Robust control design for multi-input multi-output plasma shape control on EAST tokamak using H∞ synthesis

Poster Session C-01 #063

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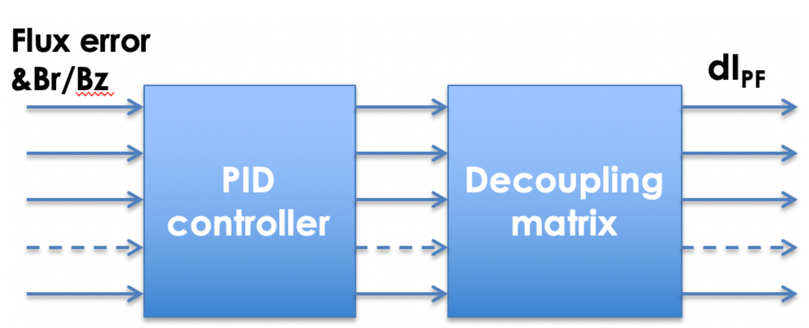
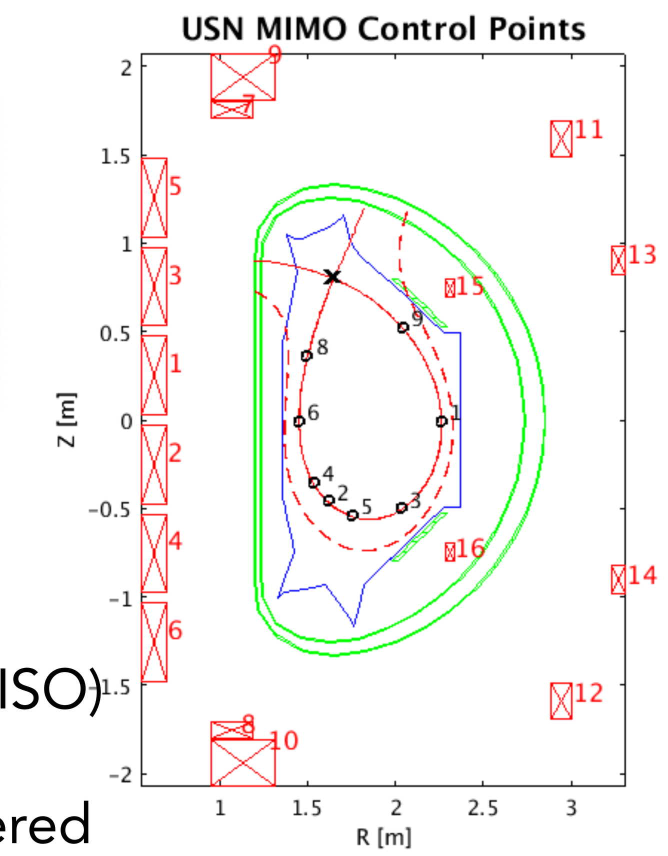
Background

Accurate plasma shape control is the basis of tokamak plasma experiments and physical research. EAST tokamak plasma shape controller designed based on a linear rigid plasma response model which contains much of the uncertainty, such as structured uncertainties and unmodeled dynamics. Meanwhile the single-input single-output (SISO) PID control approach is currently used for EAST plasma shape control. This leads to strong coupling between different parameters describing the plasma shape. To handle these problems, a H∞ robust control scheme for EAST multi-input multi-output (MIMO) shape control has been proposed.

EAST Plasma Shape isoflux control Schemes





PID controller:

1. single input single output (SISO)
2. Un-decouple control
3. Model uncertainty unconsidered

H∞ controller:

Transfer function based on H∞ control theory.

1. MIMO: multiple-input multiple-output
2. Model uncertainty is considered
   -Reduced sensitivity to plasma parameter variations
3. Robust control
   - Enable highly accurate shape control in presence of disturbances, noise and equilibrium uncertainty

H∞ control system design

Suboptimal controller design

Let plant model G have a minimal realization G=(A,B,C,D) .Then there exist unique stabilizing and positive-definite solutions X,Y to the algebraic Riccati equations

$$A'X+XA-XBB'X+C'C = 0$$

$$AY+YA'-YC'CY+BB' = 0$$

Respectively, $\gamma_{opt} = \sqrt{1+\lambda_{max}(XY)} \geq 1$

For any $1 \leq \gamma_{opt} \leq \gamma$ all suboptimal controllers are given by the parametrization:

$$K = (\Theta_{11}Q + \Theta_{12})(\Theta_{21}Q + \Theta_{22})^{-1} \qquad Q \in RH_\infty, \| Q \|_\infty < \gamma$$

