Active MHD control under different coil configurations in RFX-mod

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Several MHD control strategies in present and future experiments rely on active coils as actuators of open loop or feedback schemes. However, in any real device active coils are finite in dimension and number, and often cover only partially the outer surface of the plasma. Under such conditions the field produced necessary contains unwanted components that can be amplified by the plasma and seriously compromise the stabilization effect of the active system. In this case one can say that the *control mode* does not coincide with the *plasma mode*, meaning that their descriptions in terms of, e.g., Fourier 2D harmonics do not coincide. On the other hand, if the unstable modes behave as non-rigid objects, insufficient coil number or extension could make the control effort fruitless.

These issues are not new, but, given obvious limitations on changing active coil hardware on the same machine, many of existing studies can only compare the effect of different coil configurations on different machines. In the present paper we present a novel approach recently developed in the RFX-mod device: its 192 active coil system [1] can be now flexibly downgraded by the software control in number or space resolution. In this way it is possible for the first time to easily compare the action of many different coil configurations on the same machine and on the same plasma. What is even more important, the real time software can act only on a subset of selected modes with the reduced set of coils, while all the remaining field errors and MHD instabilities are controlled with full system capabilities. This is done in order to work with optimized background plasma and to decouple the problem of discharge optimization from the one of specific active MHD control as sketched in Fig.1. In RFX-mod the actuators are controlled by a digital full PID controller [2]. The controller elaborates the actuators waveforms according to the control scheme decided by the operator. Note that the control elaboration is normally done in the Fourier space ("mode control") and then the final current references for the 192 power amplifiers are calculated via an inverse Fourier transform.

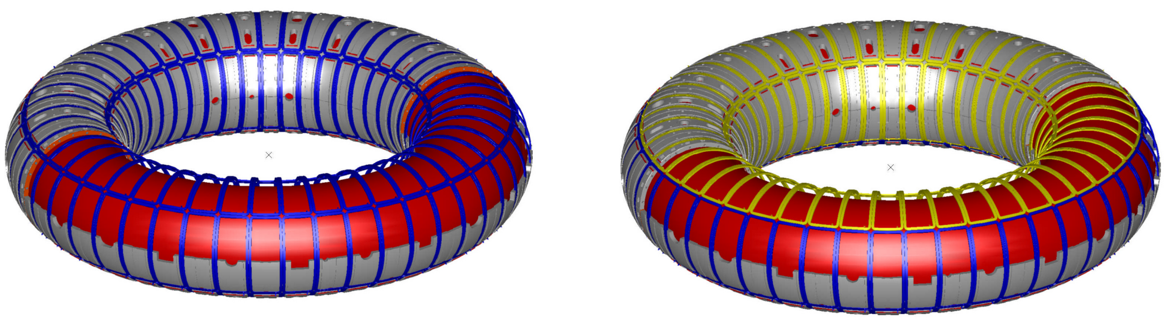

Figure 1: full control system (left) acts on the background plasma while, on the same discharge, a reduced set of coils (right) controls a selected RWM. Blue represent active coils, while yellow represents coils non active in the downgraded control part.

The new control capability is implemented by adding to each control cycle a further loop that separates in the Fourier space the harmonics that undergo a "standard" control from the ones that will be controlled by a "reconfigured" system. The second set of modal current references is converted in 192 real space current references and in this way it is very easy for example to zero some references in order to mimic a control system with a smaller number of actuators. The last step of the new control software is to sum back in the real space the "standard" and the "reconfigured" references and send the sum to each power supply. It is important to note that, thanks to the high optimization of the FFT and FFT^{-1} algorithms in the control software, the new loop did not affect the overall duty cycle time that remains below 0.5 ms. Figure 2 illustrates this procedure, while in figure 3 some examples of realized reconfigurations are shown together with the total surface covered by each configuration.

