**Tentative title of the master thesis**

*Numerical optimization of non-linear piezoelectric shunts attached to non-linear host structures*

---

**Context of the master thesis**

Nonlinearity is a frequent occurrence in engineering structures. It can be generated by a variety of mechanisms (e.g., large displacement effects, friction and contact) and can give rise to irritating and potentially disastrous dynamical instabilities. Controlling nonlinear dynamical instabilities represents a great challenge, because nonlinear systems exhibit complex phenomena. Specifically, one key characteristic of nonlinear oscillations is that their frequency depends intrinsically on motion amplitude. Any anti-vibration device that ignores this nonlinear property, such as a linear tuned vibration absorber simply does not work. This is the reason for introducing non-linear tuned vibration absorbers (NLTVA) [1]. Such mechanical devices are however difficult to implement in practice, so that an alternative is the use of non-linear shunt circuits applied to piezoelectric transducers attached to the host structure [2,3]. The working principle is based on two keys factors: (i) efficient conversion of the mechanical energy to electrical energy thanks to the piezoelectric transducer, and (ii) efficient dissipation of this energy in the electrical network connected to the transducer. In order to be efficient, the parameters of the non-linear shunt circuit should be tuned to the nature of the non-linearity present in the host structure. A key question to address is how to find the optimum shunt circuit parameters based on the knowledge of the non-linearity present in the host structure.

**References**


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**Objectives of the master thesis**

The main objective of the master thesis is to develop a methodology to tune the parameters of the non-linear shunt circuit for a host structure with a given non-linearity. The strategy will consist in developing a numerical model of the non-linear piezoelectric shunt coupled to a non-linear structure in the Matlab/Simulink environment. Then, a numerical optimization scheme will be developed in order to find the best parameters of the shunt to mitigate the vibrations of the host structure.
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<th><strong>Supervisor</strong></th>
<th><strong>Co-Supervisor</strong></th>
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<td>Arnaud Deroemaeker (<a href="mailto:deraema@ulb.ac.be">deraema@ulb.ac.be</a>)</td>
<td>Christophe Collette (<a href="mailto:ccollett@ulb.ac.be">ccollett@ulb.ac.be</a>)</td>
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<td>The student must have an interest in Structural Dynamics, active/passive vibration damping strategies, and basic programming skills in Matlab/Simulink</td>
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Context of the master thesis
Tuned mass dampers (TMDs) are used in engineering structures to passively mitigate the vibrations around a specific resonance frequency. A simple and practical way to design such devices is to use analytical tuning rules and the assumption that the main structure can be reduced to a one degree of freedom system [1]. In practice however, the resonance frequency of the host structure can vary over time due to changing operational and/or environmental conditions, which can lead to a ‘detuning’ of the TMD. This calls for a more robust approach in which the variability of the host structure is taken into account to determine the optimal parameters of the TMD. Such a ‘robust’ approach will lead to a lower performance for the nominal host structure, but higher performance when the host structure varies. It is therefore a compromise between the performance and the robustness.

References

Objectives of the master thesis
The main objective of the master thesis is to develop a methodology to tune the parameters of the TMD taking into account a certain amount of variability in the host structure. The strategy will consist in developing a numerical model of the TMD attached to a variable host structure in Matlab. Then, a numerical optimization scheme will be developed in order to find the best parameters of the TMD to mitigate the vibrations of the variable host structure.
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<td>Arnaud Deraemaeker</td>
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Tentative title of the master thesis

Topology optimization for high performance vibration control

Context of the master thesis
Active isolators are of great interest when broadband vibration isolation is required. While passive isolators are capable of isolating vibrations in the mid-high frequency range, they introduce a magnification at low frequencies which can only be eliminated while retaining the mid-high frequency isolation performance by introducing an active element into the system [1]. Over the years many companies have invested time in developing active isolating devices. As a result, many kinds of isolators of different working principles, shapes and sizes have been created. The active components of the isolator need to be somehow connected to the object in need of isolation, however, there is no dedicated approach when it comes to designing the supporting structure of the isolator.

References

Objectives of the master thesis
The main objective of the master thesis is to develop an efficient structural support for an active isolation system composed of piezoelectric stacks. A baseline solution will be found, and from there, different optimization procedures will be carried out to obtain a refined structure onto which the active stacks will be mounted.

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Working language
English/French
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**Tentative title of the master thesis**
*Design of an active seismic isolation system*

**Context of the master thesis**
Precision engineering tasks require active isolation systems that are effective at low frequency. The development of isolation tables that can offer isolation below 1 Hz is particularly challenging because of three main limitations. Firstly, the resolution of commercial sensors is not sufficient. Secondly, if the table is not carefully designed, mechanical coupling between directions may limit the performance. Finally, the controller robustness needs to be carefully addressed in order to cope with plant uncertainties.

One main application that requires to develop new active isolation system is the gravitational waves detectors. The actual systems allow to detect events down to 1Hz but more events could be detected if the frequency range of detection is extended to the sub-Hz frequencies.

Examples of 6 dof isolation systems

**References**

*To understand how the 6 dof isolation system works at LIGO*


**Other examples of 6 dof active isolation systems**

https://164.15.83.101:5001/sharing/rvoRcWrlm

[4] R. van den Braber, Low frequency vibration isolation in six degrees of freedom, TNO  
https://164.15.83.101:5001/sharing/BSewTGHBW

**Objectives of the master thesis**

The student will principally work on one limitation of the active isolation systems at low frequency: mechanical coupling. The student will have to design a structure that will connect the voice coil actuators to the payload. The payload is an hexagonal table which will have to be supported by three legs and isolated thanks to six actuators: three vertical and three horizontal. This shape corresponds to the ones used in the LIGO devices.

