PhD thesis

on

Real time data driven model learning of complex dynamical systems
Application to high-speed rotating machines operated with active magnetic bearings

We have a vacancy for a PhD student (3 years) in a joint research project between SKF Magnetic Mechatronics "S2M" (Saint-Marcel), the LIAS laboratory (Université de Poitiers) and the Ampère laboratory UMR CNRS 5005 (Ecole Centrale de Lyon).

Keywords: dynamical model learning, mechatronics, optimal data design, magnetic bearings, rotor dynamics

Context and Project Description

In recent years, high-speed rotating machines using active magnetic bearings technology have seen considerable growth (both in terms of diversity and number of applications). These machines largely address the two major challenges of the 21st century: the energy and environmental crisis.
The high rotation speed (> 20'000 rpm) combined with the principle of magnetic levitation give these systems significant advantages, such as:
• Very compact with a useful volume two to three times smaller than a conventional (low speed) machine,
• Very economical in noble materials (copper, steel, etc.),
• Very high energy efficiency,
• Very high reliability and useful life (magnetic levitation eliminates all friction, therefore wear).

All these elements give these machines very important energy and dynamic performances as well as a very low environmental footprint (throughout their entire life cycle). For all these reasons, these machines are used in many critical applications and processes: hydrogen liquefaction, semiconductor production, high-efficiency heat pumps, natural gas transport and storage using the "Zero Leak" principle, energy recovery (cogeneration) using the organic Rankine cycle, etc."

Until now, the models of the system dynamics (rotating machine + magnetic bearings + process) are mainly determined from data collected offline and in a definitive way during commissioning because such a system is by construction unstable and strongly resonant, thus requires an active control to work effectively.

Online learning from data, through its ability to follow the evolution of the system dynamics, opens the possibility of optimizing operating conditions and adapting control laws in real time. In addition, this identification would also make it possible to predict with a high reliability future failure (for predictive maintenance for instance).

The analysis of a many field data sets has allowed us to identify multiple physical phenomena leading to a structural evolution of the equipment and parts constituting the machine, but also very significant variations in the operating conditions (fluid/structure interactions related to aerodynamic processes for instance). These structural evolutions as well as these variations of the operating conditions, which have a very negative effect on the performance of the system as well as on the lifespan of the machine, fully justify the use of real-time learning techniques discussed above.

This online learning requires exciting the system permanently. In the context of this project (unlike a rotating machine using ball bearings or conventional oil bearings where only the signals from the vibration sensors are accessible), it can be advantageous to use of the active control of the magnetic bearings in order to generate radial/axial disturbances exciting the dynamics of the system persistently.

Note that the system excitation should not in any case significantly degrade the performance of the closed-loop system. Generating this type of excitation under performance constraint is one of the main scientific challenges of this doctoral thesis.

Project Goals

As indicated previously, the main objective of this thesis consists in developing new model learning tools (also called "system identification") of the dynamics of rotating machines with magnetic bearings which guarantee both precise monitoring of the dynamics of the system and maintaining the performance of the closed loop system (robustness in performance and stability).

Note that such an objective is part of a very popular research theme for many fields of engineering. This project is, moreover, particularly ambitious due to the nature and complexity of the system considered herein.

The most significant system complexity indicators are indeed the following:

- multiphysical and nonlinear system with a very high number of inputs, outputs and state variables,
- unstable open loop system (inherent to the principle of active magnetic levitation),
- weakly damped system which leads to many structural instabilities (resonance phenomenon).

Finally, as the learning procedure must be carried out online (in operation), many "real time" constraints will have to be taken into account when implementing the algorithms.

The thesis program will be structured in three main phases:

1- Bibliographic research and state of the art

- Learning and testing (in simulation) of the main and standard solutions of online identification/learning and optimal synthesis of excitation signals currently available in the scientific literature.
- Definition of the advantages and disadvantages of each method (in particular regarding the deployment of algorithms in an embedded and real-time system).

2- New developments and validation with simulated data

- Development of new online identification tools with a particular attention to closed loop performance indicators.
- Appropriation of the multiphysics model currently available (provided by SKF),
- Implementation and test of these new methods in simulation on this multiphysics model.

3- Implementation and validation on test bench

- Implementation of algorithms and identification procedures on a rapid prototyping test bench (hardware used: OpalRT).
- Setting up and conducting various tests and measurements (to be done in SKF R&I Laboratory in Vernon).
- Comparison of theoretical and practical results and search for causes explaining possible discrepancies.
- Determination of the most appropriate method for our class of system (compromise between performance and complexity of implementation).

Supervision team

This PhD project will be supervised both by academic and industrial partners.

The control team at SKF (led by A. Farhat) will supervise the project from the industrial point-of-view.

From the academic one, the project will be supervised by G. Mercère (Associate Professor at the University of Poitiers) and X. Bombois (CNRS Research Director at Ampère Laboratory). Their expertise covers the different control engineering aspects present in this research project (data-based modeling and its interplay with robust control, optimal experiment design, black box and gray box model learning, LTV, LPV model and LFR data-based modeling, statistical analysis). The PhD student will be registered at the Graduate School of Poitiers University.

Appointment

This challenging job is based on a fixed-term appointment for a period of three years during which the PhD candidate will be able to gain both academic and industrial experience.

Candidate requirements

Applicants should have a MSc degree in engineering from a good-quality engineering school. They should possess a strong background and interest in mathematics and, ideally, in system identification and advanced control. They should have excellent analytical and problem-solving skills and, preferably, well-developed programming skills. Applicants should have a good knowledge of Matlab. The candidate should have excellent oral and written communication skills in English.

Application procedure

If you are interested by this challenging project, please contact X. Bombois (xavier.bombois@ec-lyon.fr) and G. Mercère (guillaume.mercere@univ-poitiers.fr) by email with subject "Real time data driven model learning of complex dynamical systems", attaching an academic CV, a cover letter, a pdf of your diplomas and transcript of course work and grades, a recommendation letter from your MSc thesis' supervisor, a certificate of proficiency in English, as well as any other document which can enrich the application.