Motivations and perspectives of RFX-mod2, the challenge of the upgraded RFX-mod device

M. Spolaore, R. Cavazzana, L. Marrelli, S. Peruzzo, M.E. Puiatti, P.Zanca
and the RFX-mod team
Consorzio RFX (CNR, ENEA, INFN, Università di Padova, Acciaierie Venete SpA) Corso Stati Uniti 4 - 35127 Padova, Italy

Introduction In recent years the RFX-mod [1] device has been operated as a Reversed Field Pinch (RFP) and as a low-q Tokamak, and recently the H-mode has been achieved by electrode biasing in circular and Single Null configuration [2]. In both configurations the capability and flexibility of its active control system of MHD instabilities have been exploited to control RWMs and tearing mode wall locking (RFP) and to stabilize the m/n=2/1 mode to operate at q(a)≤2 (Tokamak). The dynamics of the tearing modes has been fully characterized experimentally, and simulated by the RFXLocking code [3]. At high plasma current (Ip≥1MA), RFP plasmas have been observed to self-organize into quasi single helicity (QSH) states, where a single m=1 modes dominates the spectrum of all the other secondary modes and magnetic chaos is reduced. In particular, in QSH up to the SHAx states, where the main magnetic axis becomes the helical axis of the dominant mode [4], the best plasma performance is observed at the lowest amplitude of the secondary modes.

Since secondary modes are crucial to obtain the best performance in helical states and also affect plasma-wall interaction, the beneficial effect expected from reducing their amplitude and increasing their dynamics, motivated a modification of the device load assembly. With the perspective of an improvement in the RFP confinement of at least by a factor ≈35%, with the plasma moving closer to the conductive shell, and an increase for tearing mode locking plasma current threshold from ≈120 kA to ≈400-600 kA, the two future main goals of RFX-mod2, the upgrade of the RFX-mod experiment, are then designed: improvement of the RFP confinement and knowledge expansion on a broad spectrum of plasma physics in regimes otherwise not accessible on other devices.

Physics basis for the RFX-mod2 experiment The mayor limitation of the present setup of RFX-mod device is constituted by the distance of the passive shell from the plasma. As a consequence the possibility of Tearing Modes (TM) effective reduction through the feedback magnetic boundary control is limited. A further aspect is related to the low plasma current threshold, about 120 kA, for the TM locking with consequences in the plasma wall interaction issues.

