Virtual sensing on mechatronic drivetrains using multiphysical models

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Abstract

Mechatronic drivetrains have significant advantages over traditional engine-driven mechanical drivelines in terms of – amongst others – energy efficiency, control bandwidth and noise, vibration and harshness (NVH) [1]. Hence, traditional drivelines in industrial applications are more and more replaced by their mechatronic counterpart. The same holds for vehicles, hybrid-electric ships being a particularly successful mechatronic application. With respect to energy conversion, mechatronic drivetrains are not only an indispensable part of turbines, but the electro-mechanical coupling has been shown to be of key importance to operational loading on modern wind turbines [2].

In contrast to the successful combination of electrical and mechanical power components, however, a big potential is still left unused in combining electrical and mechanical sensor data. Using a simple electromechanical model, structural health monitoring is proven to be possible based on electrical current measurements [3]. Furthermore, state-of-the-art model-based design approaches open up the possibility to use high-fidelity models in coupled state, parameter and input estimation [4].

In order to successfully combine the information from mechanical and electric sensors, a coupled electro-mechanical model needs to be constructed. In a general framework this could be obtained through a co-simulation approach. The mechanical part of the system can then be modelled using flexible multibody simulation to take the proper dynamic behaviour into account. However, this approach will lead to unacceptable computational loads for estimation purposes.

This paper therefore investigates how a typical mechatronic driveline, consisting of an electric motor and a (nonlinear) flexible cardan shaft can be modelled in a 1D environment and compares these results for a range of dynamic excitations with the results obtained from a fully coupled simulation (figure 1).

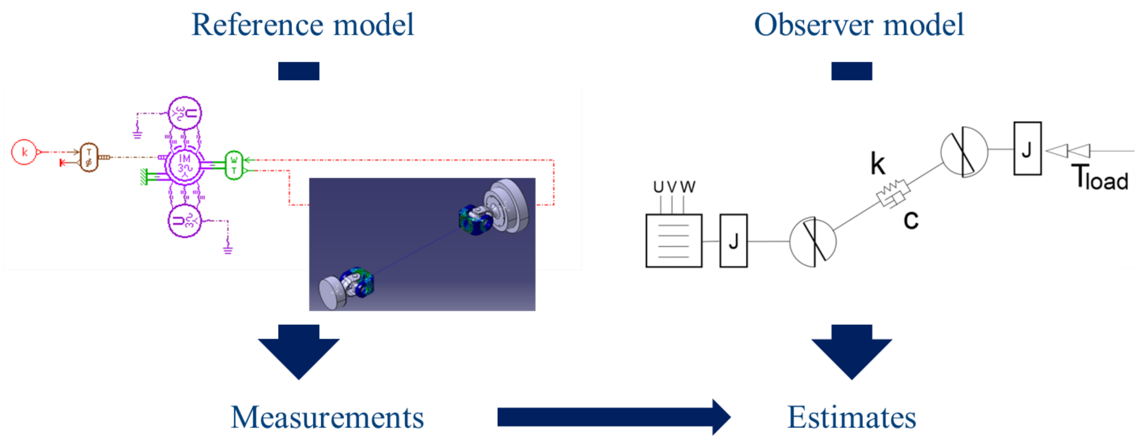

Figure 1: Virtual sensing on a mechatronic drivetrain.

Firstly, two different driveline models are discussed. Both models describe an induction motor which is connected to an inertial load through a double-cardan transmission in Z-configuration (figure 1), and where an external load is applied to the otherwise constant load inertia. The first model is a lumped-parameter description of both the induction motor and the driveline, including the nonlinear torsional dynamics induced by the presence of Hooke's joints and flexibility in the intermediate shaft. The second model treats the driveline as a flexible multibody system, where both torsional and bending dynamics of the intermediate shaft are represented by means of a modal description of this component.

Secondly, this paper also demonstrates some initial estimation results.

The more detailed model, with a flexible multibody description of the mechanical part of the driveline, serves as a reference and is used to generate a priori ideal measurements, to which realistic sensor noise is then added. Using the simplified lumped-parameter torsional model as the basis for an Unscented Kalman Filter (UKF, see [5],[6] and [7]) stable estimation results are obtained, which accurately represent the driveline's torsional behaviour. This is verified by comparing two estimates of dynamic quantities with the corresponding ones in the reference simulation, namely the a priori unknown load torque and the speed of the motor. In order to be able to virtually measure other relevant quantities, to include e.g. bending dynamics, the lumped-parameter model no longer suffices. Therefore, extending the proposed approach to include a flexible multibody model in the UKF is believed to be a valuable next step in this research track.

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