Control Issues Related to Startup of Tokamaks

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Developing robust and reproducible startup scenarios is essential for all tokamaks and especially for burning plasma devices. A tokamak startup sequence is complex and calls on control of different types of plasmas, from nearly-collisionless low temperature weakly ionized plasma just after initiation to a more conventional high temperature fully ionized plasma during the rampup phase. Control during the various phases involves different algorithms, starting with feedforward control, where poloidal field coil currents are calculated in advance, to feedback control of plasma current, shape, and other parameters later in time.

To illustrate the various control elements during startup, we use the DIII-D tokamak as an example, and examine each phase. The first step is the establishment of a poloidal field null required for plasma initiation if there is no auxiliary heating in this phase. The poloidal field (PF) coil currents needed to create this field null are calculated real-time using a multipole expansion [1]. Feedforward control is maintained during the breakdown and burnthrough phases until sufficient toroidal plasma current, I_p, allows feedback control of both the radial and vertical position of the plasma. Later in time, as I_p continues to increase, the plasma is first elongated (i.e. "stretched" vertically) and then diverted (for most experiments), with each phase requiring a different algorithm, and a "hand-off" from one phase to the next.

We will present the control requirements for each phase and discuss issues and challenges in obtaining reliable startup and I_p rampup. The DIII-D tokamak is a mature and versatile machine with 18 poloidal field (PF) coils for plasma shaping control and a separate coil set to inductively heat (Ohmic heating) and to produce a toroidal plasma current, and startup with this versatile PF system has been optimized over a period of years. However new tokamaks such as EAST and KSTAR, and burning plasma devices such as ITER, have more limited coil sets that combine the functions of Ohmic heating, I_p control, and plasma shaping. Some of the challenges in maintaining control during rampup in these devices will be discussed, using examples from the EAST and KSTAR tokamaks that have recently begun to operate.

Experimentally simulating the ITER startup scenario is important in order to validate models that can predict ITER performance. DIII-D has recently carried out a series of experiments simulating ITER startup, scaled to DIII-D parameters [2]. Unique challenges include a low toroidal inductive electric field (0.3 V/m) requiring feedforward control for a longer period of time, vertical control closer to the stability boundary, and plasma startup limiting on the low field side (i.e. the outer wall). We will discuss control issues in these experiments and implications for ITER.

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