**Titre de la thèse/Thesis title :** Uncertainty evaluation associated to small forces generation between 100 nN and 100 µN with magnetic springs – Application to the calibration of a platform dedicated to the mechanical characterization of human oocytes for in vitro fertilization

**Laboratoire d'accueil / Host Laboratory :** FEMTO-ST Institute in Besançon, France.

**Spécialité du doctorat préparé/Speciality :** Sciences pour l'ingénieur / Engineering sciences.

**Mots-clefs / Keywords :** small forces generation, microforce metrology, uncertainty estimation, magnetic springs, mechatronics, instrumentation, observation and control theory, human oocyte characterization

**Descriptif détaillé de la thèse / Job description**

The PhD thesis is proposed within the framework of the ANR TRAFALDA project, which started on February 29, 2024. This project is carried out in collaboration with the French metrology. The FEMTO-ST Institute is the project leader.

France has currently an important research deficiency in the field of small force metrology. This situation is problematic since the generation and the measurement of small forces (below 100 µN) are required in a large variety of applications such as Atomic Force Microscopy (AFM), assessment of the mechanical properties of micro- and nano-structures and surfaces, mechanical characterization of bio-components at micro- or nano-scales, etc. The ambition of the TRAFALDA project is to demonstrate that the French metrology is capable to deal with a new range of forces below 100 µN in a way that is traceable to the SI, and that it can implement a metrological calibration approach for small force measurements in a specific case of biomechanical characterization.

This ambition is declined into three objectives in the proposed PhD. The first one is focused on the development of a small force reference in vacuum over an extended range from 100 nN to 100 µN. A first version of a small force generator located in a vacuum chamber has been developed for forces superior to 10 µN. It has to be upgraded in order to generate small forces between 100 nN and 10 µN with a low uncertainty. The second objective consists in developing a transfer standard and qualifying it metrologically using the previous device. The third one will use this transfer standard to qualify metrologically an experimental platform of mechanical characterization of human oocytes. This patented platform developed by FEMTO-ST, named EGG, is located in a sterile clean room of the ART department of the Besançon University Hospital. It can measure forces up to 5 µN. The forces measured during a mechanical test are typically in the range of 1 nN to 300 nN. As for all existing nanoforces sensors, these measurements are not traceable to the International System of Units and therefore their uncertainty has to be evaluated to qualify the EGG platform.

The FEMTO-ST institute, via its Automatic and Micro-Mechatronic Systems department, will use its 20 years' experience in the field of self-stabilized magnetic springs and small force measurement/generation to carry out the first objective. The small force generator will be an upgrade of an existing nanoforce balance derived from a deadweight machine using an electromagnetic principle. This device needs to be improved in order to generate forces below 10 µN in vacuum. A methodological contribution is also necessary to improve the uncertainty associated to the forces generated in closed loop. This uncertainty is evaluated using a new approach developed in a PhD thesis that will be defended in 2024. It is based on Automatic Control theory applied to nonlinear dynamical systems in order to observe unknown input signals and on interval analysis in order to calculate and spread uncertainties.

The transfer standard associated to the second objective will be an elastic microstructure made of glass in order to be compatible with the EGG platform. Its microfabrication will be carried out in the MIMENTO technology center at the FEMTO-ST institute using 3D subtractive microfabrication. This standard will be metrologically characterized in vacuum using the low force generator in order to determine its stiffness matrix and its associated uncertainty. It will then be substituted to an oocyte to qualify and quantify the measurement performances of the EGG platform. This qualification will be performed during a mechanical loading of the microstructure by comparing the force calculated by the platform to the one deduced from the stiffness and the deformation of the microstructure.

**Références bibliographiques / Bibliography**

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[2] Jon R Pratt, John A Kramar, David B Newell and Douglas T Smith, Review of SI traceable force metrology for instrumented indentation and atomic force microscopy, Measurement Science and Technology, Volume 16, Number 11, 2005, DOI: 10.1088/0957-0233/16/11/002

[3] Richard K Leach, Simon Oldfield, Shakil A Awan, John Blackburn, Jonathan M Williams, Design of a bi-directional electrostatic actuator for realising nanonewton to micronewton forces, NPL Technical report DEPC-EM 001, 2004

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[6] S Eichstädt, K Ruhm and A Shestakov, Dynamic measurement and its relation to metrology, mathematical theory and signal processing: a review, Journal of Physics: Conference Series, Volume 1065, Issue 21, 2018, DOI:10.1088/1742-6596/1065/21/212018

**Profil demandé / Applicant profile**

Candidates with well-founded knowledge in mechanics, mechatronics, instrumentation and control theory with a high interest in experimentation are encouraged to apply. A strong interest in information processing and notably uncertainty representation is mandatory. Knowledge related to the micro- and nano-world would be great but is totally optional. The proposed Ph.D. is for motivated, curious, inventive, dynamic candidates having a strong scientific background in physics and engineering sciences and a sense of communication in a collaborative and multidisciplinary environment.

Preferred selection criteria:
- interest in mechatronics and mechanics devices development.
- Knowledge in automation and control theory.

Personal characteristics:
- Curious and inventive.
- Personal interest focused on both scientific theory AND experimentation.

**Financement : ANR - Projet TRAFALDA.**

Dossier à envoyer pour le 2024/05/31.
Début du contrat : 1er Octobre 2024
Salaire mensuel brut : 2100€

**Direction de la thèse**:/ **Thesis Supervisor**
**PIAT Emmanuel / emmanuel.piat@ens2m.fr**

**Encadrement de la thèse** : **co-directeur(s) et co-encadrant(s)**
**Abadie Joël (Ingénieur de recherche CNRS) – co-directeur / jabadie@femto-st.fr**

Applicants are invited to submit their application to the PhD supervisors.
Application must contain the following documents:

- CV
- Cover letter
- At least 1 reference letter