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Integration of Issues for Control, Research Needs, and a Possible Thrust

Control of a DEMO or a commercial fusion power plant is inherently an integrated process. Not only plasma controls, but also control of the nuclear, magnet, cooling, energy conversion, and other systems have to be integrated into a single overarching control system. This is too much to ponder for the present exercise, but it must be kept in mind that this is what we're working toward.

There are three major components of a control system: sensors (diagnostics), actuators or effectors (coils, power systems, etc), and the models used to relate the information from the sensors, the characteristics of the actuators, and the desired effect. Underlying these is the design of the controller itself. In present tokamaks, the only system even approaching integrated control is the control of the shape and position of the plasma. Other systems of limited application are being developed; for example the use of localized coils to sense and control RWMs, and the use of ECCD to track and stabilize NTMs. Development of overall integrated plasma control is in its infancy.

The ReNeW Control panel will be developing a detailed list of issues and opportunities for addressing the control problems leading up to DEMO. From the point of view of the need for integration there are a couple of things to be noted. Steady-state control in the intense radiation environment of a DEMO will require innovation in all aspects of control.
Sensors. Essentially all of the diagnostics (sensors) we're familiar with will be approaching uselessness, because they require active probing (e.g., DNBs), or because of radiation damage, or because of limited access, or for a myriad of other reasons. Also, sensors for a steady-state plasma must be able to accurately detect slow drifts in critical parameters so that corrections can be applied in time.
Effectors. Actuators we're familiar with will be less useful than at present. Coils will be further from the plasma and will have limited slew rates. Heating and current drive systems will be only a small perturbation on the self-organized plasma determined by the alpha particle power.
Models. Finally we need models that link the input from limited sensors to limited actuators with accurate knowledge of the consequence of the action being taken. These are not the same as the full plasma simulation models now being discussed. Rather they must be computationally fast, simplified models which accurately describe the relationship between the action of an actuator and the state of the system being controlled.
Controller design. Models alone are not sufficient to provide the necessary control solutions. As the system becomes more coupled and more nonlinear the type and design of the controller itself becomes much more complex if sufficient solutions are to be found. Many fields with fairly minimally coupled nonlinear systems to control have been engaged in highly advanced control research to solve these problems, and still aren't there yet. We will surely encounter similar difficulties for a true AT reactor.

Two other areas that should be closely integrated with control development are the study of what are now categorized as ‘off-normal events’, and the development of high leverage control actuators.

Off-normal events. A considerable level of effort should and will be devoted to understanding the physics underlying damaging off-normal events such as VDEs, large ELMs, runaway electrons, disruptions, etc. However, specification and development of techniques for detection of these events and their precursors can’t be divorced from the overall control thrust. Also part of this effort has to be the development of models for the control systems to use in avoiding or mitigating these events.

High leverage actuators. As with off-normal events, we can expect that there will be intense on-going efforts to develop heating and current drive systems for burning plasmas. The key aspect of this development that should be closely tied to the control thrust is the invention and development of high leverage actuators. In a burning plasma, the alpha particle power density will dominate any external heating system, and the self-consistent bootstrap current will dominate external current drive. What are needed are techniques, for example using localized heating or current drive with limited power or using small changes in plasma shape or position, can have large effects on plasma profiles and thereby on fusion power production. Also, these effects have to be accurately modeled by real-time calculations so that feedback control is possible.

In order to emphasize the research needs in each of these areas, the FESAC panel on Priorities, Gaps, and Opportunities separated Measurement, Modeling, Control, Off-Normal Events, and Plasma Modification into separate issues with separately defined gaps. However, it is clear that there are portions of each of these areas which must be coordinated and integrated in order to be able to operate and control a burning plasma facility, both within safety limits and with optimized output. A coordinated and integrated research thrust that encompasses all of the aspects of the control problem discussed here would be both productive and timely.

One key action to take in the development of integrated control is to begin this work sooner than it is needed. This is one R&D area that does not require a major new facility. The sooner the development of measurement and control for a fusion environment becomes a serious endeavor, the better. Having a good understanding of measurement and control before designing a DEMO or other burning plasma facility would strongly influence the design of such a machine.