DEVELOPING ISOFLUX SHAPE CONTROL AND REAL TIME EQUILIBRIUM RECONSTRUCTION

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Goal in 2001: accurate discharge control for all plasma conditions

1. Finish implementation of real time equilibrium analysis.
   - Best method for discharge parameter identification (shape, β etc.). Used routinely for DIII-D.
   - Requires new NSTX control system hardware with magnetic diagnostics connected.
   - NSTX implementation begun in August, 2000 (at the beginning of funding).
     - First offline test using NSTX data is complete.
     - Some additional features required for NSTX need to be implemented.
     - Final steps are implementation on the new PCS followed by real time testing as a piggyback task during normal experiments.
2. Implement the isoflux shape control technique.
   - Basic software initially will be the same as used routinely on DIII-D.
   - Shape controller may be modified for local preferences.
   - Will require some dedicated development time during plasma operations.
   - Some development will be required for each basic shape desired.

Extra slides for background

Motivation: shape control is critical to many physics experiments.

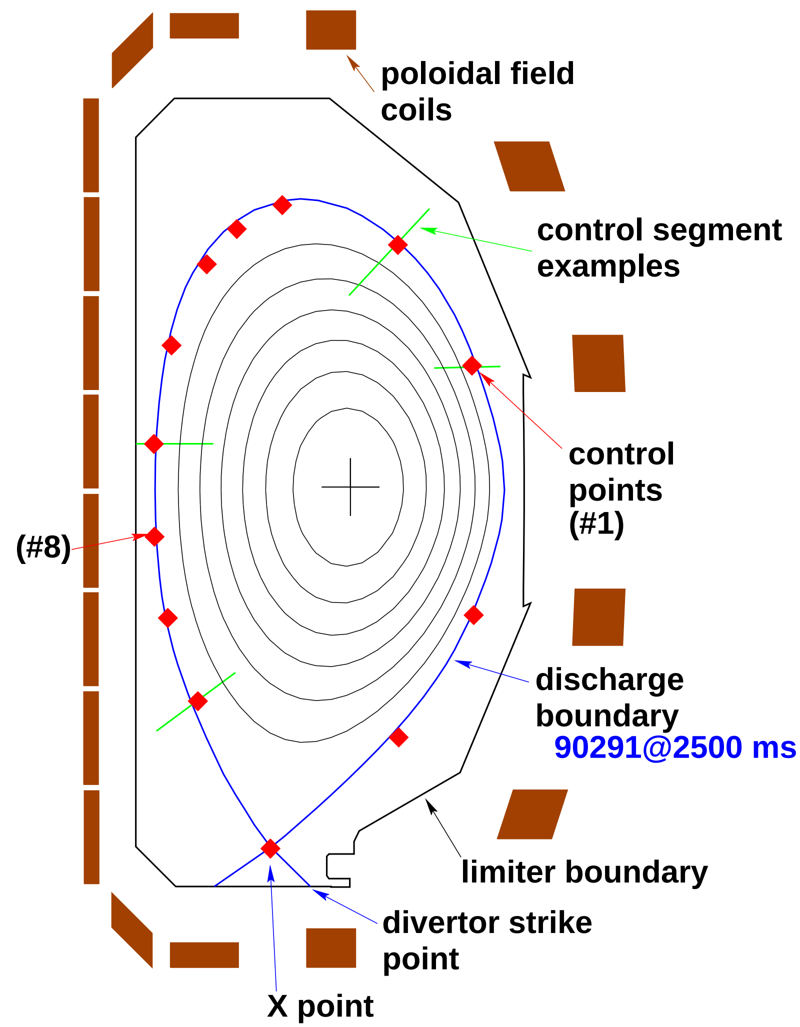
1. Control of shape in discharges with the broad pressure and current profiles characteristic of low aspect ratio devices will be a new area of research.
2. Rapid changes in the discharge stored energy or internal inductance, such as those common in high beta experiments, can result in significant changes in the discharge shape unless controlled properly.
3. The high harmonic fast wave RF heating technique depends on close coupling between the plasma and the antenna requiring good control of the plasma/antenna gap.
4. Shape control flexibility will be required to produce a variety of double-null divertor, single-null divertor, and elongated limited shapes.
5. Single-null divertor discharges required for helicity injection experiments will be challenging to control because of the low internal inductance and unusual current profiles.

Real time equilibrium reconstruction provides the basis for accurate discharge shape and profile control

- A solution to the Grad-Shafranov tokamak equilibrium relation is calculated which is consistent with measured diagnostic data.
- "Real time" reconstruction produces equilibrium solutions rapidly enough for feedback control of discharge parameters.
- The spatial distribution of toroidal current and poloidal flux are available in real time for evaluation of discharge parameters.
- Accuracy of discharge shape identification is comparable to that obtained with between-shot analysis.
- Inclusion of Motional Stark Effect data allows determination of the q profile.
- Shape identification is robust to changes in β_p, ℓ_i and edge current density.

Shape control is implemented by requiring equal flux at points on the desired boundary

- Operator specifies the required boundary shape.
- The "control points" for the boundary are at the intersection of the desired boundary and a set of preselected line segments ("control segments").
- Coil currents are adjusted to make the flux at each control point equal to be flux at the reference control point ("isoflux control").
- Reference control point:
  - Desired limiter touch point (for limited shapes).
  - Computed X point position (for divertor shapes).
- X Point: R, Z position computed in real time and controlled to be at the location specified by the operator.
- Divertor strike point controlled by specifying a control point at the desired position on the limiter.



A multiple input/multiple output (MIMO) controller includes the effect of actuator changes on all controlled quantities

- A controller is designed using plant models.
  - Power supplies, coils etc. must be modeled.
  - Plasma response model required (linear or nonlinear).
- Dynamic response can be specified.
- Controller design is automatic.
- Improvement on:
  - Empirical determination of controller gains and time constants.
  - Proportional/integral/differential (PID) controllers.

Model-based MIMO controller design is a key technology for high and low aspect ratio toroidal systems

- Systematic design method for new plasma configurations.
- Explicit means for trading off conflicting control demands (e.g. relative accuracy of gap and X point control).
- Methods for dealing with hardware constraints (e.g. giving up control accuracy as coil currents approach 0 or the maximum level).
- Integrated controllers are required for internal profile control.
  - Profile and shape control are coupled.
- Model-based MIMO controller design is a research topic with widespread interest and application throughout the fusion program.
  - Used extensively in design of ITER plasma controllers throughout EDA.