where

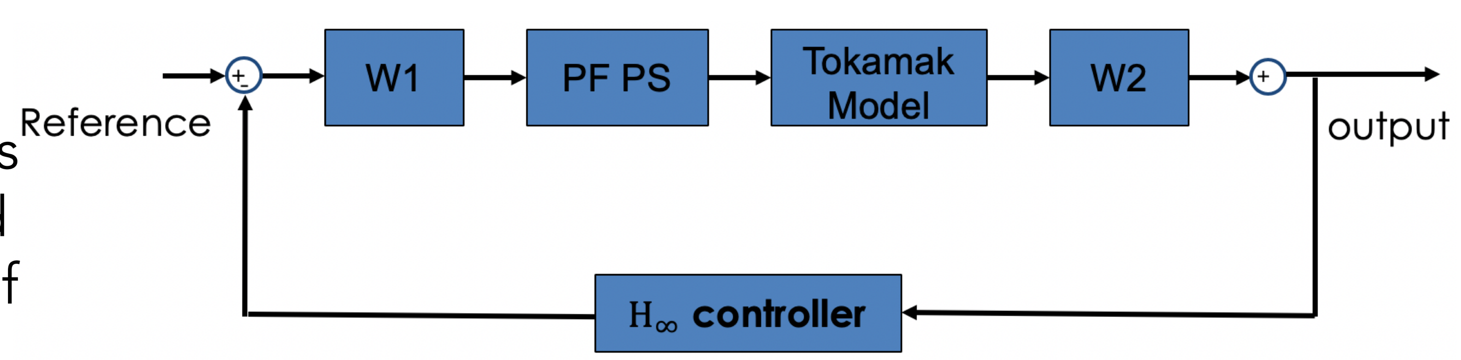
$$\Theta = \begin{bmatrix} \Theta_{11} & \Theta_{12} \\ \Theta_{21} & \Theta_{22} \end{bmatrix} = \left[\begin{array}{c|cc} A - BB'X & ZB & \beta^{-1}ZYC' \\ \hline -\beta^{-2}B'X & I & 0 \\ \beta^{-2}C & 0 & \beta^{-1}I \end{array}\right] \qquad \beta = \sqrt{1-\gamma^{-2}} \qquad Z = (I - \gamma^{-2}\beta^{-2}XY)$$

$$\Theta^{-1} = \left[\begin{array}{c|cc} Z(A - YC'C)Z^{-1} & ZB & ZYC' \\ \hline \beta^{-2}B'X & I & 0 \\ \beta^{-1}C & 0 & \beta I \end{array}\right]$$

Taking Q=0, get the H∞ controller: $K_{11} = \Theta_{12}\Theta_{22}^{-1} = \begin{bmatrix} A - BB'X - \beta^{-2}ZYC'C & ZYC' \\ -\beta^{-2}B'X & 0 \end{bmatrix}$

Loop shaping

W1, W2 for loop shaping:
loop shaping is used to shape the nominal plant singular values to give desired open and closed loop properties at frequencies of high and low loop gain.



Power supply saturation limitation and time delay

PF power supply saturation limitation		PF1-PF6	PF7/8	PF9/10	PF11/12
Limitation 1	Maximum output (V)	350	1110	700	350
Limitation 2	Limitation setup (V)	300	900	400	300

Power supply communication delay time and current rising time : ~3.3ms
Power supply apability limitation list in the Table

