OPTIMIZATION OF THE RFX-MOD EXPERIMENT FOR 2MA OPERATION

L. Zanotto, R. Cavazzana, L. Novello, S. Dal Bello, G. Marchiori, A. Soppelsa, A. Zamengo and the RFX-mod team

Consorzio RFX, Associazione Euratom-ENEA sulla fusione, Padova, Italy

1. Introduction. The RFX-mod Reversed Field Pinch [1] is producing shots with plasma current higher than 1.5MA, showing enhanced confinement properties related to the occurrence of the Single Helical Axial (SHAx) state [2]. The flexibility of the machine has allowed the exploration of various start-up scenarios for high current operation, in order to select the most efficient way to exploit the available magnetic flux and therefore to reach the highest plasma current. It turned out [3] that a ”ramped” start-up, i.e. a start-up with low bias toroidal field and quick reversal, was the most effective scheme to maximize the plasma current, as opposed to the ”matched” one, where the bias toroidal field is higher. In the ramped start-up, the toroidal flux is mostly built at the expense of the poloidal flux, through the plasma coupling, resulting in a reduced energy available to build the plasma current. Therefore, best RFX-mod shots at full poloidal flux consumption capability (15 Vs) and in standard first wall condition do not exceed 1.8MA, below the machine design point (2MA). An optimisation of the start-up phase was carried out in the past [3] to achieve higher plasma currents. It was shown that, within some limits, the transfer of poloidal energy to the plasma is more efficient with higher transfer resistors, i.e. with faster ramp up of the plasma current. Further optimisation of the start-up is achievable; however it seems unlikely that they can lead to a reliable and reproducible 2MA discharge. For this reason, while further investigations on the start-up are performed, an alternative scenario for high current operation in RFX-mod has been set up, that allows reaching 2MA. The paper will present the new scenario and the first results obtained, together with the control tools prepared to operate the machine reliably in this framework, such as the feedback control of the plasma current and of the reversal parameter.

2. Scenario for 2MA operation. In RFX-mod the discharge is performed thanks to a modular system of ac/dc converters feeding the windings of the machine. The circuit

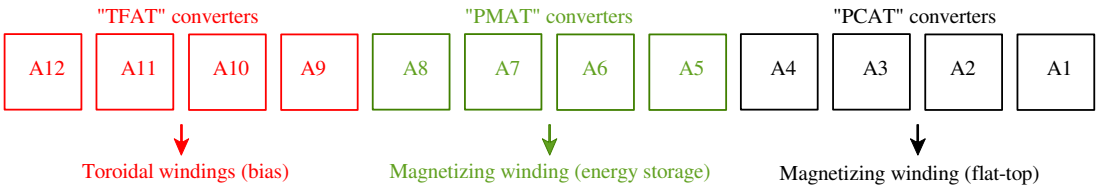

Fig.1. Arrangement of RFX-mod main ac/dc converters.

Fig.2. Arrangement of RFX-mod main ac/dc converters after the reconfiguration (same colour code as fig. 1).

is organized as depicted in fig. 1: four converters are devoted to the creation of the bias toroidal field (TFAT), four converters to the creation of the magnetizing winding current (PMAT), and other four converters for the application of the toroidal loop voltage during the flat-top (PCAT). The ramped start-up requires just a limited fraction of the total capability of the power supplies devoted to the creation of the bias toroidal field. On the contrary, additional power would be required to increase the available poloidal flux to build up the plasma current up to 2MA. The flexibility of the power supply system of RFX-mod allowed reconfiguring the circuit in order to fulfill these requirements. Given some machine constraints, the best choice for the reconfiguration is shown in fig. 2, where the capability of the flat-top converters has been strongly enhanced at the expense of the bias toroidal field converters. Thanks to the new capabilities, an alternative scenario to reach and sustain 2MA in two steps has been developed. First, the bulk of the current is obtained by exploiting the stored magnetizing flux, which is less than in the original setting-up, and then the desired current value is achieved with the application of an adequate loop voltage, taking advantage of the additional flat-top capability gained from the enhancement of the PCAT converters. Fig. 3 shows a simulation of the expected plasma current with this kind of start-up. A 2MA discharge with 100ms flat-top seems to be feasible. It can be noted that the desired plasma current is

