NSTX

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Snowflake Control

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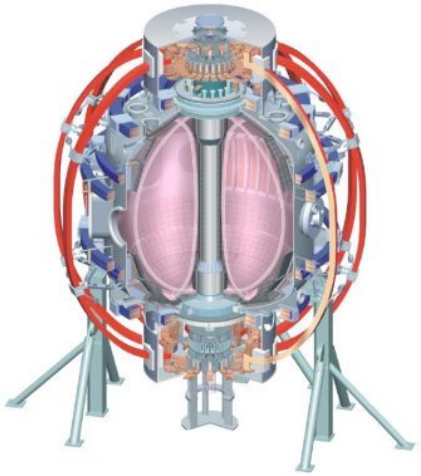
Egemen Kolemen

S. Gerhardt and D. A. Gates

M. Makowski, V. Soukhanovskii

2011 Group Review
Jun/09/2011



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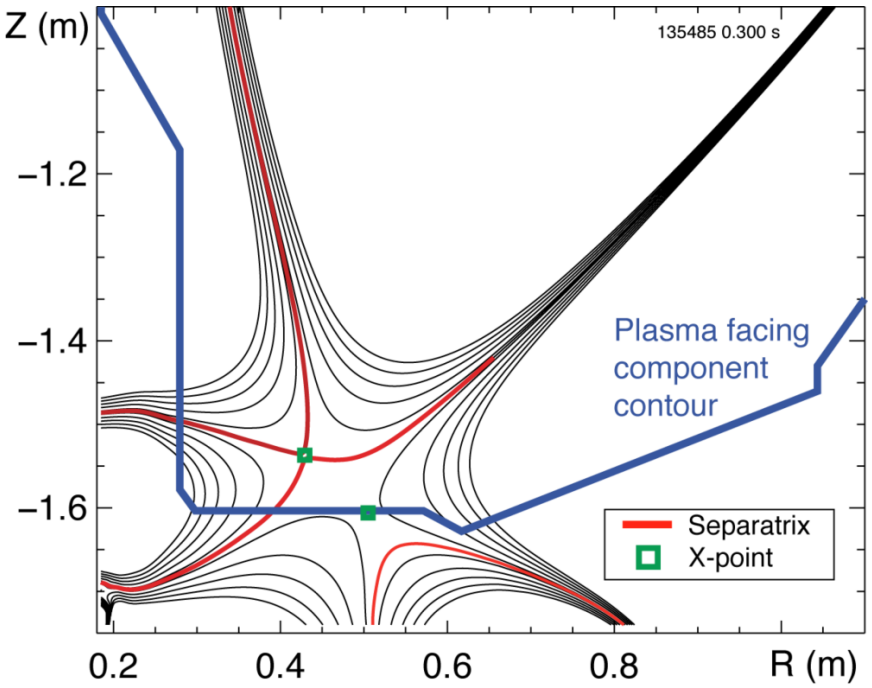
Snow Flake Divertor

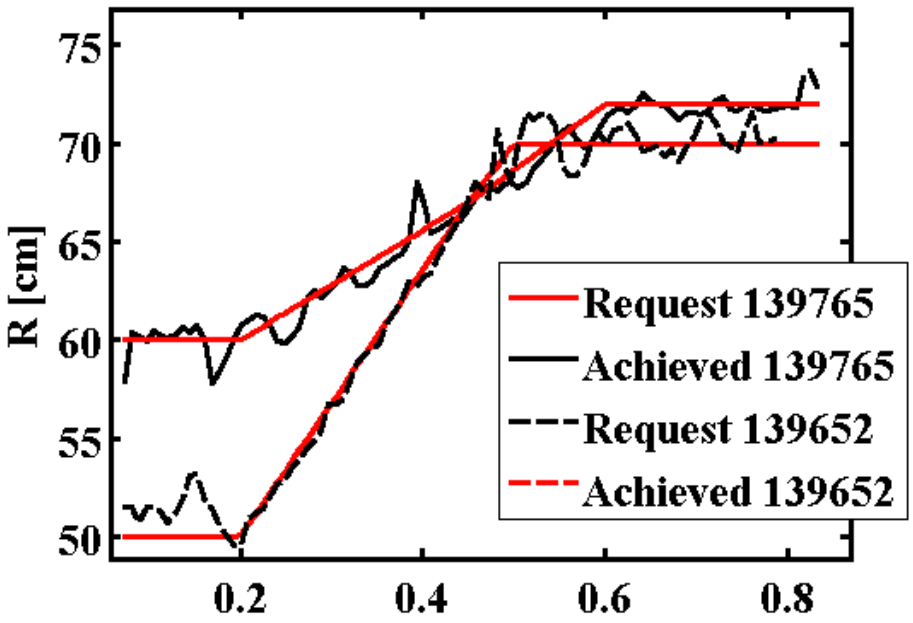


Example "snowflake" divertor configuration in NSTX.

