Studies of Resistive Wall Mode stability in multi-parametric space using Grid infrastructure

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Introduction

Stability and control of Resistive Wall Modes (RWM) are important issues for the fusion plasma research. Growing on time scale of the magnetic field penetration through the resistive wall facing the plasma RWM is seen in different fusion devices. It sets the maximum pressure value in the steady-state tokamak operational scenarios [1] and limits the discharge duration of the Reversed Field Pinch (RFP) [2]. RWM is predicted to be unstable in ITER advanced scenario and hence has an impact on the efficiency of future fusion reactors. The performance of the fusion devices is improved when the RWM growth is controlled (either applying the external magnetic field or relying on the passive stabilization due to the mode interaction with stable plasma modes or plasma particles). The plasma pressure above no-wall limit is achieved in tokamaks [3] and the discharge time is substantially increased in RFP [4].

The RWM stability depends on several parameters describing the plasma configuration, the resistive wall and the control system. Therefore the RWM related studies should be performed in multi-parametric space. Numerical studies are usually required in order to obtain reliable results for the realistic configurations. Such studies are often become time consuming and demanding on computational resources. This work describes a numerical tool developed for the efficient studies of RWM stability in multi-parametric space. The tool is a combination of full MHD code MARS-F [5] and interface to the GRID net [6]. Application of the developed tool to the RWM stability studies for ITER advanced scenario is shown.

General Scheme and Implementation.

In this work the RWM eigenvalue behavior is studied numerically in the multi-parametric space. Three parameters are chosen to define the axes of the parameter space: the plasma pressure characterized by the normalized beta β_N (defined as $\beta_N \equiv \beta(\%)a(m)B_0(T)/I_p(MA)$), the toroidal plasma rotation frequency Ω and the feedback gain G_0. First two parameters determine (in general) the value of the RWM eigenvalue without effect of external sources. Third parameter characterizes the external active control system used to suppress the RWM growth. As a result of the studies the dependence $\gamma(\Omega,\beta_N,G_0)$ is desirable. The most straightforward way to obtain the dependence is to perform serial calculations on one computational node changing the value of one parameter at a time manually and obtain one point of the parametric space after each step. Such method is not very efficient as it requires long computation sequence to obtain the final result. In this work other more efficient method is used utilizing the possibility to change the values along particular parameter axis *independently* of the other parameters. Such feature allows (using the resources of the Grid net) effective parallelization of the calculations and therefore substantial decrease of the calculation time and simplification of the computation process. The Grid resources are used to perform simultaneous computations along one axis of the parameter space. The computations are performed on several computational nodes (included in the Grid net). The distribution of the parallel jobs is managed by the interface between the front node and computational nodes. In this particular work the 'parallelization' scheme is realized for two parameters: the plasma pressure (β_N) and the plasma rotation frequency (Ω). This means that β_N-Ω plane is covered for one value of the feedback gain G_0. Note that the scheme optimization for all three parameters can be done. The workflow is developed in Kepler environment that allows graphical representation of the workflow and management of the computation process.

Results

Numerical studies of the RWM stability are performed using the model parameters corresponding to the recent design of the ITER steady-state scenario [7]. The reference case is characterized by the toroidal beta value of $\beta = 2.49\%$ at $a = 2m$, $B_0 = 5.3T$, $I_p = 9MA$, resulting in $\beta_N = 2.93$ and a bootstrap fraction of 53% over the total plasma current. Plasma equilibrium is modeled using equilibrium solver CHEASE [8]. Radial profiles of the safety factor, the equilibrium plasma pressure and the plasma rotation frequency are shown in Fig.1. The RWM eigenvalue is calculated using the full MHD code MARS-F [5] including the model of the uniform resistive wall and the active control system. The active coils are modeled using the data for the ITER ELM

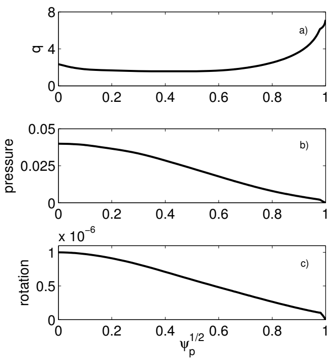


Fig.1. Equilibrium profiles as a functions of the normalized poloidal flux. a) safety factor; b) plasma pressure normalized by B_0^2/μ_0, c) plasma rotation frequency normalized by the Alfvén frequency.

in-vessel coils. The radial point-wise field measured at the radial position of the active coils is used as a sensor signal. Current control feedback scheme is assumed with the gain $K=-MG_0$, where M is the mutual inductance between the active coil and the sensor (calculated by MARS-F to be $M=0.089$ for the present model).

