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

Keywords: small forces generation, force metrology, uncertainty estimation, magnetic springs, mechatronics, instrumentation, observation and control theory, human oocyte characterization
Laboratory: FEMTO-ST Institute[1]
Location: Besançon, France
Supervision: Emmanuel Piat (associate professor) and Joël Abadie (CNRS engineer)
Duration: 3 years starting between June and October 2024
Global Founding for salary: 120 k€ / 36 months
To apply: send your CV, your master's degree, your academic transcript, a cover letter and reference letters to Emmanuel Piat (emmanuel.piat@ens2m.fr) and Joël Abadie (joel.abadie@femto-st.fr) **before 2024/04/30.**

General context

France has currently an important research deficiency in the field of small force metrology. This situation is a paradox 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. There is therefore a need for research and development so that the French metrology can establish calibration and measurement capabilities (CMCs) below the value of 1 newton that is the French low limit mentioned in the international KCDB database. Addressing this issue is currently done in the TRAFALDA project whose leader is the FEMTO-ST institute. The other partner of this ANR project is the CNAM, via its joint French metrology laboratory LNE-CNAM.

PhD context and addressed problems

This PhD ambition is declined in three objectives. 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. The associated device is a small force generator located in a vacuum chamber that must be upgraded in order to generate accurate small forces 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, developed by the FEMTO-ST institute. This patented platform, named EGG, is located in a sterile clean room of the ART[2]

1 http://www.femto-st.fr/en/
2 Assisted Reproductive Technology (ART)

department of the Besançon University Hospital (see Figure 1). 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, currently difficult to compute, has to be estimated.

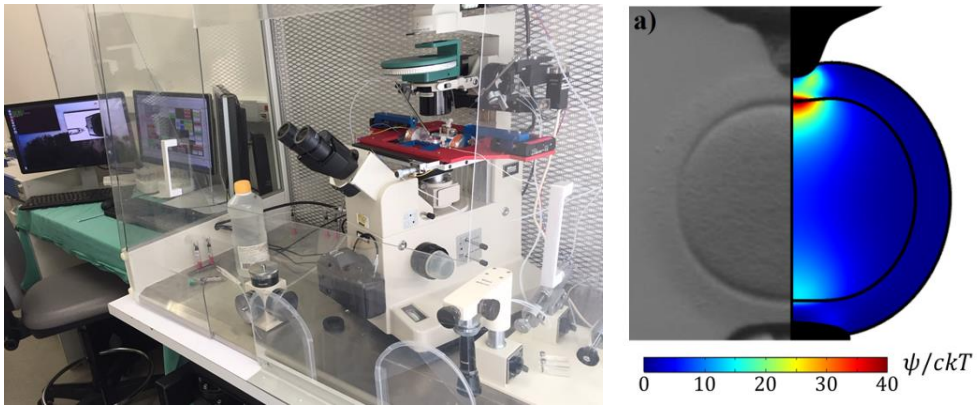

Fig. 1 – EGG Platform at the ART department of the Besançon University Hospital.

Objectives

The FEMTO-ST institute, via its Automatic and Micro-Mechatronic Systems department, will use its expertise in the field of self-stabilized magnetic springs and small force measurement/generation to carry out the first objective. The starting point will be an existing platform that combines two devices in a vacuum chamber (see Figure 2). The first device is an experimental high precision 3-axis accelerometer whose goal is to evaluate the inertial force induced by the low frequency and low amplitudes vibrations that disturb the force generator. The second one is a one-axis force generator that is derived from a deadweight machine based on an electromagnetic principle. This force generator needs to be improved in order to generate forces below 1 µN in vacuum. A methodological contribution is also needed to improve the uncertainty associated to the forces generated in closed loop. This uncertainty is evaluated with 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 glass microstructure in order to be compatible with the EGG platform. Its microfabrication will be carried out in the MIMENTO technology center of 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.

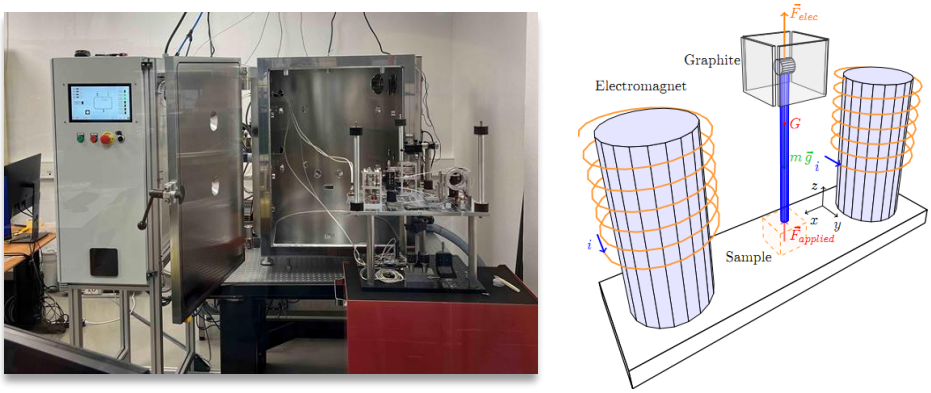

Fig. 2 – Current force generator (schematic principle on the right) associated to its 3-axis accelerometer in a vacuum chamber (left).

Requested skills

Candidates with well-founded knowledge in mechatronics, instrumentation and control theory with a high interest in experimentation are encouraged to apply. A strong interest in information processing and 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 and a sense of communication in a collaborative and multidisciplinary environment.

The Ph.D. position is part of the TRAFALDA research project supported by the French National Agency Research (contract ANR-23-CE42-0022-01). It is a full time research contract of 3 years with a possibility to have complementary part time teaching appointments.

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