Particle simulations of RMP fields effects in the COMPASS tokamak

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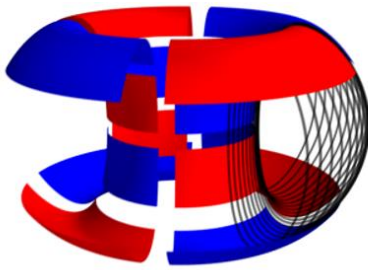
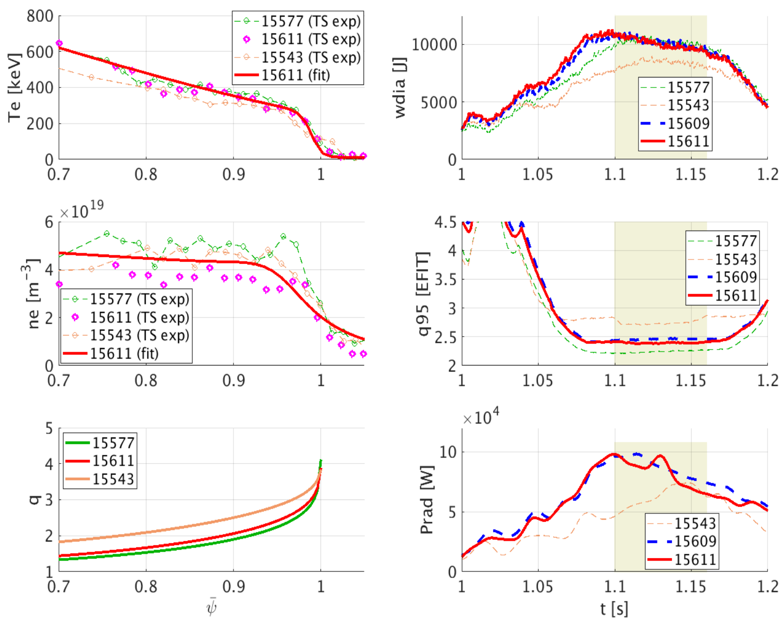
Introduction

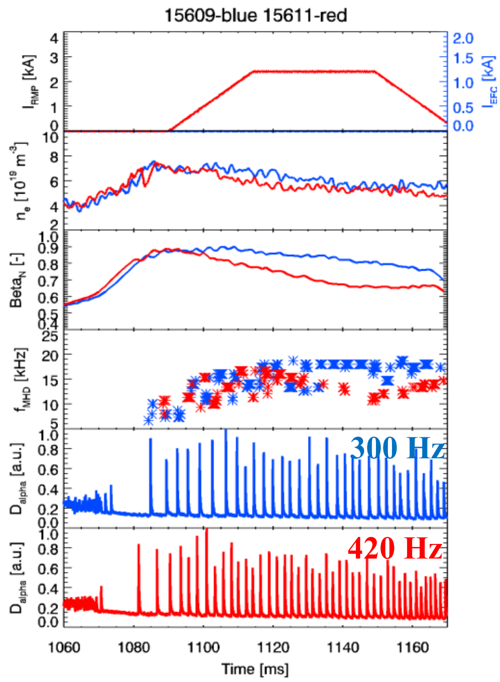
The use of Resonant Magnetic Perturbation (RMP) coils is as an experimental technique for mitigating or suppressing large Edge Localized Modes (ELMs) in a number of tokamaks. In this work, we introduce a newly developed extension of the EBdyna_go code (introduced in [1]) that was designed to resolve the full-orbit of charged particles, in a collisionless manner. The new version of the code allows to study motions in the 3D perturbed fields generated by RMPs. This field can be calculated by a Biot-Savart solver or an integrated MHD code such as MARS-F [4]. The model has been applied on the COMPASS tokamak, comparing it with its RMP experimental database [2]. In particular we have focused here in the modelling of a High-Field-Side (HFS) RMP experiment with a dominant n=2 toroidal mode number.



Experiments and equilibrium reconstruction

Detailed integrated transport modelling with the METIS code [3] has been used so that the latest experimental data can be wrapped up by self-consistent simulations and the ion temperature and plasma rotation data can be used in the RMP modelling described in this contribution. We focus here on two pulses of COMPASS : #**15609** (no RMP) and #**15611** (with RMP, coloured background) where some effect of the RMP on the plasma is observed. For comparison, we also show results for pulses #**15577** and #**15543** that do not exhibit any effect of the RMP on the plasma, despite similar density, rotation and temperature profiles. Measured time traces are given in the figure below. The time point used for analysing the pedestal is @~1.13s and we reconstruct the equilibrium at this time with the FINESSE code [5], obtaining a real poloidal angle θ and a geometric toroidal angle φ that verify q=dφ/dθ. The normalized poloidal flux $\bar{\psi}$ is used as a radial coordinate. The pedestal position is measured to be roughly at $\bar{\psi} \sim 0.985$.



