PhD course of National Interest in Technologies for Fundamental Research in Physics and Astrophysics

Annual report

Name and surname: Lorenzo Sclafani
Cycle and a.a.: 39° cycle, a.a. 2023/24
Supervisor: Prof. Antonio Carcaterra

- **Research activity carried out during the year**

The research focuses on the application of mechatronic technologies to support experimental systems in fundamental physics. Specifically, it involves the analysis of advanced sensors, actuators, and control systems for monitoring and controlling complex mechanical systems. The primary objective of the thesis is to study the relationship between fluctuations in dynamic variables and structural damping in cryogenic conditions. The study of this problem aims to conduct measurements in particularly challenging conditions, such as cryogenic environments, ensuring sensitivity levels sufficient to detect disturbances even at very low power levels.
During the first year of the Ph.D. program, one of the main activities has been conducting a literature review. As a start, key physics experiments currently carried out by INFN that could represent practical applications of the project have been identified to define the working conditions, objectives, and requirements for designing a data acquisition system. In particular, the non-intrusiveness of the sensor is crucial to avoid affecting the experiment's measurements, which imposes constraints on the materials used, such as the requirement for radiopurity, and on the acquisition techniques, since strong or variable magnetic fields could influence the superconductors used in the experiments. Additionally, the extreme temperatures reached (10 mK) pose a significant challenge for material selection, as their mechanical properties are often unknown at such low temperatures, and their behavior might no longer be explained by classical physics, requiring quantum explanations (e.g., superfluidity, superconductivity, or Bose-Einstein condensate formation). Therefore, the literature on thermal and mechanical effects at low temperatures on materials of interest, such as noble metals, has been reviewed to account for contractions and associated thermal stress in the design process.
The main difficulty has been selecting a vibration measurement methodology that meets these requirements. A literature review was conducted on available data acquisition systems based on operating principles such as oscillating systems composed of rigid and deformable bodies interacting with electrodynamic systems and acoustic and/or optical beams, functioning both at room temperature and under cryogenic conditions. The non-intrusiveness and excellent performance at extreme cryogenic temperatures led to the identification of fiber optics and FBG sensors, for measuring strain, hence vibrations.
Additionally, a first approach to statistical mechanics has been done investigating the Fluctuation-Dissipation Theorem, which links fluctuations of individual system's variables around equilibrium with the system's dissipation. This topic is currently being further explored and applied to simple mechanical systems, such as millimeter-scale cantilevers.
Another challenge was the need for a cryostat to begin the experimental phase, given the significant limitations in freedom and availability associated with using an external cryostat. This issue has been resolved by locating and refurbishing a small one-stage pulse-tube cryostat in the department, which, reaching minimum temperatures of 70 K, is perfect for an initial small-scale experimental phase. The design of this first experimental phase is nearing completion and aims to characterize the damping of a cm-scale cantilever and explore the relationship between dissipation and fluctuations, over a wide range of temperatures. The necessary components, including fiber-optic sensors and replacement parts for the cryostat, have been purchased, and the setup is expected to be completed within the next month, allowing the data acquisition phase to begin.

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- **List of attended courses and passed exams**
  - Coupled,electrical-thermal-structural Finite Element Analysis (waiting for exam evaluation)
  - Advanced electronic sensing devices (passed)
  - Deep Networks & Structured Learning (passed)
  - Fundamentals of system engineering and project management for large scientific projects (passed)
  - Machine learning and numerical techniques for inverse problems and design of electrical and electronic systems (currently following)
- **List of attended conferences, workshops and schools, with mention of the presented talks**
  - Kick-off event of the TFPA PhD course
- **List of published papers/proceedings**
  - Stagi, L., Sclafani, L., Tronci, E. M., Betti, R., Milana, S., Culla, A., ... & Carcaterra, A. (2024). Enhancing the Damage Detection and Classification of Unknown Classes with a Hybrid Supervised–Unsupervised Approach. *Infrastructures*, *9*(3), 40.
  - Stagi, L., Sclafani, L., Tronci, E. M., Betti, R., Milana, S., Culla, A., ... & Carcaterra, A. (2024, May). An Unsupervised Damage Detection Strategy for Recognizing Unseen Health Conditions in Monitoring Bridges. In *International Operational Modal Analysis Conference* (pp. 196-207). Cham: Springer Nature Switzerland.
- **Thesis title (even temporary)**

Measurements of vibrations in cryogenic conditions

Date, 05/09/2024 **Signature** Lorenzo Sclafani

Seen, the supervisor