The dependence of the RWM eigenvalue on the given parameter (i.e along one parameter axis) is obtained as a first step of the studies. The results are shown in Fig. 2 where the RWM growth rate $\gamma\tau_w$ normalized by the wall time is plotted as a function of the above parameters. The dependence on the plasma pressure is calculated for the zero plasma rotation ($\Omega=0$) and absence of the feedback ($G_0=0$). The RWM growth rate is plotted as a function of the parameter C_β that is defined as $C_\beta=(\beta_N-\beta_N^{n.w})/(\beta_N^{id.w}-\beta_N^{n.w})$ where $\beta_N^{n.w.}$ and $\beta_N^{id.w.}$ determine the RWM stability boundaries without the wall and with the ideal wall at the position of the resistive wall respectively. RWM is unstable in the range $C_\beta=0...1$. The effect of the plasma rotation is studied for the reference scenario case ($\beta_N=2.93$) and again without the feedback control. The stabilization effect seen for $\Omega/\omega_a^0>10^{-4}$ is due to the ion Landau damping of the parallel sound wave modeled in this work by the parallel viscous force [9]. The dependence $\gamma(G_0)$ is obtained for $\beta_N=3.25$ ($C_\beta\approx0.7$) without the plasma rotation ($\Omega=0$). No complete stabilization is seen, due to the fact that the radial sensor is used in the feedback system configuration in this work. It was shown [10] that the feedback effect for the tokamak configuration is sufficiently reduced when using the radial sensor, compared to the case when the poloidal sensor is used.

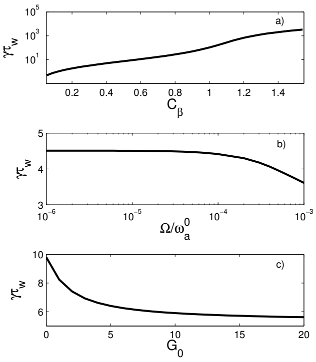
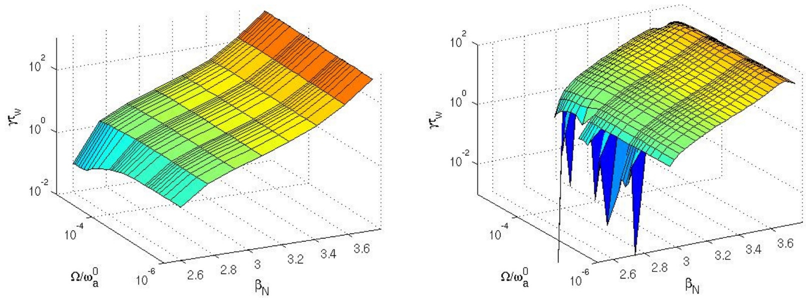


Fig. 2. Dependence of RWM growth rate along one axis of the parameter space: a) dependence on plasma pressure; b) dependence on plasma rotation; c) dependence on feedback gain. Plasma rotation frequency is normalized to the Alfvén frequency value at the plasma center.

It is seen that RWM is unstable over the range of the selected parameters. In order to judge on the RWM behavior across the parameter-space formed by the above parameters and to predict possible favorable parameter space points (in terms of RWM stability) for the future ITER operation the wide parameter space should be studied. Such studies require large computational resources (realistic plasma conditions) and computational time (large set of parameters). In this work such studies are performed using the resources of the GRID net and adopting the scheme described in the previous section. The results of the studies are shown in Fig. 3 where the RWM growth rate is plotted as a function of β_N and Ω simultaneously.

The dependence is shown for two values of the feedback gain: $G_0=0$ (Fig. 3a) and $G_0=10$ (Fig. 3b). It can be seen that without feedback RWM is unstable for the whole range of chosen parameters even in the presence of the plasma rotation.



a) b)

Fig.3. RWM growth rate dependence on β_N and Ω for two values of the feedback gain: a) $G_0=0$; b)$G_0=10$

The growth rate is decreased (i.e. mode is suppressed) when the feedback is turned on. It is seen that the mode is completely stabilized for $\beta_N<3.0$. The plasma rotation (in chosen range) does not affect sufficiently the growth rate behavior. Based on the results obtained during these studies it can be concluded that in order to assure the favorable stability conditions for RWM for the chosen configuration normalized beta should be quit low for any value of the plasma rotation frequency in the chosen range. In fact the reference scenario for the steady-state ITER operation fulfills this requirement.

References

[1] Garofalo A M *et al* 1999 Phys. Rev. Lett. **82** 3811

[2] Brunsell P R *et al* 2003 Phys. Plasmas **10** 3823

[3] Strait E J *et al* 2004 Phys. Plasmas **11** 2505

[4] Brunsell P R *et al* 2004 Phys. Rev. Lett. **93** 225001

[5] Liu Y Q *et al* 2000 Phys. Plasmas **7** 3681

[6] http://www.egi.eu/ and http://grid.bifi.unizar.es/egee/fusion-vo/

[7] Casper T and Polevoi A 2009 ITER documentation number 2V3FDF

[8] Lütjens H *et al* 1996 Comput. Phys. Commun. **97** 219

[9] Chu M S *et al* 1995 Phys. Plasmas **2** 2236

[10] Bondeson A *et al* 2002 Nucl. Fusion **42** 768