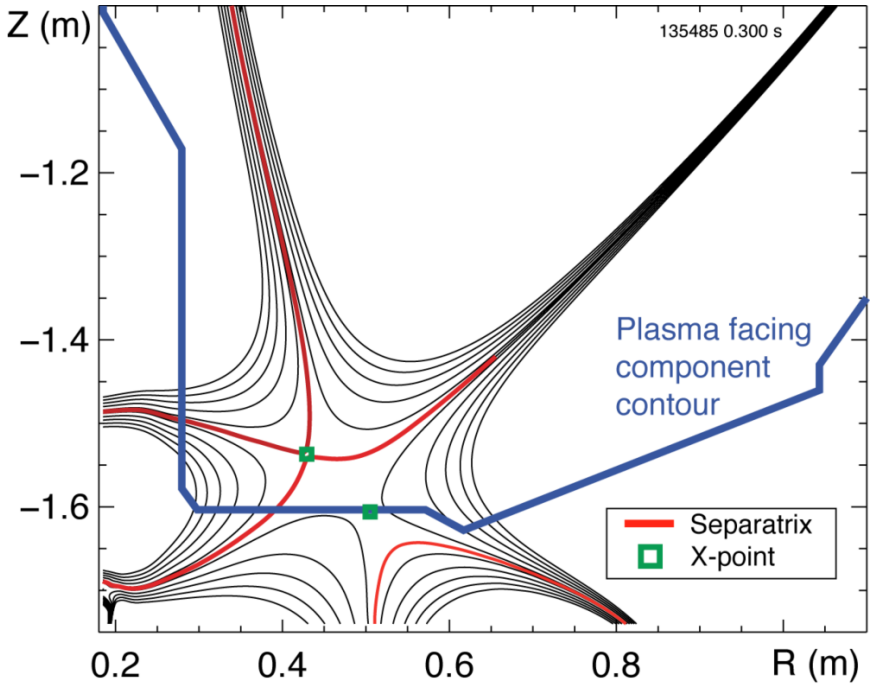
- "Snowflake" divertor configuration, a second-order null is created in the divertor region by placing two X-points in close proximity to each other.
- This configuration has higher divertor flux expansion and different edge turbulence and magnetic shear properties, beneficial for divertor heat flux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

Combined Upper/Lower-Inner/Outer Strike Point (SP) Control

- PID control for U/L-I/O SP to enable “snowflake”, LLD operation
- 8 PF coils in Single-input-single-output control (Outer gap, vertical position and 4 SP are controlled).



Example SP control



Snowflake high-flux expansion divertor obtained via SP control at NSTX

Snowflake Control: Finding the 2nd X-point

- Locate snowflake centroid & 2nd X-point
- Locally expand of the Grad-Shafranov equation in toroidal coordinates:

$$(R+x)\frac{\partial}{\partial x}\left(\frac{1}{R+x}\frac{\partial \Psi}{\partial x}\right)+\frac{\partial^2 \Psi}{\partial z^2}=0$$

- Keep the 3rd order terms and find the magnetic nulls

$$\begin{aligned}\Psi_{00} &= \Psi_f - \Psi(\rho_f \xi_f) \\ &= \Psi_f - \left[l_2\xi_f + q_3\xi_f^2 + c_4\xi_f^3 + l_1\rho_f + 2q_2\rho_f\xi_f \right. \\ &\qquad \left. + (-3c_1 - q_3)\rho_f\xi_f^2 + \frac{1}{2}(l_1 - 2q_3)\rho_f^2 + (-3c_4 + q_2)\rho_f^2\xi_f + c_1\rho_f^3 \right]\end{aligned}$$

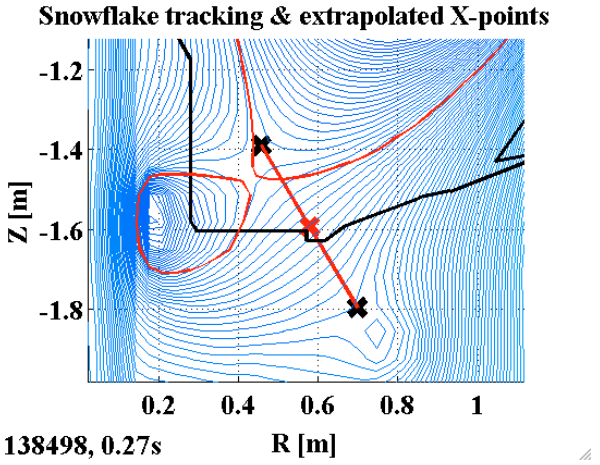
$$\Psi_1 = \Psi(\rho_1 \xi_1) + \Psi_{00}$$
$$\Psi_2 = \Psi(\rho_2 \xi_2) + \Psi_{00}$$

