Strike Point Control for NSTX

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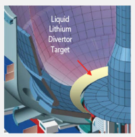
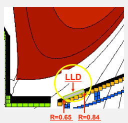
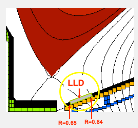
Background: LLD Density Reduction via Strike Point Control



Schematic of LLD inside NSTX



High δ : n_e reduced by 25%

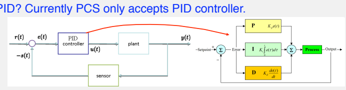


Low δ : n_e reduced by 50%

- Liquid lithium divertor (LLD), currently being installed on NSTX, will enable experiments with the first complete liquid metal divertor target in a high-power device in 2009.
- Reduced recycling with LLD
- Density reduction depends on proximity of the outer strike point (SP) to LLD
- To get better and consistent density reduction and to avoid contact with the LLD and the CHI gap, the most important parameter is SP position and it needs to be closely controlled.

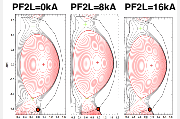
Aim: Design a Real Time Controller for the Strike Point Motion

- Design a Proportion-Integral-Derivative (PID) controller to keep the SP at the center of LLD, with ~1 cm variation from the reference value.
- Why PID? Currently PCS only accepts PID controller.

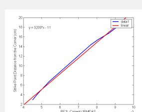


- In the schematic of the Control System: s=measured position and r=requested position of the SP.

Preliminary Study: ISOLVER Analysis



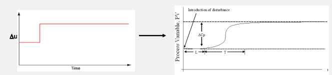
The change in the SP with different PF2L current


Depence of SP Position on PF2L

- Using ISOLVER and examining historical data showed that
  - The outer SP predominantly depend on PF2L. Use it as the sole controller for outer SP.
  - The dynamics of Single Input Single Output (PF2L current to SP change) is a linear system and can be modeled as a first order plus dead time (FOPDT) system:

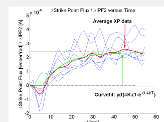
$$\frac{y(s)}{u(s)} = \frac{K}{1+sT}e^{-sL},$$

Experiment: System Identification



- System identification for FOPDT is achieved via "Open Loop Reaction Curve" where the response of the system to step control inputs is measured.

$$\Delta y(t) = K \cdot \left(1 - e^{-(t-L)/T}\right) \Delta u$$



System ID experimental data and FOPDT curvefit

- Three constants defining the dynamics are curve fitted from experimental data:
  - L = "apparent" lag in time response;
  - T = the time taken for this change to occur
  - ΔCp = K¢Δu = change in output signal in response to the initial step disturbance

PID Tuning: Ziegler-Nichols and Experimental Correction

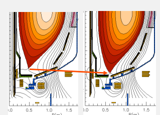
	K_p	K_i	K_d
P	1.0 T/(K L)	-	-
PI	0.9 T/(K L)	0.27 T/(K L^2)	-
PID	1.2 T/(K L)	0.6 T/(K L^2)	0.5 T/K

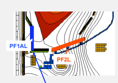
Ziegler-Nichols PID tuning rules

Shot number	133878	133879	133880	133884	133885	133886	133887	133888
K_p	550	275	275	275	400	400	500	400
K_i	0	0	200	400	600	800	1000	800

- Ziegler and Nichols based on their expertise in the controls field developed PID controller tuning rules shown on the left for FOPDT type systems based on "quarter wave decay" criteria.
- In PCS Voltage is used control as opposed to current
- PID gains converted to volts are $K_{p\text{-volt}}$=356±170and $K_{i\text{-volt}}$=722±345.
- Experimentally tuned to $K_{p\text{-volt}}$=400 and $K_{i\text{-volt}}$=800.

Inner Strike Point Control


X-points bifurcation

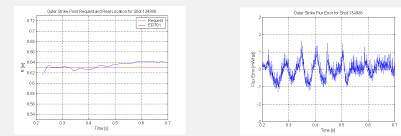


PF1AL controls inner SP in the blue segment. PF2L controls outer SP in red segments.

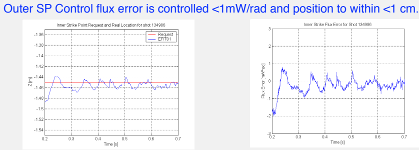
- The outer SP controller kept the controller at requested position but problems during the transition
- During the transient phase of the discharge, equilibrium bifurcated to a nearby solution with a low X-point.
- Algorithm was jumping from one solution to the other one.
- To make more stable plasma: Added inner SP controller.
- Tight control of the inner SP control was not critical.
- A louse control was obtained by manual tuning

Shot number	134978	134986	134987
K_p	1600	5000	5000
K_i	12000	5000	5000

Strike Point Control Performance

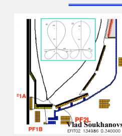


- Outer SP Control flux error is controlled <1mW/rad and position to within <1 cm.



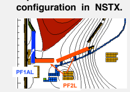
- Inner SP Control flux error is controlled <1mW/rad. Position is kept to within <1cm.
- Reconstructions by EFIT is suspected for the bias error. This issue is currently worked on.

"Snowflake" via Strike Point Control



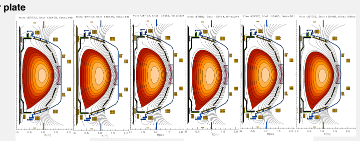
Example "snowflake" divertor configuration in NSTX.

- "Snowflake" divertor configuration, a second-order null is created in the divertor region by placing two X-points in close proximity to each other.
- This configuration has higher divertor flux expansion and different edge turbulence and magnetic shear properties, beneficial for divertor heat flux reduction, and possible "control" of turbulence and ELMs.



Added outer SP control on the inner divertor plate

- Implemented outer SP control on the inner divertor plate.
- Used inner and outer SP controller to achieve "snowflake".
- Scanned the outer SP from 44 cm to 73 cm while keeping the inner SP constant.
- With fixed SPs, used squareness and Δr_s to achieve "snowflake".


Snowflake scan from 44 to 73 cm