EVALUATION REPORT – DIPLOMA THESIS

Thesis title: Control of flexible mechanical set-up with time delays in the feedback

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The thesis, which is carefully written in very good English on 73 pages of dense text, solves four key objectives. The first one – the state of the art in the subjects of modern control design and time delay system theory with the focus on input shaping techniques and communication delays – has been solved in the chapters 1-5. Note that the overall number of references is 33, which shows that this part of work has been done very carefully. After the general introduction (Chapter 1), the author outlines modelling aspects and control design techniques (Chapter 2), which are utilized in the subsequent technical and experimental parts of the thesis. This part (in Chapter 3) also includes the key aspects of time delay system theory, documenting the understanding of the key differences from the classical delay free case that need to be taken into consideration when dealing with this functional and infinite dimensional system description. This chapter is followed by the outline of input shaper theory, with the focus on the shapers with distributed time delay and their application within the feedback loop – the subjects that have been widely studied at my research group recently. In the last state of the art section (Chapter 5) both theoretical and application aspects of internet based control systems are highlighted.

The technical part of the thesis starts with derivation and identification of mathematical model of the existing laboratory set-up, according to the second objective of the thesis. After a careful description of the set-up that consists of two carts connected with a spring and with an attached pendulum to one of the carts, the sixth order nonlinear set-up model is derived. After the model linearization, it is formulated in the state space form. Before the parameter identification, the problem of friction compensation is targeted and successfully solved by the observed based technique. The parameters of the model are then identified from a pulse response. Almost a perfect match between the model and the set-up is documented in Figs. 6.9 and 6.10. Consequently, an input delay and oscillatory mode to be compensated by the input shaper are identified. For determining the flexible mode, two approaches have been used. First, the mode is identified analytically from a submatrix of the existing model and then experimentally at the set-up.

The subsequent control design objective is solved in Chapters 7 and 8. The key novel task of the thesis, which has not been performed for the set-up before, is the internet based control. For this purpose, the loop with the computer connected to the measurement system and actuators of the set-up is closed via internet with the second computer, where the controller is implemented. This real-time connection has been worked out by the author himself, including the choice of the communication protocol and analysis of the communication delay length. The control design (Chapter 8) starts with the input shaper parametrization to compensate the oscillatory mode. Then, a Nyquist criterion based loop shaping method is applied to design of a controller that can handle both the signal shaper and the communication delay in the loop. Next to frequency domain analysis, demonstrating a sufficient gain and phase margins, the stability is confirmed by applying a spectral method. The experimental results are presented in Chapter 9, where the whole control system designed to pre-compensate the oscillatory mode of the pendulum and to deal with the feedback loop communication delay are successfully validated. The obtained experimental results are nicely presented in the graphs that are accompanied with thorough analysis. By this, the last objective of the thesis is fulfilled. The thesis is then summarised in the Conclusion Chapter 10.

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The strength of the thesis is in the complexity and wide scope of the performed work, which includes careful state of the art review, problem analysis including solution of nonstandard issues such as compensation of the friction and dealing with communication delay, theoretical synthesis of the control algorithm and their application on the real set-up. Note that the set-up dynamics is not trivial, it is of sixth order. The problem under consideration is made even more difficult by considering the delays in the shaper and in the communication channel. The author's work on the thesis was almost independent, he just consulted with me the directions to take and the way in which the results should be presented. I also like very much the style of writing and the care which has been paid to the graphical representation of the results. In my opinion, it is an outstanding thesis – one of the best I have ever supervised.

I fully recommend the thesis for defence and I suggest the grade A.

In Prague, June 23rd, 2017

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