Conceptual design of a system of RMP coils for the TCABR tokamak

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Motivation

The high confinement mode (H-mode) in tokamak plasmas is seen as a promising regime for fusion power plants. A characteristic of H-mode plasmas is the onset of periodic instabilities known as edge localised modes (ELMs). ELMs generate very large heat fluxes on the divertor plates (order of 100MW/m^2 in ITER), eroding the divertor. Experiments showed that the application of non-axissymetric resonant magnetic perturbations (RMPs) can be used to control ELMs. Although the RMP coils have been successfully used to suppress ELMs, the modelling of these discharges reveals that current physical models do not describe precisely the observed effects. To enhance the numerical results reliability, designed experiments to validate physical models are being performed in several tokamaks. In Brazil, an upgrade of the TCABR tokamak, operated at the Institute of Physics of the University of São Paulo, is in progress. In this upgrade, it is planned the installation of six arrays of 18 RMP coils, enabling the TCABR to test and validate physical models used to predict the plasma response to RMP fields. This work has the objective of designing the future TCABR RMP coil sets.

1 Computational tools

The TCABR H-mode plasma scenario used to design RMP coils was generated by the Plasma Scenario Design (PSD) code, developed by the TCABR team. The PSD code calculates the plasma equilibrium through Grad-Shafranov equation, including kinetic and neoclassical effects. With the scenario, the RMP coils design was developed through a visco-resistive, two-fluid MHD code called M3D-C^1. In this work, the M3D-C^1 linearised version was used, where the plasma is modelled as vacuum and single fluid and the equations were linearised around the equilibrium:

$$\frac{\partial n}{\partial t} + \nabla\cdot(n\boldsymbol{u}) = 0,$$

$$nm_i\left(\frac{\partial \boldsymbol{u}}{\partial t} + \boldsymbol{u}\cdot\nabla\boldsymbol{u}\right) = \boldsymbol{J}\times\boldsymbol{B} - \nabla p - \nabla\cdot\boldsymbol{\Pi},$$

$$\frac{\partial p}{\partial t} + \boldsymbol{u}\cdot\nabla p + \Gamma p\nabla\cdot\boldsymbol{u} = (\Gamma-1)\left[\eta J^2 - \nabla\cdot\boldsymbol{q} - \boldsymbol{\Pi}:\nabla\boldsymbol{u}\right]$$

$$\boldsymbol{\nabla}\times\boldsymbol{B} = \mu_0\boldsymbol{J}, \qquad \boldsymbol{\nabla}\times\boldsymbol{E} = -\frac{\partial \boldsymbol{B}}{\partial t}, \qquad \boldsymbol{E} + \boldsymbol{u}\times\boldsymbol{B} = \eta\boldsymbol{J}$$