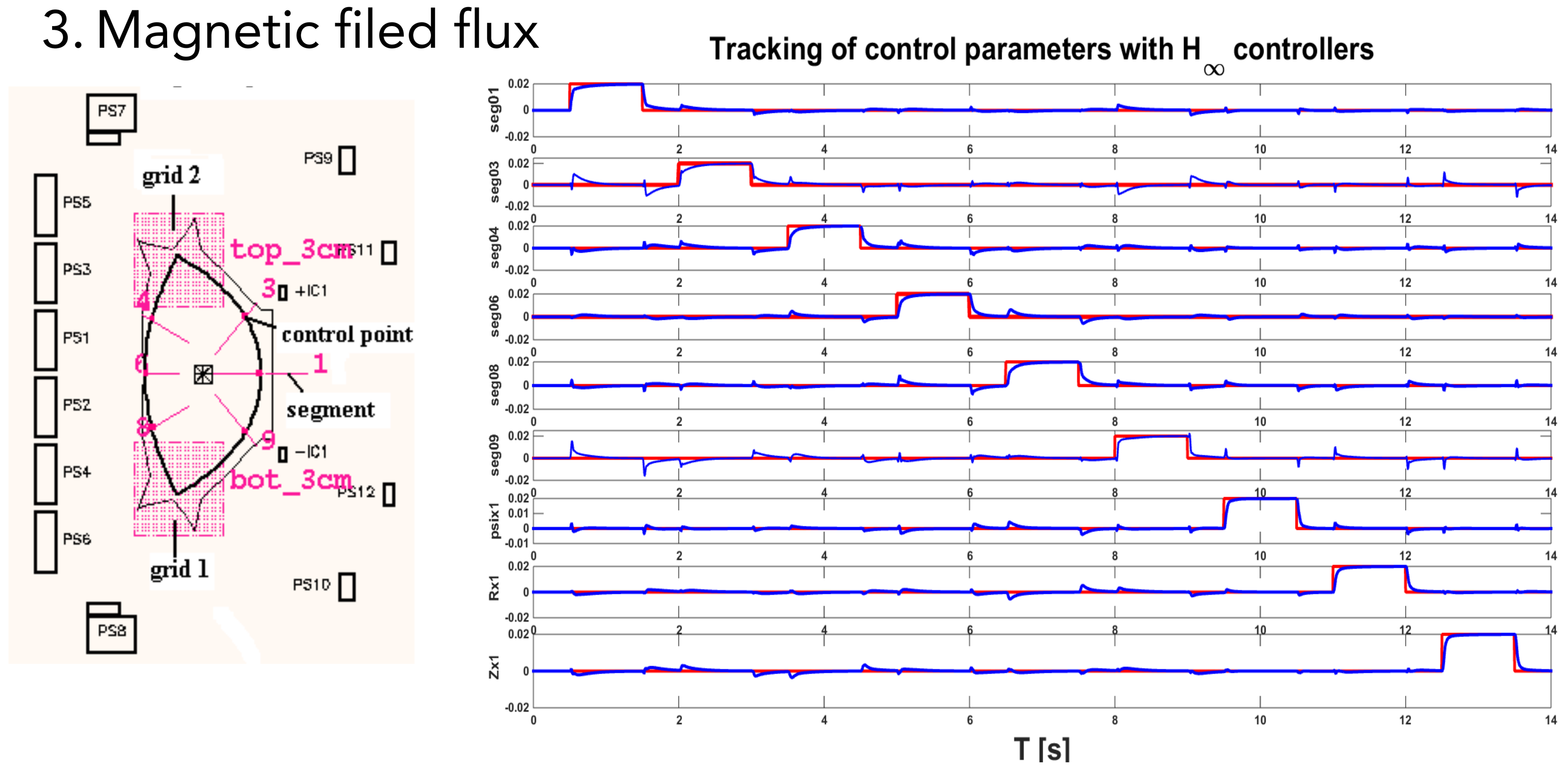
For the purposes of this study, we finally want to designed a controller that combines good robust stability margins, speed of response, dynamic tracking characteristics, and closed-loop decoupling.

Simulation Results

Control segments Decoupling

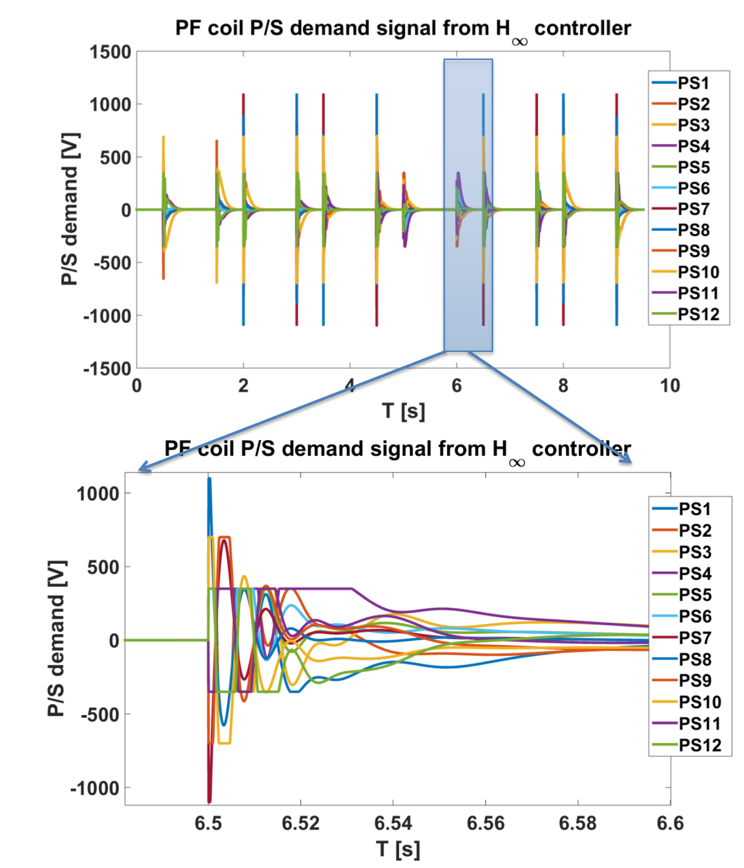
The following 9 parameters are controlled using all the 12 power supply

1. 6 control segment: seg01、03、04、06、08、09
2. 1 X-point position (grid1: Rx1&Zx1)
3. Magnetic filed flux



- Good decoupling of each control segment, only cross coupling appears at the pulse edges.
- The controller possesses all the desired properties. It shows the controller's good tracking properties.
  - speed of response
  - settling time

PF Power Supply requirements from H_∞ controller



- All PF power supply are used for each segment control.
- Good decoupling of plasma shape control and response tracking even with the power supply saturation.

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