Exploring the nonlinear dynamics of friction oscillators using experimental (control-based) continuation

Location : Laboratoire d'Acoustique de l'Université du Mans (LAUM), Le Mans, France

Duration : 24 months

Starting date : between 1st of may 2023 and 1st of December 2023

Key words : Friction induced vibrations, nonlinear dynamics, experimental (control-based) continuation, bifurcations, self-sustained oscillations, piecewise smooth dynamical systems.

Context

Friction-induced vibrations are observed in a wide diversity of physical and biological systems, from insects such as locus and crickets to vehicles (with braking noise) and musical instruments such as violins [1]. These autonomous (self-oscillating) nonlinear dynamical systems can produce a wealth of sound and/or vibration regimes (periodic, quasiperiodic or chaotic). The existence, stability and acoustical properties (amplitude, frequency, spectral content) of these regimes depend - often in a sensitive manner - on design and control parameters of the considered system. This diversity of dynamical regimes originates in complex nonlinear mechanisms, whose subtle and important details remain not fully understood nor modeled. As a consequence, predicting and controlling the nonlinear dynamics of friction oscillators remain a major challenge [2].

The project FRICTIONAL, funded by the French National Research Agency (ANR), aims to investigate, analyse and predict the complex dynamics of piecewise-smooth dynamical systems, with a focus on friction oscillators producing sound and vibration regimes. This relies on a dynamical system approach, and more particularly on the the development of advanced numerical and experimental methods dedicated to piecewise-smooth dynamical systems.

Characterising a self-oscillating nonlinear dynamical system typically requires the systematic investigation of its stable and unstable equilibria and periodic regimes, as well as their bifurcations. In physical models, numerical continuation methods allow to follow (*continue*) branches of equilibrium (*i.e.* non-oscillating) and periodic solutions with respect to a parameter of interest, and to identify their bifurcations [3]. This gives access to bifurcation diagrams, representing ideally all the stable and unstable solutions of the system in a parameter of interest (for example, the bow speed in the case of a violin) [2].

In an actual experiment, accessing a global knowledge of the dynamics is much more challenging. Controlled test benches (« bowing machines ») allow to explore the sound/vibration regimes while a parameter of interest is varied in a controlled manner. Such a robotised test bench has been developed recently at LAUM to investigate the experimental dynamics of a bowed string while controlling the bow speed and the normal contact force between the bow and the string. However, only stable regimes are observed, and only one of them in case of multistability, that is to say when several stable regimes coexist for a given parameter set. In such a case, which regime is observed in practice depends on the initial conditions. As a consequence, only a partial knowledge of the dynamics is accessible.
Experimental continuation methods have been proposed by different research groups to overcome these limitations. These methods give access to both stable and unstable solutions and can provide information on the existence of multistability [4,5]. As such, they provide a more in-depth knowledge on the dynamics. However, experimental continuation has been developed for forced (non-autonomous) dynamical systems, but never for self-oscillating systems.

Work program :

This post-doctoral project aims at developing experimental continuation for autonomous (self-oscillating) systems in general, with a focus on the characterisation of dry friction oscillators [6]. As a first step, an academic dry-friction oscillator will be considered. Depending on the first results, more complex systems will be considered, to go towards a bowed string system.

The main objective is to access experimental bifurcation diagrams, representing ideally all the coexisting equilibrium and periodic regimes regardless of their stability. This will provide *cartographies* of the oscillation regimes in the space of parameters of interest, to be compared with the bifurcation diagrams of physical models of the considered oscillators that will be computed by other members of the ANR project. Overall, this aims at accessing a better understanding and improved modeling of the physical phenomena responsible for the production of sound and vibrations.

The work program is organised as follows:

- « Experiment simulation » : using a physical model of dry friction oscillator, the first step aims at developing a non-invasive feedback controller that can stabilise the unstable oscillation regimes of the system in practice [4,5,6].
- Experimental implementation of the stabilising feedback controller using a DSP system. The objective is to observe the originally unstable oscillation regimes of the experimental oscillator. These are not observable otherwise but nevertheless play an important role in the system dynamics.
- Coupling the stabilising control algorithm to a continuation method, to measure experimental bifurcation diagrams. These diagrams will allow to perform a global, in-depth comparison between the experimental dynamics and the dynamics of the models. This will open the way to the identification of laws and parameters which can not be measured in a direct way, including friction laws and coefficients.

Necessary skills:

- PhD in acoustics, mechanics or applied mathematics
- Skills on nonlinear dynamics, control, experimental mechanics or acoustics

Experience or skills in numerical continuation methods, delay systems, friction induced vibrations, physical modelling in acoustics or mechanics are not necessary but will be considered positively.

Environment:

The postdoctoral researcher will be part of both research groups on *Physics of musical instruments* and *Nonlinear dynamics and waves* of the Laboratory of Acoustics of Le Mans Université (LAUM). He/She will interact with the members of the project FRICTIONAL, in particular:

- Soizic Terrien, research scientist, CNRS
- Frédéric Ablitzer, lecturer, LAUM, Le Mans Université
- Emmanuel Brasseur, Engineer in experimental techniques, CNRS
- Sylvain Maugeais, Lecturer, Laboratory of Mathematics of Le Mans, Le Mans Université
- Philippe Béquin, Lecturer, LAUM, Le Mans Université

Salary according to experience, following the CNRS salary scales.

Contact:

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Application through the CNRS employment website.

Références :

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