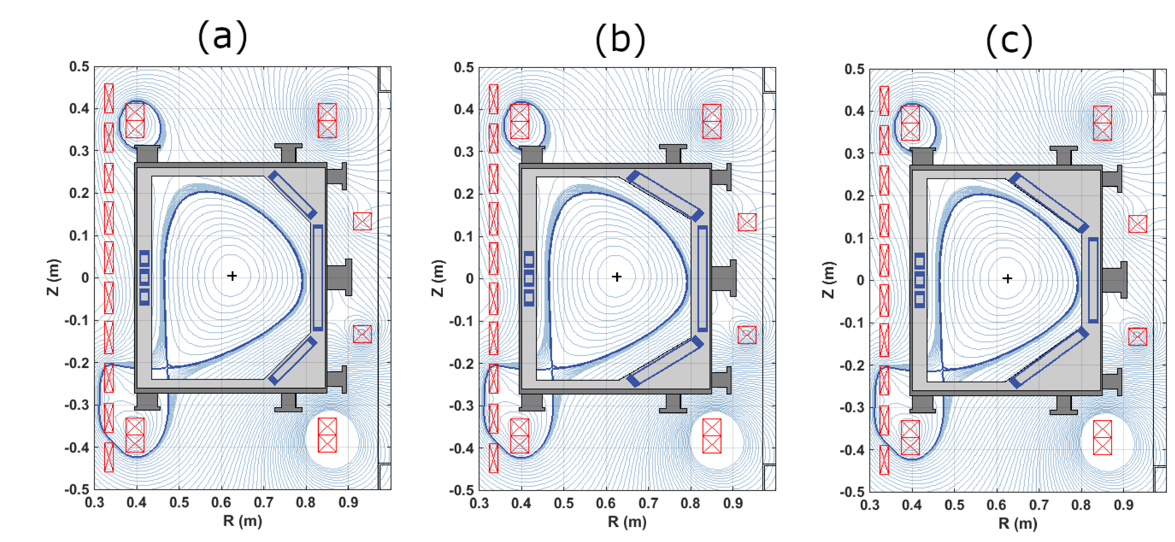
2 Physical criteria

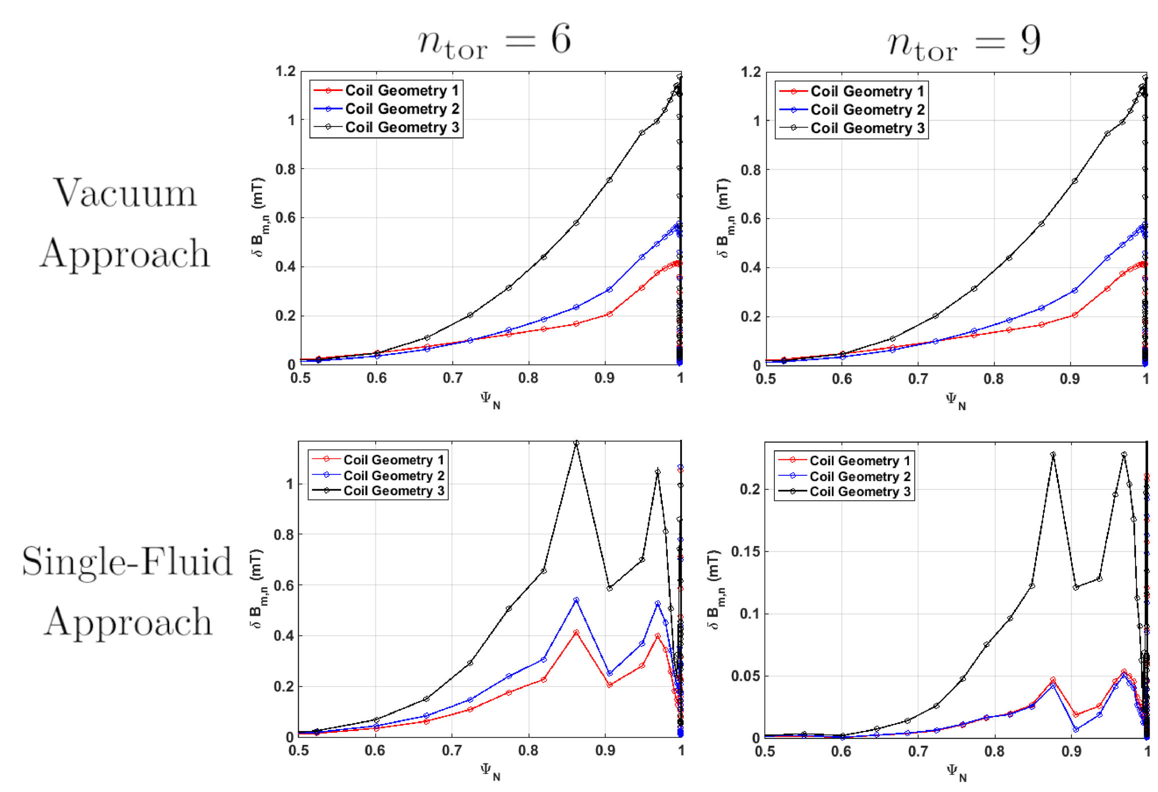
The RMP coils design was done through a set of empirical physical criteria:

- Perturbation criterium: At $\psi_N = 0.95$, $\frac{\delta B_{m,n}}{B_0} \geq 1\times10^{-4}$, where $\delta B_{m,n}$ is the magnitude of the Fourier decomposed RMP field perpendicular to the flux surfaces;
- The Chirikov criterium: $\sigma_{\text{Chir}} = \frac{\Delta\psi_{m,n}+\Delta\psi_{m+1,n}}{2(\psi_{m+1,n}-\psi_{m,n})} > 1$, where $\Delta\psi_{m,n}$ is the width (in ψ_N units) of a magnetic island on the rational surface $q(\psi_N) = m/n$.
- The VIOW criterium: $\Delta_{\text{VIOW}} > \Delta_{\psi_N} = 0.08$, where Δ_{VIOW} is the vaccum island overlap width.

3 I-coils design

The set of RMP coils that will be installed on the low field side (LFS) is called I-coils. This set is composed of 3 arrays of 18 coils each. Firstly, a geometry design study was performed in 2 RMP configurations (n_{tor}), where 3 designs were proposed:





The results shows coil geometry 3 (shown in figure (c)) is the optimal by a factor of 2, at least. Then, a coil current optimisation was studied, where the coil current is modelled as: $I_{\text{coil}}(t) = I_{\text{RMP}}(t)\cos[n_{\text{tor}}\phi + \phi_0(t)]$. For $n_{\text{tor}} = 6, 9$ and $I_{\text{RMP}} = 24$ kA-t, a scan ϕ_0 values for upper and lower array I-coils was carried. It was found that, $\phi_0 = 270°$ was the optimal for both arrays, where all physical criteria were satisfied.

4 CP-coils design

The set of RMP coils that will be installed on the high field side (HFS) is called CP-coils. This set is composed of 3 arrays of 18 coils each. A coil current optimisation was studied in the same way as for I-coils ($n_{\text{tor}} = 6, 9$ and $I_{\text{RMP}} = 60$ kA-t), where a ϕ_0 scan for the upper and lower array CP coils was carried.

For $n_{\text{tor}} = 6$, the optimal ϕ_0 for the upper array is 270°, while for the lower array is $-270°$. All physical criteria were satisfied. For $n_{\text{tor}} = 9$, the optimal ϕ_0 for both arrays is 0°. However, no physical criteria were satisfied. A geometry design was also carried, but no further optimisation was found in both n_{tor} configuration.

5 Conclusions

The design of RMP coils for TCABR was developed. For I-coils, a geometry design and coil current optimisation were done and the optimal configuration satisfied the physical criteria. However, for the CP-coils, after the coil current optimisation and geometry design, only $n_{\text{tor}} = 6$ satisfied the physical criteria.

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