Current multiplication and flux amplification in NSTX-CHI XP

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Definitions

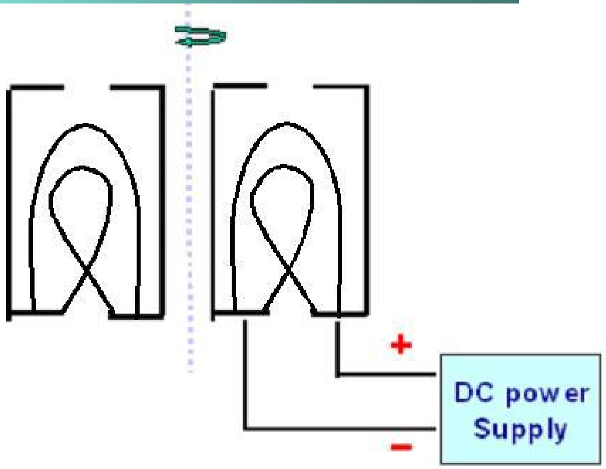
- Flux and current in three regions:
  - Closed flux: “c”
  - Open flux: SOL “os” and diverter private “op” fluxes
- Current multiplication factor (CM)
  - Ratio of toroidal plasma current vs. injector current

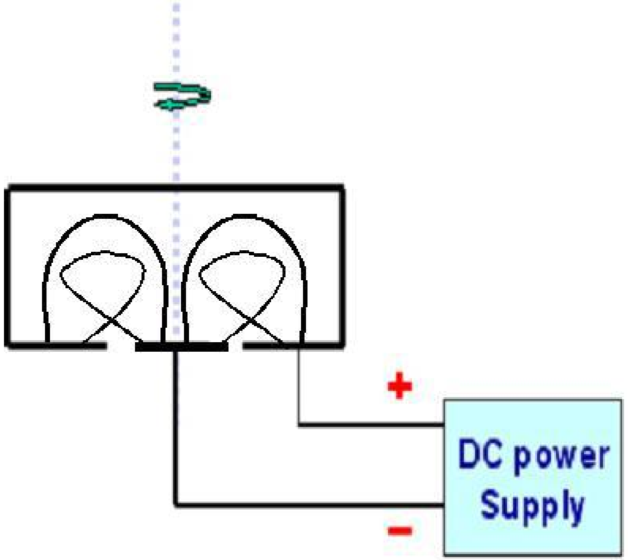
$$\mathcal{M}_C \equiv \frac{I_p^c + I_p^o}{I_{inj}}.$$

- Flux amplification factor (FA)
  - Ratio of closed poloidal flux vs. injector flux

$$\mathcal{A}_F \equiv \frac{\chi^c}{\chi^o}.$$

- Why they are important?
  - High CM good for electrode power handling.
  - High FA implies improved engineering efficiency.





CM independent of FA in Taylor relaxed ST-CHI

- Taylor state is a limit of force-free plasma.

$$\mathrm{j} = k(\chi)\mathrm{B},$$

- ST-CHI: CM is independent of FA

$$I_{inj} = k_0\chi^o; \quad I_p^c = k_0\psi^c; \quad I_p^o = k_0\psi^o.$$

  - Equal to initial vacuum toroidal/injector poloidal flux ratio

$$\mathcal{M}_C = M \equiv \frac{\Psi_0}{\chi_{inj}}.$$

- Spheromak or ST-PCC: CM is tied to FA

$$\mathcal{M}_C = \alpha(1 + \mathcal{A}_F).$$

CM negatively correlated with FA in partially relaxed ST-CHI

- Consider the two-scale model: (k^o, k^c)
  - Sustained CHI discharge has

$$k^o > k^c$$

- CM bounded from above by M.

$$\mathcal{M}_C < M \equiv \frac{\Psi_0}{\chi_{inj}}.$$

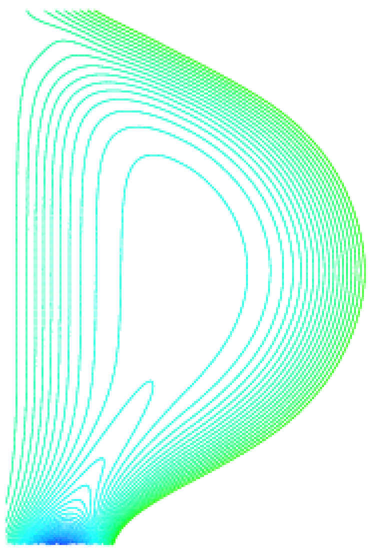
- Convoluted dependence (RHS)

