Recent studies in support to MHD stability and control on JT-60SA

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Introduction MHD stability is one of the most important performance limiting factors in modern fusion devices. This will be also the case of operations in JT-60SA [1], the large fully superconducting tokamak device, presently under construction as part of the Broader Approach agreement between Europe and Japan, and under the Japanese national program (see also Figure 1). JT-60SA mission is to develop plasma scenarios relevant to support ITER operations and to finalize the design of DEMO [2]. To this purpose, the JT-60SA Research Program document [3] has been extended in 2011 as collaboration between Japanese and European scientific communities. This paper summarizes the main new contributions in the field of MHD, highlighting MHD stability issues and studies on MHD active control tools. The paper is organized in four sections: Neoclassical Tearing Modes (NTMs), Resistive Wall Modes (RWMs), Sawteeth (ST), and disruptions. In the discussion special attention is paid to the different phases presently envisaged for machine operation where different plasma scenarios and actuator capabilities naturally evolving in time should be taken into account. Other complementary studies on JT-60SA physics are presented at this conference [4-6].

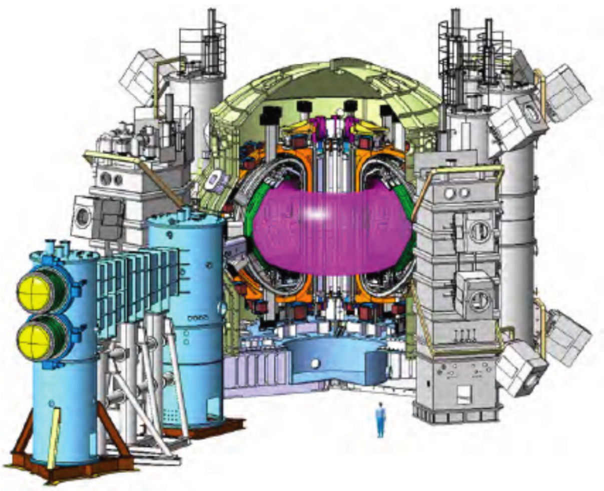

Figure 1: The JT-60SA device.

Neoclassical Tearing Modes (NTMs) NTMs instabilities are frequently excited in high β_N plasmas. They can either cause moderate confinement degradation, as is the case of the *m/n*=3/2, or they can lead to full plasma disruptions, as it is often the case of the more dangerous *m/n*=2/1 mode.

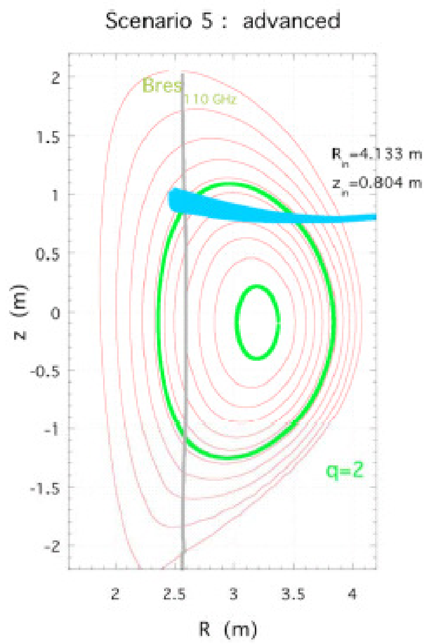

Figure 2: Equilibrium representative of scenario 5 plasmas: green contours correspond to q=2 surfaces and blue traces to beam tracing.

