REMEDIATION OF TIME-DELAY EFFECTS IN TOKAMAK AXISYMMETRIC CONTROL LOOPS BY OPTIMAL TUNING AND ROBUST PREDICTOR AUGMENTATION

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With the introduction of fully superconducting tokamaks comes the need to understand how to operate and control plasmas within these devices, given new constraints imposed by superconducting PF coils. There is a concern about AC losses triggering coil quench. The minimum distance of coils from the plasma is increased due to cryogenic insulation requirements. There is a greater emphasis on minimizing the number of control coils due to cost. Passive structures are often more conductive, due to requirements for increased structural strength, multiple conducting walls, or intentional placement of highly conductive passive conductors near the plasma to reduce the growth rate of instabilities. All of these changes from present devices tend to change the plasma shape control properties, several of them negatively because of increased delays in responding to plasma disturbances. It is sometimes assumed that, because superconducting tokamaks already have significant intrinsic or imposed sources of control delay, introducing extra delays into the axisymmetric control loops will have negligible detrimental impact on the plasma control. In fact, introducing extra delays into the axisymmetric control loops of certain superconducting tokamaks can have significant detrimental consequences. This study exposes and quantifies the detrimental effects imposed by time delays in the control loop in superconducting tokamaks, using as an example the plasma current control and radial position control in a vertically stable circular plasma in the KSTAR tokamak [1] (delays in the power supplies, data acquisition, and vessel structure are taken into account). Two PID controllers are synthesized based on a decomposition of control action into ohmic flux and vertical field to control plasma current and radial position respectively. Extremum seeking [2] is proposed for optimal tuning of the PID gains in presence of time delays. Extremum seeking, which is a nonmodel-based method, iteratively modifies the arguments of a cost function (in this application, the PID parameters) so that the tracking error is minimized [3] (see references therein for alternative PID tuning methods). In addition, an augmentation of the control loop by the introduction of a predictor has been proposed to improve the performance of the time-delayed closed-loop system. It is shown that the proposed predictor is robust against uncertainties in the values of the delays. The stability analysis of closed-loop systems is carried out using the dual-locus diagram (also called Satche diagram) method [4]. The dual-locus diagram method is an extension or a variant of the well-known Nyquist diagram, and is also based on the celebrated argument principle in complex theory. The dual-locus diagram method is simple, intuitive and quite effective in assessing stability of time-delay systems when the time delays appear in only one of the loci.

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