LabeXAction
Integrated smart systems

PhD thesis position within the framework of the laboratory of excellence (Labex) Action (WP2: Wave propagation in structured materials)

Collective dynamics and soliton-based waveguides in periodic nonlinear lattices for vibration energy harvesting applications

Location(s)	FEMTO-ST Institute, Department of Applied Mechanics (Besançon - France)
Supervisor(s)	Manuel Collet (CNRS), Najib Kacem (UFC), Noureddine Bouhaddi (UFC)

Job description

1. Context

The phenomenon of localization has attracted much recent attention in many applications in physics because of its important role in the qualification as well as quantification of system's operations. The localization can be generated either by the "disorder" in a lattice (Anderson localization) or by the interaction between the non-linearities and a discrete system. One of the most popular localization phenomena, that have attracted the interest of physicists, is the nonlinear energy localization. Such localized energy excitations, called intrinsic localized modes ILMs, also known as "discrete breathers" or "lattice solitons" can occur in defect-free periodic nonlinear structures, extending over only a few sites.

The remarkable property of solitons is their exceptional stability against disturbances. They are also able to occur spontaneously in a non-autonomous physical system even if the initial excitation does not exactly correspond to an ILM. Actually, if a system has characteristics that allow the existence of solitons, then an intense excitation will potentially lead to their creation. Therefore, solitons play a fundamental role in the properties of energy transport for a variety of fields such as optics, acoustics, and hydraulics.

2. Objective

The principal goal of this thesis consists in the functionalization of the localization phenomenon by modeling the collective dynamics of a vibrating energy harvester based on a periodic lattice of coupled nonlinear resonators. Particularly, we consider the case of mono-directional lattices of MEMS cantilevers having a geometric Von Kármán nonlinearity coupled linearly via the overhang and non-linearly by the Van Der Pol nonlinear damping. Then, the model will be extended to the case of bi-directional lattices and specifically for periodic arrays of CMUT (capacitive micromachined ultrasonic transducers). The devices will be fabricated in the clean rooms of MIMENTO.

3. Main tasks

- **State of the art**

As a first step, the candidate has to analyze and synthetize the state of the art of periodic non-linear structures and vibrating energy harvesting techniques while investigating the intrinsic localized modes, as well as identifying the appropriate quasi-analytical and numerical solving techniques for systems of coupled nonlinear partial differential equations.

- **Multiphysics model and investigations of physical phenomena**

In this part, the candidate has to model and understand the collective dynamics of a periodic array of vibrating structures involving functionalized nonlinearities. To do so, an important choice of the type of localized nonlinearities (Duffing, Van Der Pol, NES…) will be made and depending on the obtained results, the model can be extended to distributed nonlinearities.

The model will then be used for the identification of the solitons associated to the collective nonlinear dynamics of the considered periodic lattices. These solitons can canalize the energy injected into the system following a path defined by an intrinsic localized mode. Each mode determines the type of transduction and its location to convert this canalized vibration energy into electrical energy. Besides, the transduction can generate nonlinearities (electrostatic, magnetic…) that have a significant impact on the collective dynamics of the lattice and should therefore be taken into account in the complete multi-physics model.

- **Parametric analysis of soliton-based waveguides**

These investigations will lead to several design rules for the functionalization of localized and (or) distributed nonlinearities in order to optimize the waveguides as well as improve the performances of the harvester in terms of energetic efficiency and bandwidth.

- **Uncertainty propagation and robustness analysis**

Modeling random uncertainties in the periodic multi-physical systems must be taken into account to analyze the robustness of predictive models. We propose a parametric probabilistic approach for uncertainties in structural nonlinear dynamics which allows the candidate to model uncertainties in data (non-linearity, loading ...) as well as in periodicity defects. The method relies on the introduction of the theory of generalized polynomial chaos theory for the quantification of uncertainty in nonlinear periodic structures.

4. Positioning and integration within FEMTO-ST

The use of solitons exists in several researches in optics and acoustics. It is very innovative and upstream in mechanics for vibration energy harvesting (VEH) using the collective dynamics of nonlinear periodic lattices. The implementation is therefore very challenging as it involves several scientific issues and requires prior advanced modeling. Collaboration with other departments of Femto-ST is envisageable. At the national and international levels, solitons are used in physics and acoustic insulation but to our knowledge few or no research teams are using it for VEH.

Candidates profile

The candidates should have a master degree in applied mechanics, physics or applied mathematics. They have to prove their relevant knowledge in the following disciplines: vibrations, nonlinear dynamics and advanced numerical methods. The candidate must perform extensive computer simulations and data analysis. A disposition for numerical work and programming is required. Proficiency in English is important.

Application

The application consists of ONE pdf-file comprising:

- Curriculum Vitae with list of publications
- Short summary of the master's thesis
- Suggestion of two referees with contact details
- Provide detailed explanation justifying your choice for this PhD project

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