Global parameter control in ITER and a steady-state DEMO: a white paper for ReNeW

John Ferron, March 19, 2009

Issues

The discussion here is concerned with the control of global parameters such as Ip, beta, and line average density and the control of the discharge shape, position and divertor configuration. ITER and DEMO have a number of issues in common that are related to this control and there are some additional issues unique to DEMO.

- The expectation is that in burning plasma tokamaks the poloidal field coils will be located farther from the plasma than is common in the current generation of experiments. There will be one, integrated, set of coils responsible for both shape control and inductive generation of plasma current. There is limited experience as yet with this type of poloidal field coil configuration.
- The coil set in ITER and DEMO will be superconducting. This introduces a particular set of constraints on shape control capability. Again, there is as yet limited experience with this type of coil set.
- Because of the potentially high heat load on plasma facing surfaces in a burning plasma tokamak, there are tighter constraints on the control of the plasma to wall gaps and the consequences of a deviation from the control tolerances are more severe than in present experiments. This is especially true in the divertor region where specific surfaces have been designed to handle the anticipated heat load.
- Because the plasma will be largely self-heated by alpha particles, the present method of controlling beta using the external heating power as the actuator may not be effective in a burning plasma tokamak. Other methods for controlling the total stored energy will be required.
- In a steady-state DEMO with zero toroidal electric field, new methods for control of Ip will be required. The total plasma current control will result from a combination of indirect control using the total stored energy actuators and the external current drive actuators which could be relatively weak if only a small fraction of the external current is driven externally.
- Control of the line average density will depend on the effectiveness of the available actuators, pellet injection for instance.
- Identification of the discharge shape, required for control, presently depends on real-time reconstruction of the equilibrium. This requires dependable magnetic diagnostics which will need to be appropriate for steady-state operation in a nuclear environment. If magnetic diagnostics will not be available, a new method of shape identification will be necessary.
- For the most part, shape control algorithms are developed empirically during tokamak operations. This method should be replaced by off-line development of model-based controllers using modern control techniques.
- Discharge simulation tools that can be used to develop and test controllers need to be available.
- There is presently no experience with control of a complete discharge from breakdown to the steady-state phase through rampdown in a configuration with little or no ohmic heating capability.

Research requirements

- Model-based shape control algorithms for tokamaks with superconducting coils located far from the plasma must be developed and tested on the present generation of tokamaks.
- Shape control schemes for ITER should be tested on the present generation of tokamaks. Robust shape control with sufficient accuracy and adequate response to perturbations must be demonstrated.
- Density control actuators appropriate for use in ITER and DEMO should be validated on the present generation of tokamaks.
- Simulation tools for shape, stored energy and line density control should be validated using comparisons to discharges in the present generation of tokamaks.
- Experiments on control of plasma current in discharges with 90% bootstrap current are required.
- Experimental simulations of control of self-heated plasmas should be executed.
- Demonstration of plasma current ramp up to a steady-state phase followed by rampdown using a minimum of ohmic heating is required.

Research thrusts

Many of the research requirements can be satisfied using experiments in the present generation of tokamaks and in ITER. The issues that must be resolved in order to transition from ITER to DEMO are primarily those associated with steady-state operation.

- A program focused on development of model-based shape, position, plasma current and density control is required. Capability to develop controllers off-line should be implemented and the resulting controllers brought into routine operation on the present generation of tokamaks in order to allow the models to be validated against experiment and operating experience to be gained.
- Control schemes envisioned for ITER should be tested on the present generation of tokamaks using some set of constraints that will allow the present sets of poloidal field coils to be used to model the performance of the ITER coil set.
- Shape control diagnostics and density control actuators appropriate for a nuclear environment should be tested on the present generation of tokamaks.
- A program of control experiments on discharges with as close to 100% bootstrap current as possible should be implemented.
- Control techniques and actuators for a steady-state DEMO should be tested in a reduced scale burning plasma experiment.