Recent results on RWM research on RFX-mod

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Outline

Introduction

Statistical investigation of RWM growth rates on RFX-mod

RWM active rotation: experimental issues

RWM active rotation: first (not fully validated) results

Conclusions and future work
MHD active control in RFX-mod

Total of 192 active coils.

100% coverage of the mechanical structure external surface.

Each saddle coil is fed with its own power supply.

<table>
<thead>
<tr>
<th>Radial field at 24 kAt</th>
<th>$&lt;B_r&gt;$ (mT)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DC</strong></td>
<td>50</td>
</tr>
<tr>
<td>@10Hz</td>
<td>35</td>
</tr>
<tr>
<td>@50Hz</td>
<td>12</td>
</tr>
<tr>
<td>@100Hz (I=16 kAt)</td>
<td>3.5</td>
</tr>
</tbody>
</table>
MHD diagnostics: external probes

48 x 4 = 192 Br saddle probes
48 x 4 = 192 Bt and Bp pick up probes

+ other probes for toroidal and poloidal
Vloop, plasma current, halo current
measurements

TOTAL \(\approx\) 650 probes
**MHD control scenarios: Mode Control**

- **Mode Control (MC)**: controls single modes or groups of modes (from 1 to all) each mode is assigned its own regulator. derivative control to compensate for radial field penetration delay due to the passive structures (delay depends on mode number) 1-pole Butterworth filter to smooth the derivative action.

A. Luchetta et al., IAEA conference, Chengdu (2006)
Main achievements on RWM

- Full control of the RWM spectrum (multiple RWMs are always unstable)
- Identification of RWM growth in discharges with partial (selective) mode control
- Test of RWM control after some time of free growth
- Controlled growth of different combinations of unstable RWM and TM
- First RFA studies
First part

Statistical investigation of RWM growth rates on RFX-mod
Very precise determination of RWM exp. growth

RWM experimental growth rates: (m=1, n=-5) and (m=1, n=-6); F=-0.07
Calculation of each RWM growth rate

An automatic procedure finds the interval with the best exponential fit ("true RWM growth")

- Plasma current
- $m=1,n=-6$ mode amplitude
- Logarithmic mode amplitude

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RFX-mod has unique capabilities to explore low (<0.3 MA) to high (up to 1.5 MA reached at present) plasma currents.

RFX-mod is also equipped with a complete set of diagnostics to characterize the background plasma (not only an extensive set of magnetics, but also density and temperature profiles, spectroscopic measurements, etc.)

Parameters chosen for the study:

- plasma current: 350 kA < I < 700 kA
- F parameter: -0.4 < F < -0.05
- plasma density: 1 \times 10^{19} \text{ m}^{-3} < n_e < 3 \times 10^{19} \text{ m}^{-3}
- electronic poloidal beta: 0.01 < \beta_{p,e} < 0.04

**total of 234 points**

N.B. Preliminary study: non independent parameters!
Statistical analysis for $n=-5$

Clear IFI dependence, agreement with theory

No other clear dependencies

M. Baruzzo thesis
Clear IFI dependence, agreement with theory

No other clear dependencies

Plasma current dependence appears?

Possible explanations? Error field influence should grow with I.

M. Baruzzo thesis
Second part

RWM active rotation experiments
How to rotate a RWM?

Open loop rotation

Main advantage: external perturbation amplitude and phase perfectly under control
Disadvantages: long trials and errors procedure

Feedback rotation

Main advantage: the system “self-adjust” itself to the best possible mode control configuration (amplitude)
Disadvantage: amplitude and phase of plasma and perturbation not trivial to calculate
The idea (feedback control)

Perfect control
- Total field = 0
- External field

Incomplete control
- Total field ≠ 0
- External field

Incomplete control with phase shift (torque on the mode?)
- Total field ≠ 0
- External field
Incomplete \( (1,-6) \) control - 0 phase diff.

Control from 130 ms
Phase scan at fixed (normal) Gp. I=400 kA

Phase velocity depends on pre-programmed phase difference
Phase scan at fixed (normal) Gp. I=600 kA
Induced rotation data analysis

- From total br measurements to plasma vs external fields
- External br field at the measurement radius obtained from coil currents (including mutual inductances and machine structure).

**Model developed by G. Marchiori**

- Plasma br field by subtraction
- Time evolution of external and plasma harmonics (amplitude and phase)
- If the experiment is successful (torque balance):
  - constant rotation
  - constant phase difference
  - torque calculation and comparison with models
#22595 (reference): Kp=140; φ=0°

Full line: total br measurement. Dotted line: reconstructed “external” br. Dashed line: reconstructed “plasma” br. (NB non-fully validated run)
#22596: Kp=162; φ=30°

**Full line:** total br measurement. **Dotted line:** reconstructed “external” br. **Dashed line:** reconstructed “plasma” br. (NB non-fully validated run)
Full line: total br measurement. Dotted line: reconstructed “external” br. Dashed line: reconstructed “plasma” br. (NB non-fully validated run)
Future work

Continuation of RWM characterization, fill the operational space, test plasma current influence, comparison with models.

Feedback rotation successful for the first time!
Continue with data analysis and further experiments (AUG collaboration)

Experimental data are ready for comparison with numerical models in order to clarify the leading torque mechanisms.

Play the “EF search” game: open loop EF correction at the beginning of the discharge; study the RWM phase dependencies; Resonant Field Amplification experiments

Experiment vs theory-modelling main issues:

  include all the relevant physics in the models (tokamak benchmark)
  go from “qualitative” to “quantitative” agreement at least for the simplest cases (RFP benchmark)
  quantitative comparison: quantification of real-wall effects on growth rates