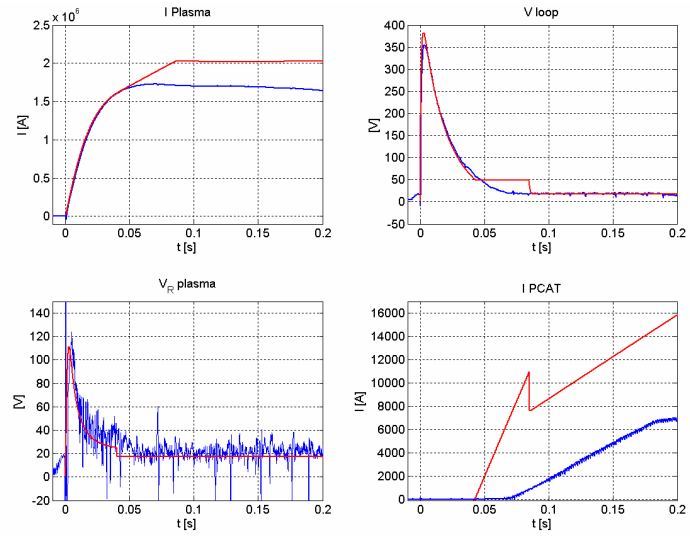

Fig.3. Simulation of 2MA scenario with current ramp-up (red), compared to a standard high current shot (blue).

obtained through a slower ramp-up, which is expected to be beneficial from the point of view of the control of the MHD instabilities, of the equilibrium and of the limitation of the error fields due to machine asymmetries.

3. Control tools for 2MA operation. The feedback control of global quantities, such as the plasma current and the reversal parameter F (defined as the ratio between the

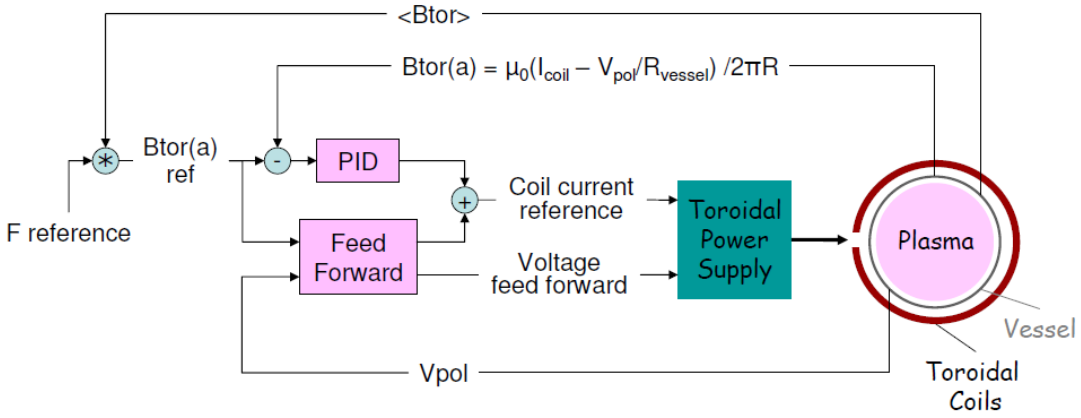

Fig.4. Scheme of the feedback control of the reversal parameter.

toroidal field at the wall and the average toroidal field across the poloidal section), is very important to operate reliably near the machine design limits and, in general, to help producing repeatable shots. In particular, since RFX-mod usually operates at shallow F (between -0.05 and 0), the feedback control of the reversal parameter is essential to avoid accidental loss of the RFP configuration due, for instance, to variations of the plasma current or density. In the new scenario for 2MA operation, the feedback control of F becomes even more important, as the plasma current ramp-up can affect the behaviour of the reversal parameter, which therefore is difficult to be pre-programmed. A feedback control of F has been implemented and tested in RFX-mod according to the scheme of fig. 4. First results of the F controller are very encouraging, as shown in fig. 5, where an example of plasma discharge with active feedback on F is shown. The reversal parameter follows very well the reference even in presence of plasma current variations. Concerning the feedback on the plasma current [4], its main purpose is to increase the possibility of having reproducible

