6
Summary, future works and publications

This Thesis is a joint work between PUC-Rio and Université Paris-Est in a program of double diploma supported by the Capes-Cofecub project (number $17795/12-5$).

In relation to the motor-cart system, we analyze the effect of the electromechanical coupling, i.e., the mutual interaction between the mechanical and electric systems. We formulated the time-evolution of the system dynamics as initial value problems, in which the coupling torque appears as a parametric excitation, i.e., a time variation of the system parameters Numerical simulations were performed for different values of system parameters, and their results, as the graphs the systems variables over time, FFT and *phase portraits* were analyzed. The main results observed were: the existence of a periodic solution with a relation 2:1 between the period of rotation of the disk and the period of the current (a typical phenomenon of parametric excited systems) and, the characterization of the nominal eccentricity of the pin of the motor, as a parameter that controls the nonlinearities of the equations of motion of the system [42]. In [18], the existence and asymptotic stability of a periodic orbit to this motor-cart system were obtained in a mathematically rigorous way.

In relation to the motor-cart-pendulum system, by numerical simulations it was verified that the pendulum introduces a new feature to the system dynamics: it can pump energy from the motor and, in certain cases, revert the relation master-slave [42, 45, 47, 53].

In relation to the electromechanical system with internal impacts, we analyzed from a deterministic and from a stochastic view point the maximal energy stored in the barrier in impacts as function of some parameters of the electromechanical system, as gap/l_p and Δ [54]. It was verified that for values of Δ near zero, the graph of the impact energy as function of gap/l_p, is very similar to the graph with $\Delta = 0$ m (which can be nicely predicted from conservation of energy). However, as Δ increases the form of the graph changes completely and in an unexpected fashion.

In relation to the percussive electromechanical system, we performed a robust optimization respect to design parameters in order to maximize the impact power under the constraint that the electric power consumed by the DC motor is lower than a maximum value. The construction of the solution for this robust design optimization problem, has been prepared by carrying out

a sensitivity analysis with respect all the possible design parameters. This pre-analysis has allowed for reducing the number of design parameters to two parameters. The nonlinear constrained design optimization problem was formulated in the framework of robust design. It is solved for different levels of uncertainties, and also for the nominal value of deterministic design. The results are different and this show the importance of the stochastic modeling.

6.1 Future works

During the period of the thesis, several research topics arose from the study of electromechanical systems. In relation to the vibro-impact electromechanical system, some of the plans are:

- to analyze the impact power for different models to the barrier, considering for example, plasticity in the displacement, i.e., the barrier moves irreversibly in one direction, simulating a penetration. The objective is to model the propagation of waves in a continuous heterogeneous media, which is unbounded (due to wavelengths that would be generated), and thus there is an additional dissipation by radiation to infinity.
- to develop a controller acting the source voltage in order to synchronize the hammer and the cart movements. Since the total hammer velocity is equal to the cart velocity $\dot{x}$ added to the relative hammer velocity in relation to the cart $\dot{h}$, if we could control the system in a way that x and h be in phase, the total hammer velocity could achieve higher values, and consequently, the impact power could grow.
- to consider different variables to measure the system performance, and to include this new variables in the formulation of the robust design optimization problem. Examples of these new variables are the number of impacts and frequency of impacts.

6.2 Publications

Concerning publications, during the period of Thesis, we have published three journal papers, see [57, 55, 42]:

[J1] "Robust design optimization with an uncertain model of a nonlinear vibro-impact electro-mechanical system"; R. Lima, C. Soize, and R. Sampaio. Communications in Nonlinear Science and Numerical Simulation, 23, pp. 263-273, 2015.

[J2] "Robust design of a vibro-impact electro-mechanical system"; R. Lima, C. Soize, and R. Sampaio. Mecánica Computacional, XXXIII(27), pp. 1813-1819, 2014.

[J3] "Stochastic analysis of an electromechanical coupled system with embarked mass"; R. Lima e R. Sampaio, Mecánica Computacional, XXXI(14), pp. 2783-2800, 2012.

We have submitted others two journal papers:

[J4] "Two parametric excited nonlinear systems due to electromechanical coupling"; R. Lima e R. Sampaio.

[J5] "Electromechanical system with internal impacts and uncertainties"; R. Lima e R. Sampaio.

During the period of this Thesis other works have been developed besides the work of the Thesis, which have originated four journal papers, see [52, 18, 26, 46]:

[J6] "Stick-mode duration of a dry-friction oscillator with an uncertain model"; R. Lima e R. Sampaio. To be published in Journal of Sound and Vibration, 2015.

[J7] "Asymptotically stable periodic orbits of a coupled electromechanical system"; M.J.H. Dantas, R. Sampaio and R. Lima. Nonlinear Dynamics, 78, pp. 29-35, 2014.

[J8] "Robust Identification and passive control of vibration of a test rig under uncertain conditions"; C. Fonseca, R. Lima, G. Wagner and R. Sampaio. Mecánica Computacional, XXXIII (27), pp. 1767-1781, 2014.

[J9] "Some remarks about stick-slip oscillators"; R. Lima and R. Sampaio. Mecánica Computacional, XXXII (8), pp. 647-668, 2013.