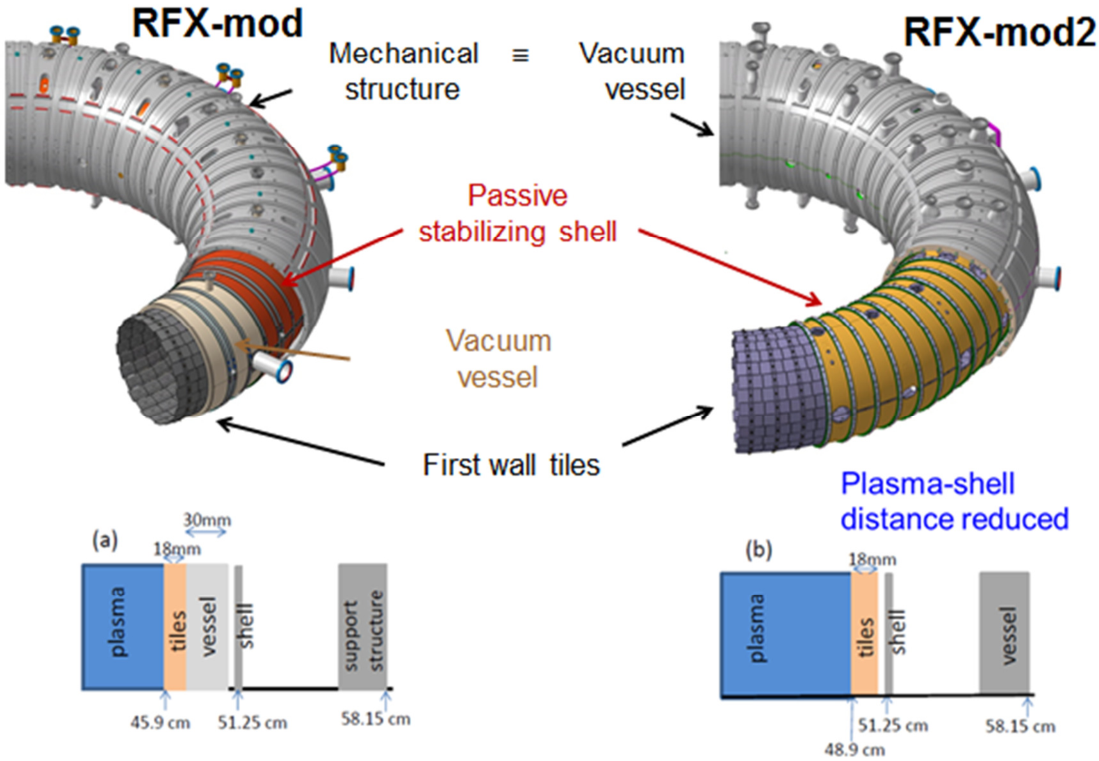

Figure1 Scheme of the actual RFX-mod setup compared with the new design of the RFX-mod2.

The dynamics of Tearing Modes under feedback control has been modeled by the RFXlocking code and verified experimentally. Assuming a given core Tearing Mode spectrum and for a given a passive boundary geometry [3] a minimum edge mode amplitude exists [5]. The value of this minimum is tightly related to the first continuous wall conductivity and its distance from the plasma. The wall conductivity also governs the TM wall locking and is not characterized by hysteresis under feedback control [6]. It is worth noting that low values of secondary tearing modes are associated to wider internal transport barriers, as suggested by the experiment, and a transition from narrow to wide barriers is interpreted in terms of reduced island overlap in the helical geometry [7].

According to these premises a key ingredient of the design of the upgrade of the RFX-mod device (RFX-mod2) to achieve the first goal is the enhancement of the plasma-shell proximity, which is expected to provide a significant reduction of the amplitude of RFP tearing modes [5]. This amplitude reduction will lead to the positive cascade effects of magnetic chaos mitigation with confinement improvement, reduced plasma wall interaction and better mode control capability.

The RFX-mod2 device is presently in its final design stage, in figure 1 is compared with the former RFX-mod. The bottom panels of figure show schematically the increased plasma minor radius, a, for RFX-mod2 from 0.459 m to 0.489 m, while the conductive shell radius, b, is kept at the same radial position b=0.512 m. The new RFX-mod2 device (R=2.0 m, a=0.490 m, b=0.512 m) design then foresees a total reduction of the b/a ratio from 1.15 to 1.04 [6]. In the top panels of figure 1 the structure of RFX-mod and RFX-mod2 are compared. The goal of increasing the minor radius is achieved basically by removing the former inner Inconel vacuum vessel while the mechanical structure will be suitably modified in order to play also the role of the new vacuum vessel. In this way, the conductive shell will approach the plasma.

