Simulation of MST Tokamak Discharges with Resonant Magnetic Perturbations

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MST is studying runaway electrons in tokamak discharges.

To get runaway electrons, very low density plasmas are generated.

- Discharge parameters: $B_t \approx 0.14$ T, $I_p \approx 50$ kA, $q(a) \approx 2.2$, $n_e \approx 10^8$ m$^{-3}$, $T_e \approx 150$ eV

Resonant magnetic perturbations (RMP) have been used to suppress runaway electron populations these discharges.

- Each RMP applies a single “$m$ mode” whilst having a broad $n$ spectrum.
- An RMP with $m = 3$ can be made to strongly suppress the measurement of runaway electrons.
- An RMP with $m = 1$ of similar magnitude does not lead to similar suppression.
MST applies an RMP at a single toroidal location

- 40 drive coils produce a “$m = 1, 2, 3...$” RMP
- Feedback from the 32 poloidal array pickup coils is used to impose a sinusoidal signal
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The equilibrium is deduced from experimental measurements.

- Equilibrium profiles from MSTfit provide an initial condition. The equilibrium is re-solved with nimeq.
- For nonlinear calculations the equilibrium is re-solved with zero-$\beta$. 

![Safety Factor](image1)

![Plasma Pressure](image2)
The functional form of the RMP at the boundary in NIMROD satisfies $\nabla \cdot B = 0$

- A “tophat” function is assumed for the RMP in the toroidal direction. This function is then projected onto toroidal mode number in the NIMROD Fourier representation.

$$\frac{B_{RMP \text{ gap}}}{2\pi R} \cos (m\theta) + \sum_{n=1}^{N_{\text{max}}} \frac{B_{RMP} R_0}{n\pi R} \sin \left( n \frac{\text{gap}}{2R_0} \right) \cos (m\theta)$$

- $B_{RMP}$ is the magnitude of the field that would be seen in the poloidal pickup coils.
- $\text{gap}$ is the width of the region that has normal magnetic flux.
- $N_{\text{max}}$ is generally taken to be half of the maximum Fourier mode in the calculation.
The RMP vacuum field is obtained from diffusion of an applied boundary normal field.

\[ m = 1 \]

Re BR and BZ

\[ m = 3 \]

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The (1, 1)-kink and (2, 2)-tearing modes are linearly unstable in these discharges.
Nonlinear simulations with and without an applied RMP reproduce important experimental dynamics.

- No RMP, an \( m = 1 \) RMP, and an \( m = 3 \) RMP have been applied in simulations.
- Some of our findings may be in line with what has been seen experimentally.
- These results use values of \( B_{RMP} = 0.02 \) T and \( gap = 10 \) cm for the applied RMP. This produces a projection of about 1% of \( B_{RMP} \) onto the low toroidal mode number components. (Close to what’s reported in R. Fridstrom et al. Phys. Plasmas 23, 062504 (2016).) \( S = 10^5 \) and \( Pr_m = 1 \) for these results.
Energy time traces show sawtoothing behavior.

No RMP

$m = 1$

$m = 3$
Different RMP modes produce different field topologies.

Initial condition

Low $n = 1$ phase

Crash phase

No RMP

$m = 1$

$m = 3$
These results may help explain the runaway electron findings in MST.

- With the $m = 3$ RMP, degradation of outer flux surfaces is shown in simulation. This could be the reason for lack of runaway electrons, since they may not be confined well.
- The $m = 1$ case does not show the same degradation, which may explain why it does not affect runaway electrons like the $m = 3$ RMP.
We are looking to confirm theories on the origin of the stochastic region and test the robustness of current results.

- Running the same calculations with $S = 10^6$ keeping other parameters constant.
- Vary the RMP magnitude:
  - To see how stochastic region is affected, e.g. degree of stochasticity or width of stochastic region.
  - To try to isolate the (3, 2) and/or other resonant response from the RMP near the edge, which may indicate the origin of the stochastic region.
- Try to develop an understanding of the effects of an $m = 2$ RMP since those results have been unclear in the experiment.
Initial results have led to a working hypothesis on runaway electron suppression with RMPs in MST.

- Even with zero-$\beta$ nonlinear simulations produce good agreement with the experimental sawtoothing period.
- The stochastic region observed in the edge of $m = 3$ simulations appears to be pivotal in the runaway electron suppression observed in MST. The relatively large region of magnetic reorganization likely provides transport to near the stochastic region, which then allows transport to the wall.
- Understanding of the mechanism for suppression by the $m = 3$ RMP could lead improved experimental investigation of the $m = 2$ RMP.