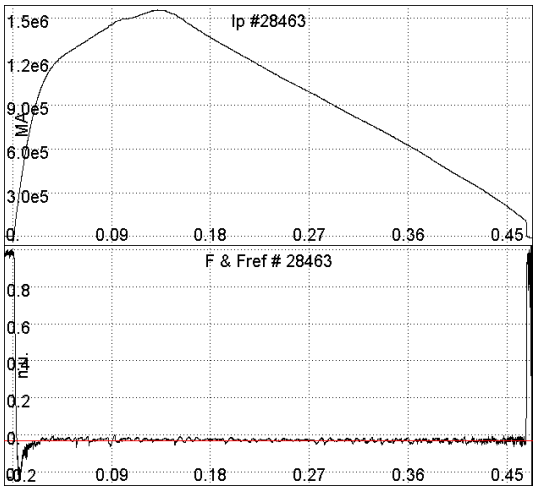

Fig.5. Shot#28463: first feedback control of F. Plasma current (above) and F (below, reference in red).

plasma pulses in presence of perturbative events which increase the plasma resistivity (e.g. pellet injection, variation of the reversal parameter, etc.); moreover, in the 2MA scenario, it can be used to design precisely the desired current ramp-up and flat-top. Basically, the controller acts in feedback on the plasma current by varying the applied toroidal loop voltage. A real time protection is set on the maximum ohmic power dissipated in the plasma, that switches off the power supply if a threshold is exceeded. This feature is particularly useful to operate safely, especially when attempting to reach 2MA.

4. First attempts of current ramp up. First discharges with the reconfigured power supply circuit have been produced in RFX-mod. To test the new circuit and the overall concept at low power, some shots have been performed between 36kA and 40kA of magnetizing current, out of a capability of 45kA. The applied loop voltage during the current ramp-up has been varied first in open loop, and then by using the plasma current controller, to obtain different ramp slopes. The results are shown in fig. 6.

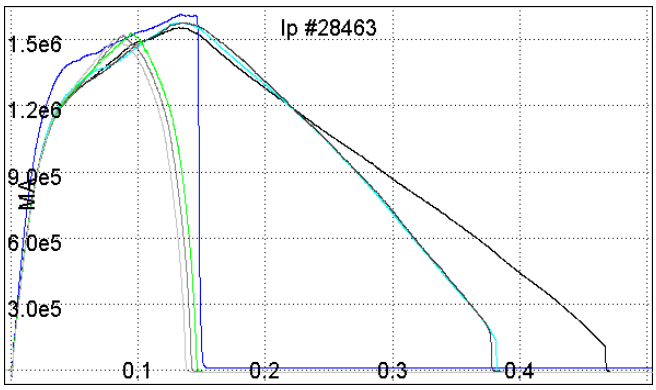

Fig.6. First discharges with reconfigured power supplies.

5. Conclusions. The operative scenario to reach 2MA in RFX-mod has been established and first results after the reconfiguration of the power supplies have been obtained. Although there is still room for optimisation, this new scenario can be used in the near future to achieve 2MA without further improvements in the start-up. The controllability and repeatability of the discharges, which are essential for such high current operations, will be guaranteed by means of the feedback control on the plasma current and on the reversal parameters, which has been successfully tested.

References

[1] Rostagni G., Fusion Engineering and Design, Volume 25, Number 4, 2 January 1995 , pp. 301-313(13)

[2] Lorenzini R. et al. Nat. Phys. 2009

[3] Zanotto L. et al., 36th EPS Conference on Plasma Phys. Sofia, June 29 - July 3, 2009 ECA Vol.33E, P-2.188 (2009)

[4] P. Fiorentin, E. Gaio, G. Marchiori, V. Toigo, Fusion Engineering and Design Volume 31, Issue 3, 1 August 1996, Pages 221-238