The main tool for NTM control in JT-60SA will be a double-frequency (110 GHz and 138 GHz) electron cyclotron system, providing an injection power up to7 MW from 9 gyrotrons. The available ECH power will develop following a staged approach: this implies that during the first few years of operation (the so-called initial research phase) the main operational scenarios should be tested using a total of 3 MW ECH power. In order to study in advance the possibility of realizing and controlling some of the target scenarios with this reduced capabilities, EC power and driven current densities have been estimated by the ECWGB and GRAY beam tracing codes. Two cases representative of standard and advanced (scenario #2 and #5 respectively in ref. [3]) operational scenarios have been explored. In Fig. 2 equilibrium and beam trajectories (given by ECWGB code) are shown for the advanced scenario case. The stabilization of (2,1) and (3,2) NTMs has been studied as well by solving the Generalized Rutherford Equation. As result of this study, Fig. 3 summarizes the EC power needed to stabilize the most dangerous (2,1) mode for different values of driven EC current. These preliminary results show that, for advanced tokamak plasmas, 3 MW seem to be sufficient to control the possible instability of the 2/1 NTM. A more extensive presentation of these studies can be found in [7].

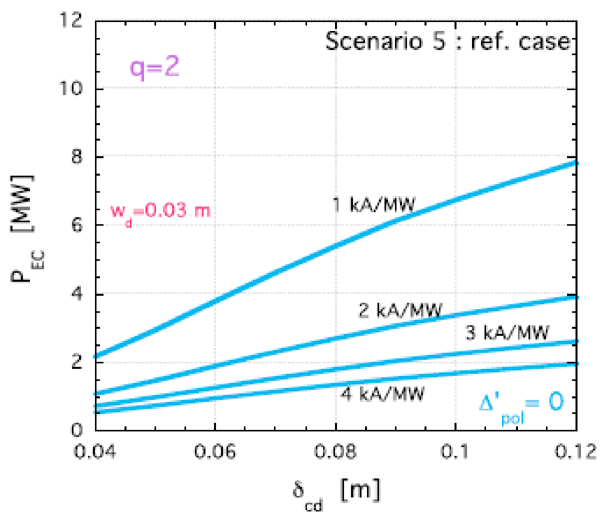

Figure 3: EC power needed to stabilize the 2/1 mode for 4 values of driven EC current and typical island threshold width, due to the perpendicular transport, w_d=0.03 m versus the full e^{-2} beam width δ_{cd}.

Resistive Wall Modes (RWMs) RWM instabilities are considered the utmost MHD limit to high β_N advanced tokamak operations. For this reason a careful evaluation of RWM stability thresholds, of the different stability terms and, finally, of the capabilities of the foreseen active control strategies is of paramount importance to properly establish the Research Plan of JT-60SA.

In Fig. 4 the main in-vessel systems for passive and active MHD control are presented. RWM stability will be mostly affected by the presence of a thick stabilizing plate and by a set of 3 (poloidally) x 6 (toroidally) active coils placed on the inner surface of the stabilizing plate. The Error Field Correction Coils system will instead provide an optimal correction of the main error field, avoiding in such a way the Resonant Field Amplification phenomenon. Due to the peculiar radial profiles of the main plasma parameters, advanced tokamak operations are the most affected by RWM instabilities. The joint Japanese-European efforts are then concentrating on plasma equilibria representative of scenario 5 (steady state, β_N=4.3) operations. As first step of this study, the no-wall limit has been evaluated by means of MARS-F code for modes with dominant n=1, 2, 3, i.e. for the first three most unstable RWMs: Fig. 5 shows the normalized growth rate of these ideal kink instabilities for different values of the β_N parameter. While the exact value of the limit can depend on several factors, such thermal and fast particle effects, not taken into account in the present estimate, one important result of the analysis is that to reach the target β_N value of the scenario, the feedback system should control a multiple unstable RWM structure.