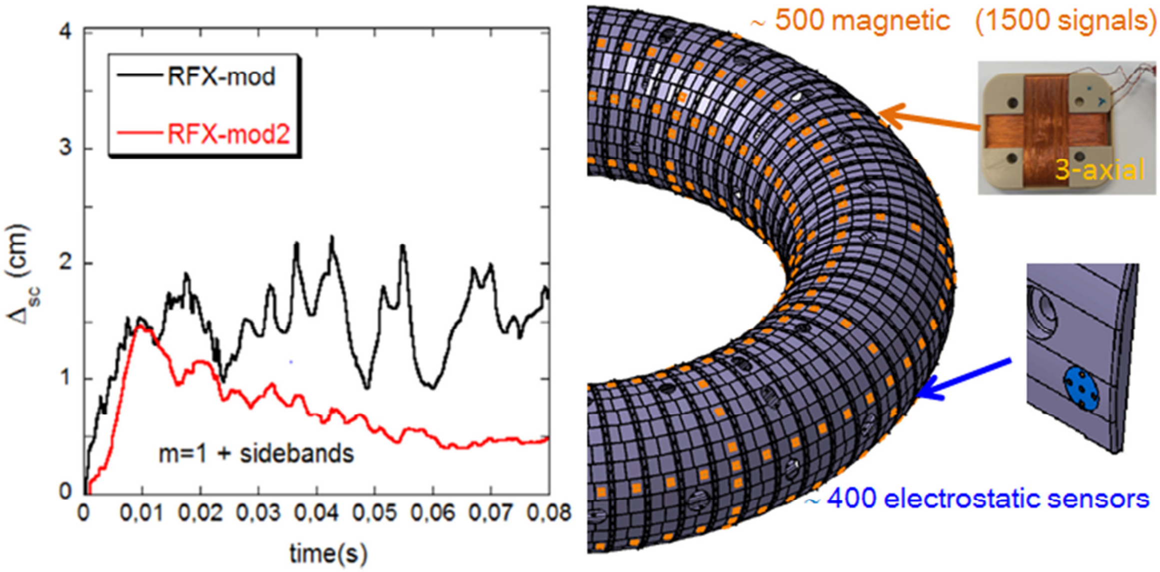

Figure 2 Left panel: Simulation of the deformation of the Last Closed Flux Surface (LCFS), with the vacuum vessel removed (red) and in present RFX-mod configuration (black). Right panel: In-Vessel sensor ongoing design update for RFX-mod2.

According to RFXLocking simulations the deformation related to m=1 modes, where m is the poloidal number, will decrease by a factor ≈35%. A representative result is shown in the left panel of figure 2. The figure shows the deformation of the Last Closed Flux Surface accounted for the m=1 TM, in the present RFX-mod setup and the clear reduction expected with the improved design for RFX-mod2. In spite of the expected reduction of magnetic chaos and of edge magnetic deformation, an accurate control and monitoring of the edge boundary region remains a crucial point to improve the performance. To this end an extended and improved diagnostic setup is designed. As a matter of example in the right side of figure 2 a schematic summary of the foreseen in-vessel sensors is shown. In particular a distributed set of sensors on the whole toroidal first wall will be installed, including about 1500 magnetic fluctuation coils, arranged in 3-axial sensors and about 400 electrostatic sensors.

Challenges and R&D activities The new design raised two critical issues. The first one is the presence of an electrical insulating vacuum-tight triple joint on the support structure: the developed solution uses standard Viton O-rings, custom PEEK gaskets and G10 fiberglass spacers, and has been successfully tested on a dedicated mock-up [8]. The other involves the electric fields induced in between the plasma facing graphite tiles, at the gap on the copper shell and between the copper shell. The latter issue has been addressed by keeping all the first wall graphite tiles at the same electrostatic potential by means of a continuous conductive frame, and by placing insulation material at the gap and by conditioning the involved components by means of limited current arc discharges in presence of background plasma [9]. A number of corollary modifications aimed at widening the RFX-mod2 operational space are planned. In particular they aim at improving the density control, magnetic field topology control and diagnostic capability, in the three different magnetic configurations in which RFX-mod2 is expected to operate: 100 kA - 2 MA RFP, 40 - 180 kA tokamak, 20 - 800 kA Ultra –low-q.

Conclusions Based on the RFX-mod results, in order to extend the explored operational scenarios, the device upgrade RFX-mod2 will be implemented. The motivations can be summarized as follows: (i) Reduction of residual magnetic chaos and achievement of more robust helical states by means of a different magnetic front-end with increased plasma-shell proximity; (ii) Improvement of density control and extension of high density regimes by means of plasma-facing components optimization; (iii) Easier transition to H-mode in tokamak configuration by means of a better control of plasma shape through an increased number of poloidal sensors and of the installation of a 1 MW NBI; (iv) More effective characterization of both RFP and tokamak plasmas with innovative or improved diagnostic systems.

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