A machine learning perspective on frictional contacts and self-excited vibrations.

Maël Thévenot*[1], Merten Stender[2], Jean-François Brunel[1], Charlotte Geier[2], Philippe Dufrénoy[1] and Norbert Hoffmann [2,3]

[1]*Univ. Lille, CNRS, Centrale Lille, UMR 9013 - LaMcube - Laboratoire de Mécanique Multiphysique Multiéchelle, F-59000, Lille, France*

[2]*Hamburg University of Technology, Dynamics Group, Hamburg, Germany*

[3]*Imperial College London, Department of Mechanical Engineering, London, United Kingdom*

Summary. Braking systems of modern cars require a high speed contact between a rotating and a stationary part, with material flows taking place in between for optimal functioning. During those situations, self-excited vibrations can lead to squeals phenomena which can be of high intensity. A high speed contact test rig was developed to recreate various contact conditions occurring in a road profile. Thermal and mechanical instrumentation were used in each test, coupled with surface observations and numerical modeling. Establishing an understanding of thermo-mechanical phenomena and tribological behavior of the contact to guide machine learning models allows to develop a more accurate, physics-based estimation of the squeal occurrence in a frictional contact.

Pin-on-disk interaction

The self-excitation of friction-induced vibrations has a long history in tribology and vibrations research, and still today lacks a full-explanatory framework of mechanisms, driving factors and instability conditions [1, 2]. Most uncertainty stems from the frictional interface, which is notoriously difficult to access, measure and characterise in practice [3]. However, data retrieved from the interface carry information representative of the whole system (state of materials, vibrations from all scales...). In this work an experimental study of frictional contact between a pin and a rotating disk is conducted (Fig. 1), with self-excited vibrations and squeal sound emissions. The set-up is heavily-instrumented at the system and contact scales. Particularly, along thermomechanical characterization from sensors on the pin and disk, surface observations such as profilometry are realised on both parts between solicitations to track the interface evolution. Cross-checking those pieces of information allows for the deduction of which phenomena will be in play during the contact and to establish a better understanding of their influence on vibrations and squeal. Tests are realised with various contact parameters (in term of normal load, rotating speed of the disc, contact duration and duration between each contact) to represent different road profiles.

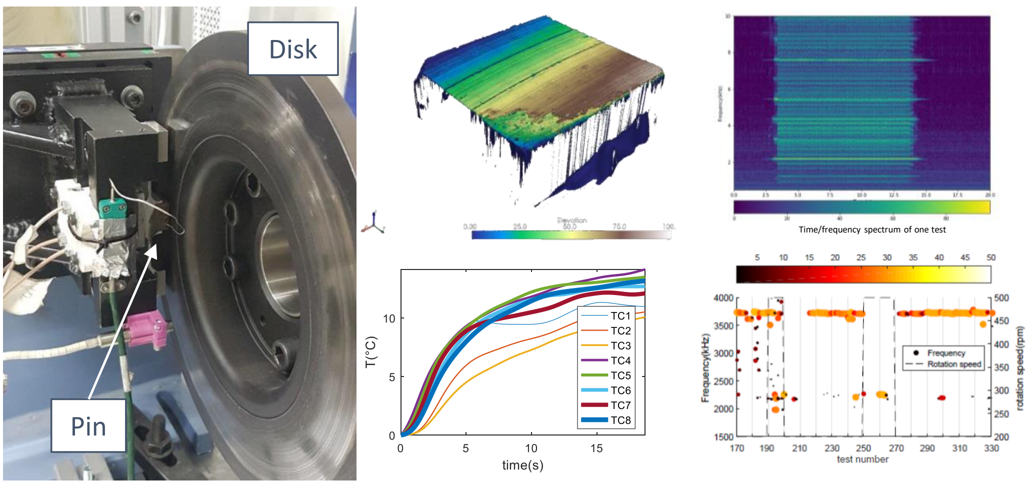

Figure 1: Pin and disk assembled on the test bench - sample recordings of temperatures, frequencies and surface observation.

Data analysis

The aim of this work is to establish the relation between phenomena involved at the interface and the propensity of high-amplitude self-excited vibrations for the system at hand. In order to further reveal the relation of effect and cause, a data analytics perspective is taken. Machine learning models are set up to replicate the dynamical system in the sense of a digital twin model, and recognize patterns in the high-dimensional space of loading conditions acting in the interface and the structural response [4]. Based on the extensive experimental measurements and with the help of appropriate processing algorithms the study of correlations between physics expected to be responsible of self-excited vibrations and squeal occurrence is investigated [5]. Deep learning methods, namely recurrent and convolutional neural architectures, are employed to approximate the functional relationship of external loads (frictional contact loads), internal states (interface temperatures and friction), and the vibrational response of the structure at hand. A multivariate sequence classification task is set up to predict a binary target indicating linear instability and the resulting nonlinear high-amplitude vibrations. Neural architecture search is performed upfront for selecting proper model hyperparameters and results are reported in terms of binary classification metrics with an intentional correction of imbalanced data sets. Correlations are identified, for example, between heating and squealing events, which are signs of variations in load-bearing area [6] and in the contact interface morphology.

Conclusion

Post-mortem observations of the surfaces (profilometry, camera) allows the identification of various material flows through the contact, which are used to establish a phenomenological model of the third body at the interface. Thermo-mechanical characterisation realised during tests allows to better understand the mechanisms underlying those material flows and to locate them in time and place. The influence of contact parameters is investigated to guide machine learning models, which highlight the relationships between the identified phenomena and the occurence of self-excited vibrations. The treatments also show the importance of considering the history effects corresponding to the evolution of the tribological situation. This study shows the contribution of machine learning models in the prediction of non-linear vibrations from frictional contact.

References

[1] Singla N. (2020) Experiment to Investigate the Relationship Between the Third-Body Layer and the Occurrence of Squeals in Dry Sliding Contact. *Tribology Letters* (volume 68)

[2] Duboc M. (2020) Experimental set-up and the associated model for squeal analysis. *Mechanics and Industry* (volume 21)

[3] Lai V.-V. (2022) Squeal occurrence related to the tracking of the bearing surfaces on a pin-on-disc system. *Mechanical Systems and Signal Processing* (volume 165)

[4] Stender M. (2021) Deep learning for brake squeal: Brake noise detection, characterization and prediction. *Mechanical Systems and Signal Processing* (volume 149)

[5] Stender M. (2019) Determining growth rates of instabilities from time-series vibration data: Methods and applications for brake squeal. *Mechanical Systems and Signal Processing* (volume 129)

[6] Lai V.-V. (2020) Multi-scale contact localization and dynamic instability related to brake squeal. *Lubricants* (volume 8)