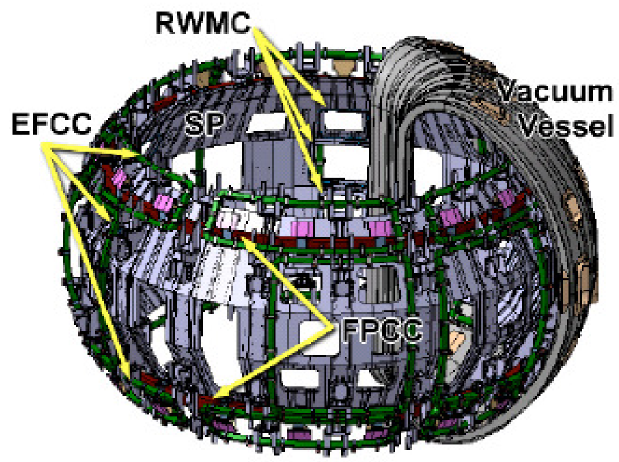

Figure 4: JT-60SA in-vessel tools for MHD stabilization: Stabilizing Plates (SPs) close to plasma, a couple of Fast Plasma Position control Coils (FPPCs), 18 Error Field Correction Coils (EFCCs) and 18 Resistive Wall Mode Coils (RWMCs).

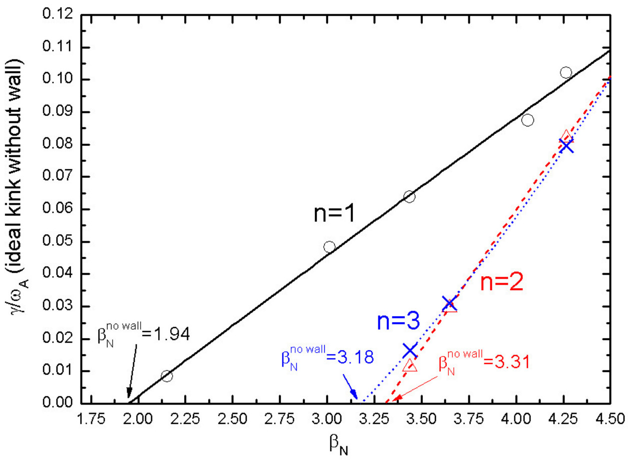

Figure 5: Preliminary estimate of no-wall limit for n=1, 2 and 3 modes.

Sawtooth oscillations Sawteeth are not expected in advanced tokamak operations aiming at assessing the feasibility of a high-beta, steady state DEMO; however, they will appear as an issue for ITER baseline scenario and strategies for their control could become relevant in a more conservative pulsed inductively-driven DEMO design. It is well known that large sawteeth (as the one expected in burning plasmas due to the stabilizing effect of fusion born α particles) can act as triggers for NTMs and cause in the end confinement degradation. JT60SA will be able to test whether sawtooth control through co-ECCD with a resonance inside q=1 can result in NTM avoidance at high plasma pressure. This has been demonstrated in H-mode plasmas in present-day devices, but not extended to plasmas with a very large fast ion beta. With its flexible NBI system, composed by 12 positive NB (E=85 keV, 20 MW total power) and 2 negative NB (E=500 keV, 10 MW total power), a demonstration of the effectiveness of ECCD in the presence of a significant population of core energetic ions is suggested.

Disruptions JT-60SA operations will be extremely important to establish reliable disruption mitigation and avoidance techniques in view of safe operations in ITER and fusion reactors. To control plasma position evolution during fast disruptions, JT-60SA has a passive stabilizing plate and FPPCs inside the vacuum vessel as shown in Fig. 4. In addition to that, several other systems such as massive gas injection, killer pellet, ECRF, RWMCs and EFCCs will be used as actuators when testing and comparing different disruption mitigation schemes. Collaborative studies between Japan and European experts recently started discussing the possible requirements of massive gas injection system. Disruption studies and establishment of disruption control should be done in Initial Research Phase that will be the most favourable in terms of radio activation level allowing an easier maintenance of in-vessel components.

Conclusions Several joint Japanese-European studies on MHD stability and control in JT-60SA are producing results with important implications for the careful definition of the device Research Plan. In particular MHD subjects relevant for the first years of operation are being reviewed with the aim of preparing reliable and safe operations for ITER and to allow an early definition of DEMO characteristics.

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