In addition, the suspensions used to support the payload will be studied. Finally, the performance of the structure developed will be tested on a prototype with a robust controller.

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**Working language**

English/French

**Student profile**

Electromechanical Engineering

**Prerequisites/special skills (optional)**

The student must have an interest in Structural Dynamics, active/passive vibration damping strategies, and basic programming skills in Matlab
**Tentative title of the master thesis**

*Hybrid damping of non-linear aerospace structures*

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**Context of the master thesis**

Controlling Aerospace structures in order to reduce fuel consumption and potentially disastrous dynamical instabilities represents a great challenge, because nonlinearity is a frequent occurrence in these structures and these nonlinear systems exhibit complex phenomenon. Specifically, one key characteristic of nonlinear oscillations is that their frequency depends intrinsically on motion amplitude; and the other key factor is related to the limitations of purely active and purely passive methods. Any anti-vibration device that ignores these two factors, such as a linear tuned vibration absorber simply does not work. This is the reason for introducing nonlinear hybrid control. Hybrid control strategy combine both active and passive damping treatments in order to improve the performance, robustness as well as reliability of the system. Nonlinear Positive Position Feedback (PPF) and nonlinear Digital Shunt controllers are proposed for active and passive part respectively. PPF controller works as a second order filter in the system in order to damp the desired mode of vibration. Moreover, the working principle of shunted piezoelectric is based on two keys factors: (i) efficient conversion of the mechanical energy to electrical energy thanks to the piezoelectric transducer, and (ii) efficient dissipation of this energy in the electrical network connected to the transducer. In order to apply this controller, it is possible to model the inductor and resistor digitally inside the MicroLabBox like the first order filter instead of using passive electrical devices.

**References**


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**Objectives of the master thesis**

The objective of this project is to apply nonlinear hybrid control numerically based on the available powerful Structural Dynamics Toolbox (SDT) in MATLAB and implement it experimentally on the available academic setup in the Precision Mechantronics Laboratory (PML) at ULB.
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Tentative title of the master thesis
Development of a high resolution compact tiltmeter

![Figure 1. A tilted inertial sensor](image1.png)

![Figure 2. A commercial tiltmeter](image2.png)


Context of the master thesis

Inertial sensors are measuring either linear or angular motions. Good reviews about rotation sensors can be found in Lee et al. [1], about linear motion is discussed in Collette et al. [2]. Inertial sensors are widely used in many fields like seismology, structural engineering, and navigation. However, traditional inertial sensors cannot satisfy the advanced requirements of active vibration isolation. One of the reasons is the tilt-horizontal coupling problem [3, 4], which means a linear motion sensor senses rotation motion or in the opposite. To solve the problem, the project proposes to design a high resolution tiltmeter measuring the pure rotation. The tiltmeter can be used individually, Meanwhile, it can help to remove rotational signals from a linear motion sensor.

References


### Objectives of the master thesis

The objective of the master thesis is to develop a high resolution compact inertial sensor. The tasks include two main parts, one is related to the readout. The student should investigate and select the best sensing technology and modify it for the tiltmeter. The other one is related to the mechanical structure. The students should design a good structure which is insensitive to horizontal motion, also the structure should be insensitive to ambient noises (magnetic field, temperature variations, etc.) as well.

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### Working language
English

### Student profile
Electromechanical Engineering

### Prerequisites/special skills (optional)
*The student must have an interest in Structural Dynamics, Mechanical designing, and basic programming skills in Matlab/Simulink*
**Tentative title of the master thesis**

*Design and control of a nano-positioning system for tomography experiment*

**Context of the master thesis**

Stewart platforms consist of 6 prismatic actuators in parallel. It permits to position the top platform in all 6 degrees of freedom with respect to the bottom platform. The developed Stewart platform will be used to cancel the vibrations produced by a bigger positioning platform using active vibration control techniques. A good mechanical conception is essential in order to obtain wanted performance (reduction of vibrations up to few nanometers).

**References**


**Objectives of the master thesis**

- State of the art of nano-positioning Stewart platforms
- Translation of the global requirements (maximum size, stiffness, stroke, weight, ...) into requirements on the mechanical parts (actuators, joints, top and bottom platform)
- Selection of the appropriate architecture
- Selection/design of mechanical part
- Finite element simulations in order to validate mechanical properties (stiffness, resonance modes)
- Extraction of a state-space model using FEM software
- Importation of the model on Matlab/Simulink to use for the control part

**Supervisor**

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**Working language**

English/French

**Student profile**

Electromechanical Engineering

**Prerequisites/special skills (optional)**

The student must have an interest in Structural Dynamics, active/passive vibration damping strategies, and basic programming skills in Matlab
Tentative title of the master thesis

Violin resonance suppression in gravitational wave detectors

Context of the master thesis
Events of binary star systems, supernovae, etc generate detectable gravitational waves, which contain observational data for astrophysics study. To obtain the gravitational waves, large scale detectors are built/building over the world, and the Laser Interferometer Gravitational-Wave Observatory (LIGO) is one of this kind of detector. The figure above shows a simplified sketch of the LIGO structure. The fundamental working principle is Michelson interferometer. In order to be isolated from ground vibration, the mirrors of this Michelson interferometer are suspended by compliant structures. However, the resonances of these structures are responsible for sharp peaks, which are reducing the quality of the measurement.

References

Objectives of the master thesis
The objective of this project is to develop a simplified model of the structure supporting the mirrors, and develop a control strategy for damping actively the resonances. This strategy will be further validated experimentally on a scaled prototype.

Supervisor
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