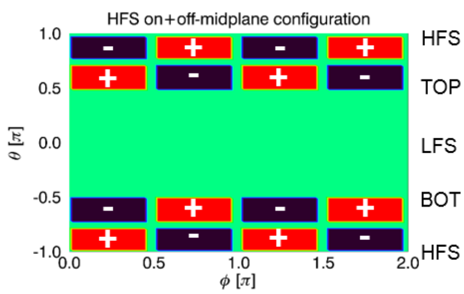


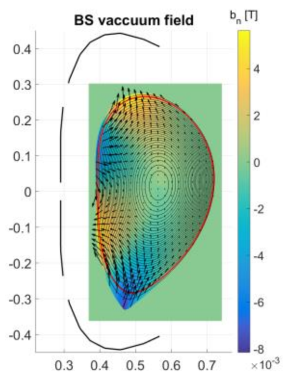
HFS RMP triggers no significant energy loss (wdia) and a moderate density pump-out in the edge region, whilst still able to modify f_{ELM} and n_e pedestal height. Only the configuration in #15611 is triggering a measurable change in plasma behavior.

Biot-Savart (BS) solver to represent the vacuum field of RMPs

The first step we take in the modelling effort is the calculation of the 3D combined field created by the HFS coils, using their coordinates and the value of current from the experiment.

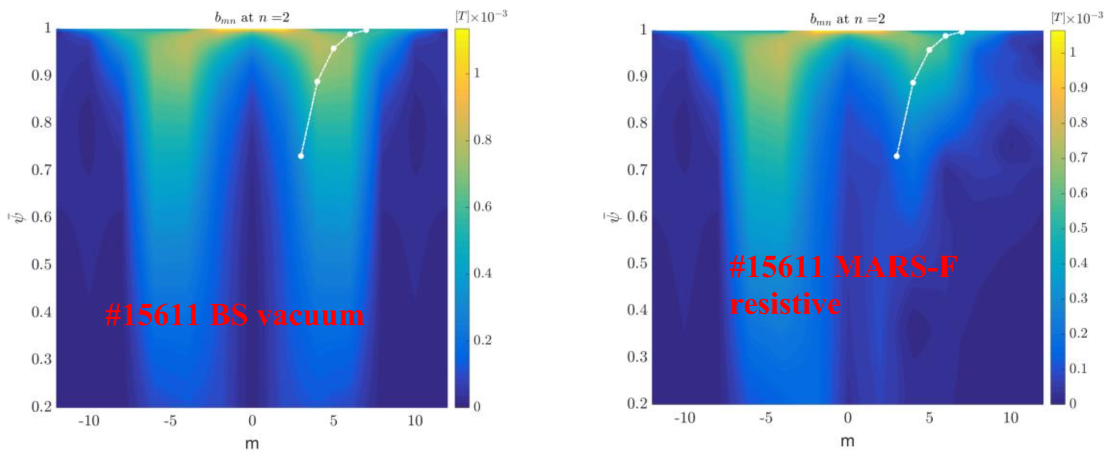
Exp #	RMP current	Ip [kA]	Bt [T]
15577	1.65 kA	300	1.15
15611	2.40 kA	300	1.27
15543	3.55 kA	230	1.15