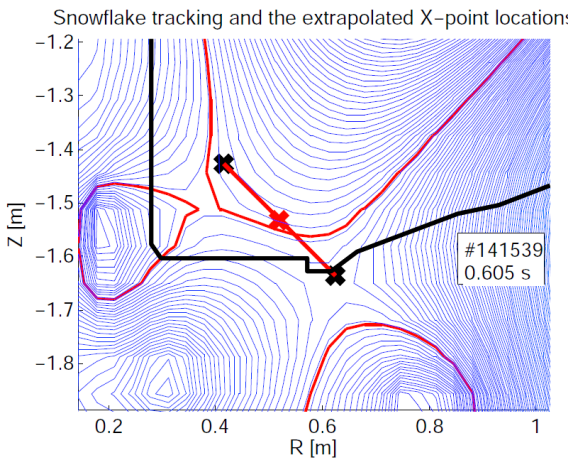
- Find coefficients from sample points
- No Iteration, one step fast algorithm with reasonable accuracy.

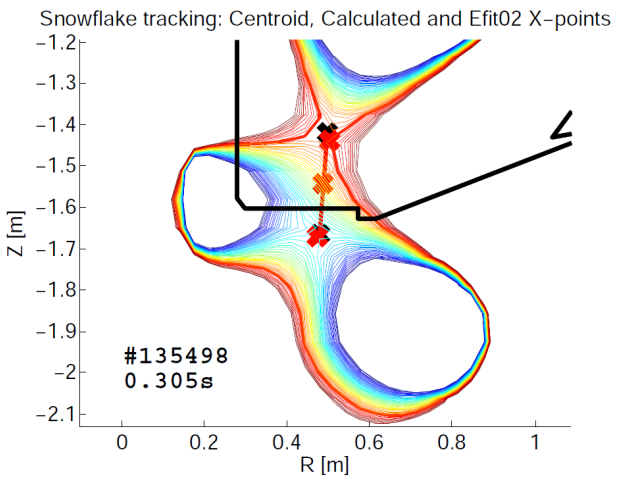
Ref. M.A. Makowski & D. Ryutov, "X-Point Tracking Algorithm for the Snowflake Divertor"

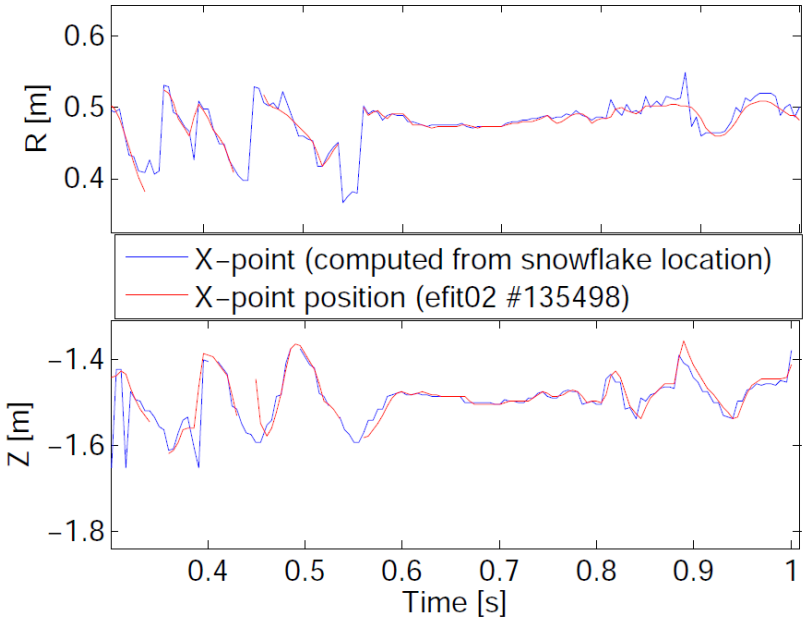
M.V. Umansky et al.. "Analysis of geometric variations in high-power tokamak divertors." LLNL-JRNL-410565.

