WYDZIAŁ MECHANICZNY
POLITECHNIKA LUBELSKA
ul. Nadbystrzycka 36, PL-20-618 LUBLIN
Tel. (0 81) 538 4573,fax. (0 81) 538 4205, e-mail: g.litak@pollub.pl

Prof. dr hab. Grzegorz Litak, Lublin, 10 lipca 2016

Reviewer report of PhD dissertation submitted by Mr Krzysztof Jankowski, entitled „Modelling friction for the analysis of different dynamical systems" prepared under main supervision of prof. Andrzej Stefanski and subsidiary supervisor dr Asesh Saha, Łódź 2016.

Friction is an important phenomenon which appears in the technical systems. It is associated with mechanical energy dissipation. It provides nonlinear damping to the dynamical system which could be required or unwanted, depending on aim of the structure design. The friction process shows the multiscale properties or multiple relaxation rates and therefore it was modeled by many approaches with more or less detailed descriptions. Most common is a quasi-statistic approach which successfully reflect the average response of the system. However in the limit of small interval and small acting surface it cannot be applied. The author of thesis is aware of this peculiar properties of friction and his objective is to elaborate a model which could reproduce this phenomenon in wide ranges.

The structure of the thesis, the individual chapters and their discussion:

The dissertation consists of about 100 pages with a list of symbols, summary and references. The main part consists of 7 chapters: 1. Introduction 2. Friction phenomenon and its characteristic features, 3. Contact mechanics, 4. Friction models, 5. Dynamical systems, 6. Results and discussion, and 7. Conclusions. The bibliography consists of 95 scientific papers.

The first chapter is dedicated to the introduction to a friction phenomenon. The author discuss the main features, their role and importance to modern industry, applications, and also historical views including the origin of the word "friction" . In the subsection 1.1 the author provided the objective of the thesis which is a detailed study devoted to the analysis of friction assorted phenomena and interactions present on the contacting surfaces, which consequently lead to the description and derivation of selected dynamical friction models. A special emphasis was given to the friction hysteresis including nonlocal memory effect, as mechanism governing its formulation are to be explained in details. In the subsection 1.2 the Thesis organization is provided.
In the second chapter the author provided a formal discussion on existing models of friction and referred to existing bibliography. Subsections 2.1 and 2.2 refer to differences in static and dynamic friction. Subsections 2.3, 2.4, 2.5 introduces drift phenomenon, stick-slip motion, and hysteretic effect, respectively. The last part in extended to include various aspects of hysteretic friction.
The chapter 3 is an introduction to the contact mechanics. He briefly discussed aspects of several contact theories, which are: Hertz theory , Johnson, Kendall, Roberts theory , Derjaguin, Müller, Toporov theory, Greenwood, Williamson theory, Björklund theory. The author claimed that among them, the most interesting approach one was Björklund, as an extension of Greenwood-Williamson theory, which is further elaborated to include the direct summation technique.
The chapter 4 is focused on friction models. The author discussed various models friction them into few groups dividing into Static models, dynamical models, physics-based approaches and Maxwell slip

models, and hybrid models. At the end of this chapter the author introduces his new proposal called Pol-Ind model.

In the chapter 5 the author describes the dynamical systems with friction, including simple friction oscillator, friction induced, and also stick-slip system.

In the chapter 6, the author provides the results and comparative discussions for the selected models including the proposed Pol-Ind model.

Chapter 7 is a final section. The author claimed that by introducing stochastic elements in the number and height of asperities, are granting unique derivation of normal force, which depended upon properties of each individual asperity. Distinct formulation of rate of change of asperity deflection and application of the exponential function nested in threshold value of asperity deflection, allowed to reproduce the drop of friction force force at low velocity regime. The new model was capable to capture range of friction phenomena, with hysteretic effects of friction captured in both, the presliding and pure sliding regimes. Due to composite degree-of-freedom structure based on asperity hights, it allowed to observe non-local memory effect in presliding regime, and also in pure sliding regime, standing the advantage over other models. .

Critical remarks and questions to the doctoral student:

- Thesis aims are very broad and thesis questions to be proven not clear. However the main content of the thesis is to perform modeling of the dynamical system with friction including hysteresis.
- It is a pity that the author has not performed experiments. In this way he could verify the discussed models and the results obtained from them. But this could be a continuation of the above thesis.
- A hysteretic system is characterized by multiple relaxation rates. Has the author studied the corresponding damping rates (for instance in results from Fig. 6.23) ?

Further questions:

- The author could make some links to the friction phenomenon to the technological systems, for example cutting [1] or milling [2] processes.
  [1] J Warminski, G Litak, MP Cartmell, R Khanin, M Wiercigroch, Approximate analytical solutions for primary chatter in the non-linear metal cutting model, Journal of Sound and Vibration 259 (2003) 917-933.
  [2] T. Insperger, B.P. Mann G. Stepan, P.V. Bayly
  Stability of up-milling and down-milling, part 1: alternative analytical methods
  International Journal of Machine Tools & Manufacture 43 (2003) 25–34
- The author has not mentioned Preisach model which could be used for friction modelling [3]
  [3] JJ Choi, JS Kim, SI Han, Presliding friction control using the sliding mode controller with hysteresis friction compensator, KSME International Journal 18 (2004) 1755–1762.
- There is also a concept based on hysteretic friction based on a fractional derivative which can be responsible for multiple relaxation rates [4]. Can the candidate comment this approach?

WYDZIAŁ MECHANICZNY
POLITECHNIKA LUBELSKA
ul. Nadbystrzycka 36, PL-20-618 LUBLIN
Tel. (0 81) 538 4573,fax. (0 81) 538 4205, e-mail: g.litak@pollub.pl

[4] D Guyomar, B Ducharne and G Sebald, Time fractional derivatives for voltage creep in ferro electric materials: theory and experiment, J. Phys. D: Appl. Phys. 41 (2008) 125410 (see Sec. 2.1: Quasi-static considerations (analogy between wall movements and 'dry-friction' mechani sms)

Main achievement:

- The main achievement PhD candidate is proposing the new model (called Pol-Ind model). This model has some important advantages versus previous models. Among them, the model properties as non-drifting properties, frictional lag and rate-independence provide capability to more realistic simulations of all known macroscopically measured friction force dynamics.
- The author was able to obtain realistic results for hysteresis in both limits: presliding and pure sliding.

Summary

Listed above shortcomings and weaknesses of the thesis do not diminish the value of Mr. Krzysztof Jankowski achievements, which I evaluate unambiguously positive. In his dissertation he answered some important questions on friction modelling and simultaneously proved his scientific thesis. While working on his PhD degree Mr. Jankowski demonstrated ingenuity and perseverance. The dissertation was prepared and printed carefully. He was also able to published some of results in a good journal - *Tribology International.*

In conclusions, the work presented meets the requirements of doctoral dissertations. I put the request for admission MSc. Krzysztof Jankowski to the public defense.

Grzegorz Litak