\dot{z}$, $\ddot{z}$ and i_{bob} five zones of behaviour can be found. In the Figure 1b is shown a multiple variable of state graphics with the result of this quasistatic magnetic force and his relations with z_0 and i_{bob}, and also attached phase trajectories obtained from the solution of the full coupled system for particular values of z_0, the amplitude A and frequency ω of the signal v_{pwm}. Whith this numerical methodology it is obtained a first estimation of the response of the signals for a complex design for an electromagnetic actuator. For example in zones 1 and 2, faraway to the magnet and for any value of A and ω, a quasi linear response is presented and in zones near the magnet 3, 4 and 5, high values of A could bring nonlinearities.

Keywords: electromagnetic actuator for mechanical vibrations, linear statics analyses, magneto statics problems.

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DETECTING LOSS OF TIGHTENING TORQUE IN BOLTED JOINTS USING GAUSSIAN PROCESS REGRESSION

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ABSTRACT

Non-invasive methods able to detecting loss of tightening in bolts are a topic of ongoing research since several built-up structures are assembled with bolted joint connections [1]. One of the main issues regarding the development of indices that capture variations in the tightening preload lies in the difficulty of distinguishing what appears from nonlinear behavior and what is preload changes, especially in the early stages where there is superposition between these effects. So, the present paper proposes a new approach to detect loss of tightening torque on bolts based on the indirect correlation of reduced-order metamodels with the tightening torque using Gaussian Process Regression (GPR). The experimental setup is the Orion beam benchmark, which consists of two assembly aluminum beams with contact patches at each bolt connection, as seen in Figure 1. The identification of metamodels is performed in

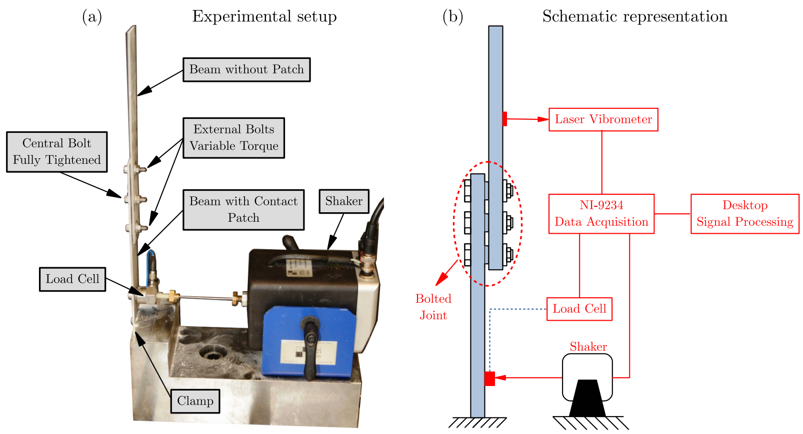

Figure 1: Experimental setup of a structure assembled by bolted joints.

a Bayesian paradigm through the tracking of experimental backbone curves. During the training phase, the GPR are updated assuming different excitation amplitudes and tightening torque conditions, as illustrated in Figure 2. Then, the GPR are identified with this dataset to observe the trend in the metamodel curves and to calibrate the healthy state (safe torque). To test the effectivity and reliability of the method for detecting loss of torque,

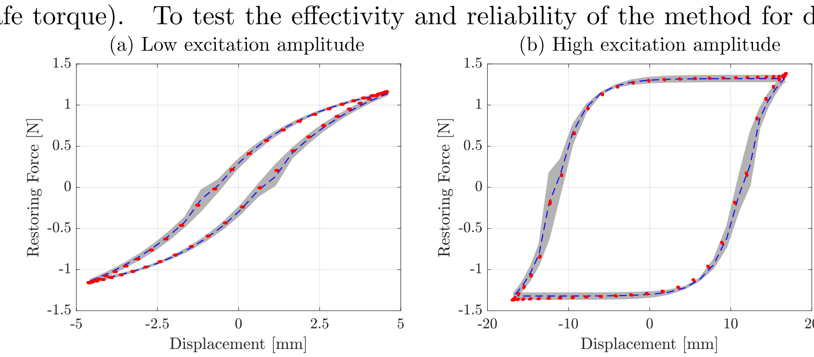

Figure 2: Representative hysteresis loop. ▇ represents the 99% model response confidence bands, and • are experimental realizations.

some damage indices are computed and tested considering a new set of experimental measurements of three similar Orion beams. The previous results have demonstrated an adequate correlation to help us to detect a threshold for monitoring the safety of bolted joints with a confidence interval to accommodate incertitudes.

Keywords: Structural Health Monitoring, Bolted Joints, Reduced-Order Models, Stochastic Modelling, Gaussian Process Regression, Frequency Response Curves.

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Nonlocal Shell Model for Vibration Analysis of Carbon Nanoscrolls

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ABSTRACT

Rolling a monolayer graphene sheet into a spiral multilayer structure forms a special nanostructure called Carbon Nanoscroll (CNS). The open configuration of CNS contains two boundaries along the curved edges and two boundaries along axial direction. For the first time, CNSs have been introduced as graphite whiskers in 1960 by Bacon [1] and have received significant intensity after discovering a new production procedure in 2003. CNSs can be used in different fields as biosensors [2], hydrogen storage devices [3-4] and etc.

This research presents a nonlocal shell model for linear vibration analysis of CNS, where, Eringen's nonlocal elasticity formulation has been applied and small-scale effects have been studied. The model considers elastic and classic boundary conditions for CNS. The interactions between the layers of CNS are modeled as van der Waals forces and in order to solve the eigenvalue problem of CNS vibration, the assumed mode method is used. Chebyshev polynomials of first kind are used to obtain the eigenvalue matrices. The natural frequencies and corresponding mode shapes of CNS in different boundary conditions are evaluated. The results indicate the considerable effect of small-size effect on the magnitude of natural frequencies and mode shapes.

Keywords: Carbon Nanoscroll, Nonlocal elasticity, Shell Model, Natural frequency

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