Tracking Works for Snowflake -/+ and Non-Snowflake







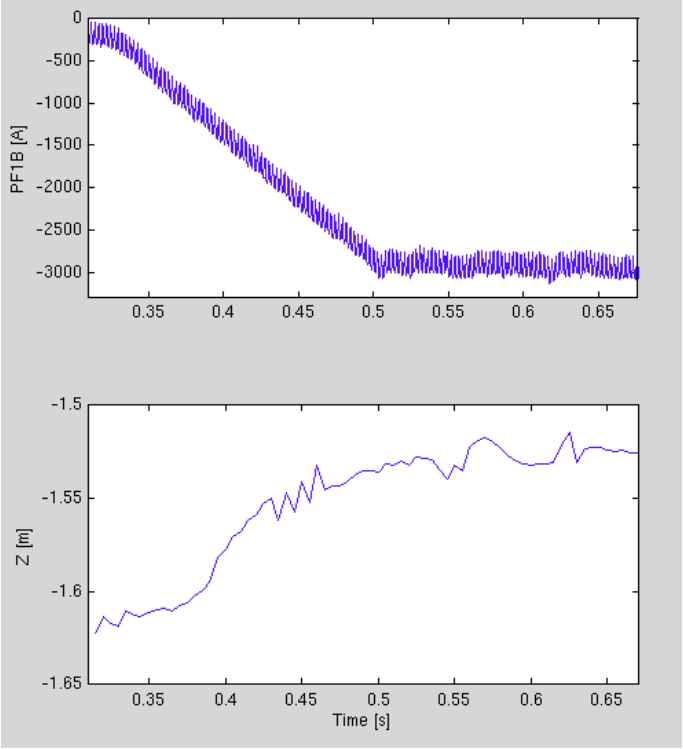


Above: Snowflake tracking for NSTX:

1. ***Red cross is the tracked snowflake centroid***
2. ***Black crosses are the calculated X-points locations by the snowflake tracking algorithm***

Left: X-point position computed from the radius and angle obtained from the snowflake tracking and position of the 2nd X-point.

Actuators to Control 2nd X-point



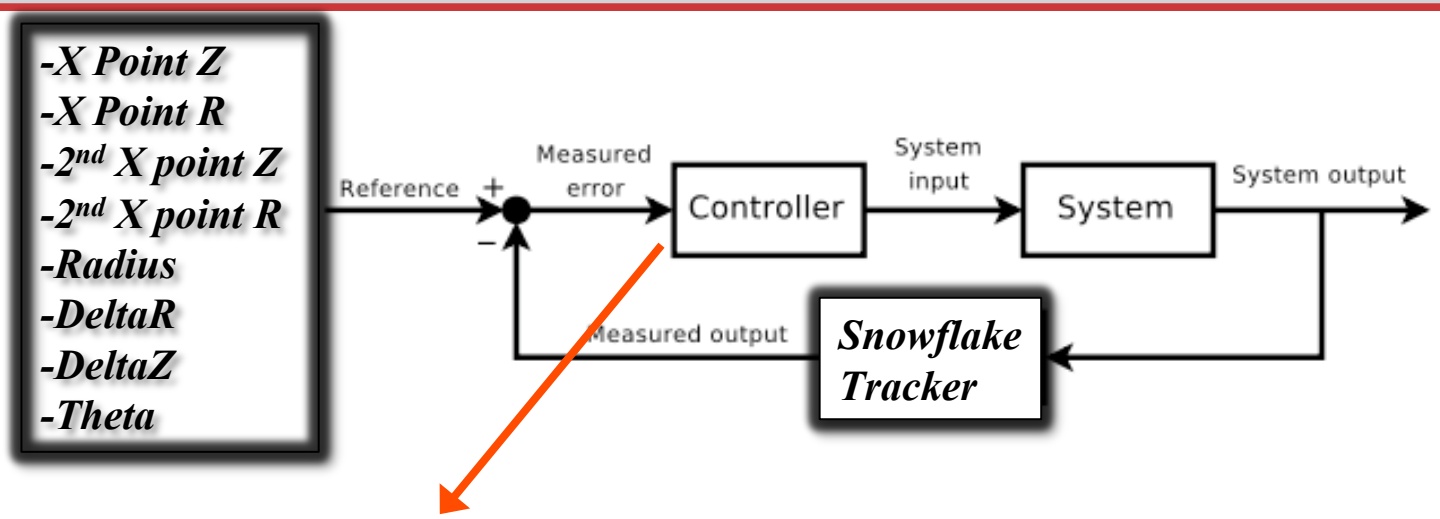
Example: Effect of PF1B on 2nd X-point Height

- Control both the location of the X-points with PF coils.
  - Need 4 independent actuators for full control
  - Optimal use of the capability we have 3 PF coils (PF1AL, PF2L and PF1B)
  - Control the best combination of properties of interest (Relative distance/angle between the X-points)
- After lower snowflake divertor, extend this algorithm to control the upper snowflake configuration as well.