In relation to these woks developed besides the work of the Thesis, we have submitted another journal paper:

[J10] "General results of existence and asymptotic stability for a class of

electromechanical systems, M.J.H. Dantas, R. Sampaio e R. Lima.

I published a book [85].

[B1] "Modelagem Estocástica e Geração de Amostras de Variáveis e Vetores Aleatórios", Sampaio, R. and Lima, R., Notas de Matemática Aplicada, SBMAC, 2012.

We have published fifteen conference papers: [56, 20, 48, 50, 19, 49, 25, 51, 54, 17, 16, 53, 47, 45, 43]. With the financial support of Laboratoire de Modélisation et Simulation Multi-Echelle (MSME) of Université Paris-Est and PUC-Rio, I had the chance to present papers in several international conferences, such as Uncertainties 2012 (Maresias, Brazil), COMPDYN 2013 (Kos, Greece), USNCCM12 2013 (Raleigh, EUA), EURODYN 2014 (Porto, Portugal), ENOC (Vienna, Austria) and Uncertainties 2014 (Rouen, France). I presented works also in CNMAC 2012(Águas de Lindóia, Brasil), and CMAC-NE 2012 (Natal, Barzil), in which I gave the mini-course "Modelagem Estocástica e Geração de Amostras de Variáveis e Vetores Aleatórios".

[C1] "Optimal design of a vibro-impact electro-mechanical system with uncertainties", Lima, R. and Soize, C. and Sampaio, R., 17th International Symposium on Dynamic Problems of Mechanics (DINAME 2015), Natal, RN, Brazil, 2015.

[C2] "General results of existence and asymptotic stability for a class of electromechanical systems", Dantas, M.J.H. and Sampaio, R. and Lima, R., 35^o Congresso Nacional de Matemática Aplicada e Computacional (CNMAC), Natal, RN, Brazil, 2014.

[C3] "Analysis of the stick-slip dynamics with a stochastic approach", Lima, R. and Sampaio, R., 35^o Congresso Nacional de Matemática Aplicada e Computacional (CNMAC), Natal, RN, Brazil, 2014.

[C4] "Stick-mode duration of random dry-friction oscillators", Lima, R. and Sampaio, R., 8th European Nonlinear Dynamics Conference (ENOC 2014), Vienna, Austria, 2014.

[C5] "Dynamics of an electromechanical system forced near the resonance", Dantas, M.J.H. and Sampaio, R. and Lima, R., 8th European Nonlinear

Dynamics Conference (ENOC 2014), Vienna, Austria, 2014.

[C6] "The random dynamics of an embarked pendulum in a vibro-impact electromechanical system", Lima, R. and Sampaio, R., 9th International Conference on Structural Dynamics (EURODYN 2014), Porto, Portugal, 2014.

[C7] "Design of a nonlinear dynamical absorber for an uncertain system", Fonseca, C and Lima, R. and Wagner, G. and Sampaio, R., 2nd International Symposium on Uncertainty Quantification and Stochastic Modeling (Uncertainties 2014) Rouen, France, 2014.

[C8] "Uncertainties on the stick-slip dynamics", Lima, R. and Sampaio, R., 2nd International Symposium on Uncertainty Quantification and Stochastic Modeling (Uncertainties 2014) Rouen, France, 2014.

[C9] "A vibro-impact electromechanical system: models of the random dynamics of an embarked pendulum", Lima, R. and Sampaio, R. and Soize, C., 22nd International Congress of Mechanical Engineering (COBEM 2013), Ribeirão Preto, SP, Brazil, 2013.

[C10] "Stable periodic orbits in an electromechanical system", Dantas, M.J.H. and Sampaio, R. and Lima, R., Congresso Nacional de Dinâmica e Controle (DINCON 2013), Fortaleza, CE, Brazil, 2013.

[C11] "Existence of periodic orbits in an electromechanical system under parametric end external excitations", Dantas, M.J.H. and Sampaio, R. and Lima, R., VII Encontro Nacional de Análise Matemática e Aplicações (ENAMA 2013) Rio de Janeiro, Brazil, 2013.

[C12] "Uncertainty quantification of the nonlinear dynamics of electromechanical coupled systems", Lima, R. and Sampaio, R. and Soize, C., 3rd South-East European Conference on Computational Mechanics (COMPDYN 2013), Kos Island, Greece, 2013.

[C13] "Uncertainty quantification of coupled electro-mechanical systems with an embarked pendulum", Lima, R. and Sampaio, R., XV International Symposium on Dynamic Problems of Mechanics (DINAME 2013) Búzios, RJ, Brazil, 2013.

[C14] "Stochastic Analysis of mechanical systems with nonideal source of power", Lima, R. and Sampaio, R., Congresso Matemática Aplicada e Computacional (CMAC-NE 2012), Natal, RN, Brazil, 2012.

[C15] "Analysis of Markov Chain Monte Carlo Method and example of its application in random vibration simulations", Lima, R. and Sampaio, R., 1st International Symposium on Uncertainty Quantification and Stochastic Modeling (Uncertainties 2012), Maresias, SP Brazil, 2012.