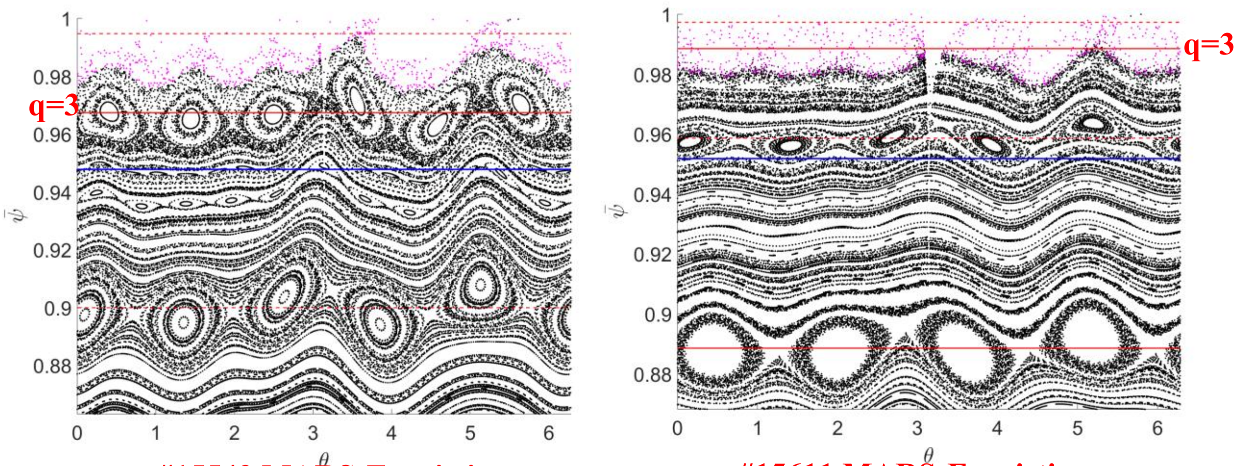


MARS-F code used to estimate the n=2 resistive response of the plasma

The solution obtained from the Biot-Savart solver is compared with a more elaborate solution that includes the plasma response to the perturbed field, calculated with the resistive MHD code MARS-F [4]. The plasma response results depend on the flow screening, the plasma resistivity, and the parallel sound wave damping. Out of the MARS-F code the resistive terms seem to induce a mere damping (~50%) of the vacuum solution.



The radial perturbation generated by the RMP coils is analysed through the Fourier transform of the plasma response (figure above) and we only consider the main harmonic n=2, neglecting the impact of further sidebands.

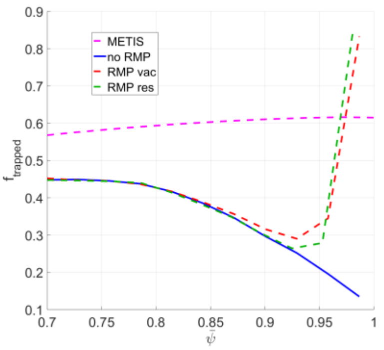


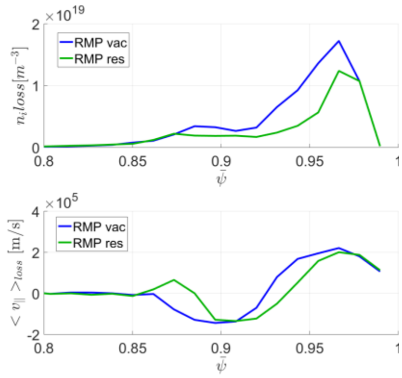
#15543 MARS-F resistive #15611 MARS-F resistive

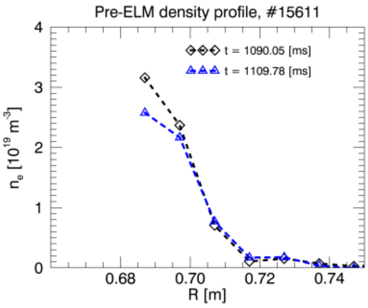
By evolving slow D ion markers along the field lines, we can trace the field in the poloidal plane. The figures compare the perturbed field as obtained from the resistive plasma response in the case of two pulses. It seems #**15543** does not resonate because @q=3, no stochastic losses (magenta dots) occur. In #**15611**, the q=3 flux surface is in the same location as the pedestal, thus allowing for the coils to affect the MHD through significant losses.

Changes in radial profiles of bulk Deuterium due to additional losses

The RMP coils trigger an increase in the losses that we can correlate with a change in the distribution function of the bulk plasma.







The losses after 8ms of simulation in EBdyna_go are shown above in the figures (left and middle). On the experimental side, a drop of density at the top of the pedestal is measured (right plot). Furthermore, we find experimental evidence of a change in bulk plasma rotation through the decrease of the (1,1) mode frequency as estimated by the Mirnov coils.

Conclusion

HFS RMP experiments show the possibility of increasing the ELM frequency without any loss of performances. A resonance occurs when the rational surface q=3 is close to the pedestal region. In the case of these HFS RMP experiments, the only specific feature of the plasma resistive response (with respect to the vacuum solution) seems that it lowers the amplitude of the perturbed radial field. The particle simulations do not show a significant qualitative difference between resistive and vacuum response, except in the loss pattern that induces velocity shearing at a more outward radial location in the resistive case. No clear evidence in the modelling of the effect of the plasma response could be found that explains the specific resonance of #**15611** compared with higher or lower safety factor values.

This work has demonstrated the possibility to combine the output of a complete MHD solution for the magnetic field from the MARS-F code with a 3D orbit-following code such as EBdyna-go. Further applications include the study of the redistribution of fast particles by RMP coils.

[1] - Jaulmes F., Westerhof E. and de Blank H.J. 2014 *Nucl. Fusion* **54** 104013

[2] - Markovic T. et al 2016 *Nucl. Fusion* **56** 092010

[3] - Artaud J.F. et al. 2010 *Nucl. Fusion* **50**, 043001

[4] – Liu Y., et al. 2000 *Phys. Plasmas* **7**, 3681

[5] - A.J.C. Beliën et al. *Journal of Comp. Phys.* **182**, 91