Snowflake Control

- Locations of the X-points → feedback-control
- System Id:
  - Utilize Toksys to find the effect of PF1AL, PF1BL, PF2L coils on the separation of the two X-points.
  - Use the new relay feedback system ID in PCS.
- The aim of the control:
  - Primary aim is the distance between the two X-points.
  - Secondary aim relative angle between the X-points.
- Actuator: PF1B as the primary controller, PF1A/2 secondary
  - PF1B is a very effective coil in moving the secondary X-point
  - Not used in any other control loop
  - MIMO using PF1A, PF1B and PF2L will be probably be obtain control objective.

Snowflake Control Algorithm



$$V_{PF} = X_{mat} PID(Err_{snow}) + M_{mat} PID(Err_{seg})$$

- For convenience leave all the possible references.
- Define X Matrix similar to the M matrix.
- For unused references set X row to zero.
- Add the segment PID and snowflake PID.

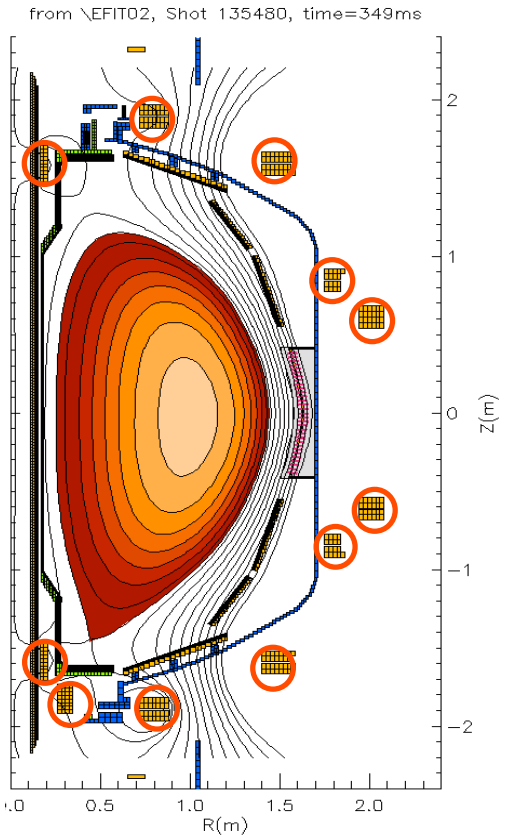
1 Day XP Run Plan

- Test the new control software (XMP?)
- Load shot 141539 (Snowflake -) or newer shot.
- System Id:
  - We will utilize Toksys to find the effect of PF1AL, PF1BL, PF2L coils on the separation of the two X-points.
  - Still we will need to tune the control using the new relay feedback system ID in PCS.
  - 3 set of coils and 4 references (Radius, Theta, X_R, X_Z), we looked at the effect of PF1A on X-point. Thus 10 shots are needed for full Id.
  - Start with a PF1B-Radius, PF1B-Theta and PF2L-X_R (3 shots)
- Tune the control
  - First, use the PF1B for Radius, PF1AL for X_Z, and PF2L X_R. Manually tune the transition and gains (3 shots). *Very optimistic, may take >10 shots*

1 Day XP Run Plan

- Test Snowflake Radius Control with PF1B (1AL- X_Z, 2L-X_R)
  - Decide if control is good enough, scan Radius from ~30 cm to as close to zero as possible (4 Shots). [20, 10, 5, 0]
- Tune the control with PF2L doing more snowflake less X_R (3 shots).
  - Repeat System Id for PF2L to Radius, Theta, X_R (3 shots) with PF1B in snowflake control and PF1AL in X_Z control. Sequential tuning.
- Test Snowflake Radius Control with PF1B+PF2L (1AL- X_Z)
  - Scan Radius from ~30 cm to as close to zero as possible (4 Shots). [20, 10, 5, 0]

- *Repeat this for snowflake + control (ex. 135498) (12 shots)*
  - Scan Radius from ~20 cm to as close to zero as possible. [15, 10, 5, 0]
- *If time allows add the upper snowflake control (12 shots).*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1
0
−1
−2
Z(m)
.0
0.5
1.0
1.5
2.0
R(m)