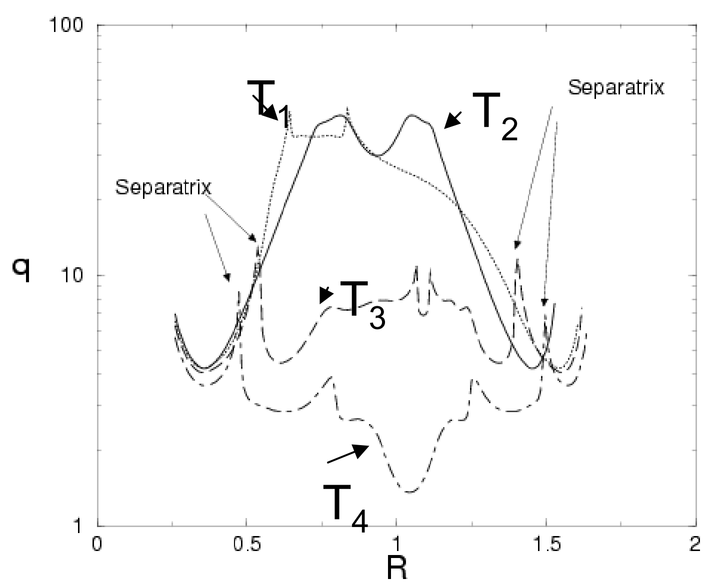
$$M - \mathcal{M}_C = \left(1 - \frac{k^c}{k^o}\right)\mathcal{A}_F\frac{\psi^c}{\chi^c}$$

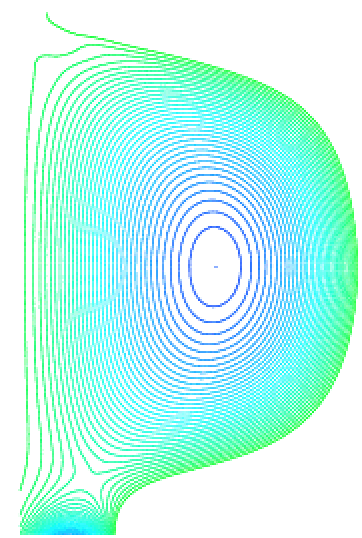
  - First term: deviation from Taylor state, limits maximum FA;
  - Second term: almost independent variable, but bounded from M by an amount determined by the first term.
  - Third term: average q, mostly geometry, but also affected by the first two terms through the current on open flux.

NSTX Transient CHI for Startup

- Fast Transient (FT-) CHI:
  - Pinch-off of an axisymmetric plasmoid.
    - High CM, but limited FA.
    - Exp: no helical mode present during pinch-off.
- Relaxed Transient (RT-) CHI:
  - Axisymmetric pinch-off of a 3D relaxed CHI plasma.
    - Relaxation → high FA target
    - Pinch-off → 2D reconnection and decay of helical modes → high FA and CM ST target.







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NSTX

Experimental implications on forming an ST

- FT-CHI:
  - No FA, so initial injector poloidal flux must be large.
  - High CM only achieved with high vacuum toroidal flux.
    - Problematic proposition with current TF system.
  - TF coil current swings down post-pinch-off.
- RT-CHI:
  - High CM achieved by reducing injector flux while holding vacuum toroidal flux fixed (good!).
  - High FA to compensate for the small injector flux (good!).
  - Most promising with current NSTX TF and PF coil systems.

Summary

- Current multiplication factor is independent of flux amplification in Taylor relaxed ST-CHI plasmas.
- Current multiplication factor is negatively correlated with flux amplification in a more realistic partially relaxed ST-CHI plasmas.
- Very different from spheromak and ST-PCC.
- To form an ST plasma, transient CHI insures closed flux surfaces, while
  - FT-CHI needs high field PF coils to provide adequate poloidal flux, and high field TF coils to reach high CM.
  - RT-CHI only needs conventional TF coils, weak field PF coils enables high CM, and FA by relaxation provide the ST poloidal flux.