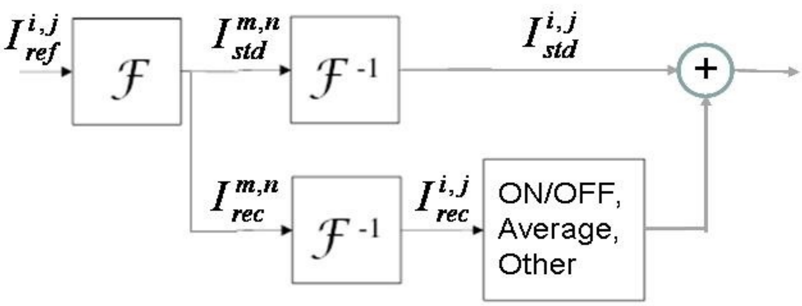

Figure 2: architecture of the software block for reconfiguration experiments.

The first set of experiments was carried out in vacuum to compare the harmonic content of different coil configurations trying to follow the same control request (in both open and closed loop). As expected, when the number of active coils is decreased, the Fourier spectrum of the system action is becoming less and less pure. Measurements are always performed by the full system of 48x4 saddle coil sensors located between the vacuum vessel and the shell.

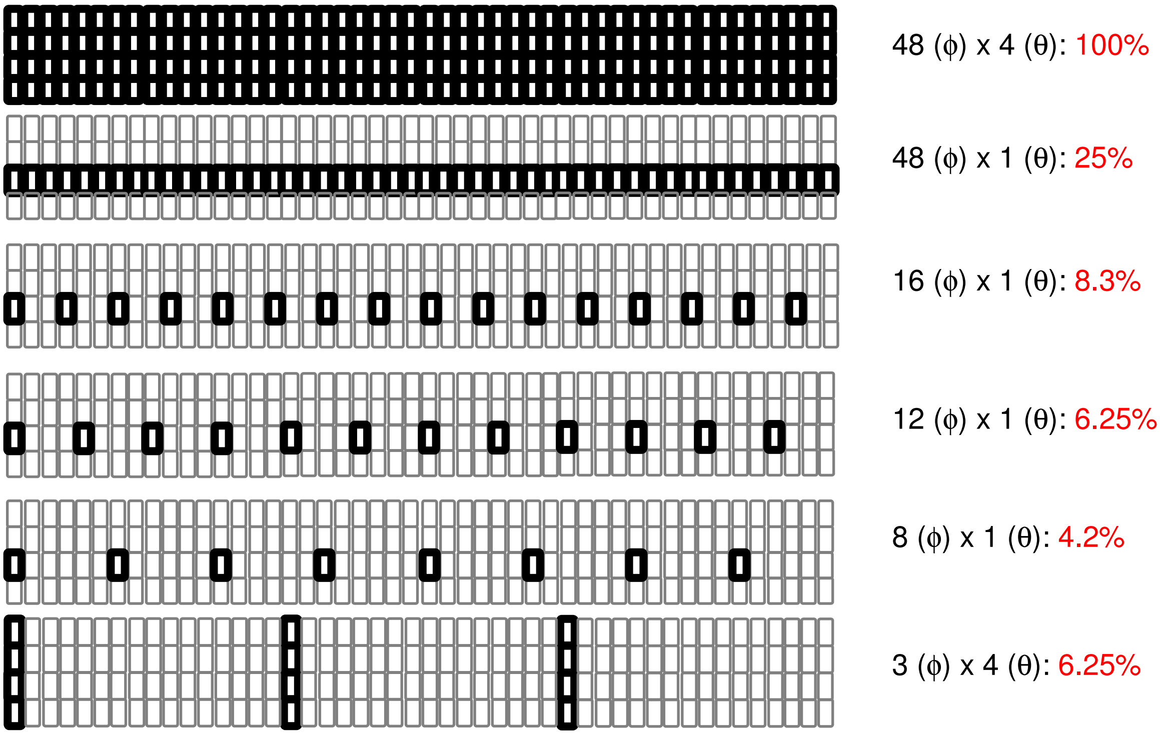

Figure 3: new control configurations made possible by the software algorithm. On the right hand side the number of toroidal times poloidal coils active is summarized together with the surface covered by active coils.

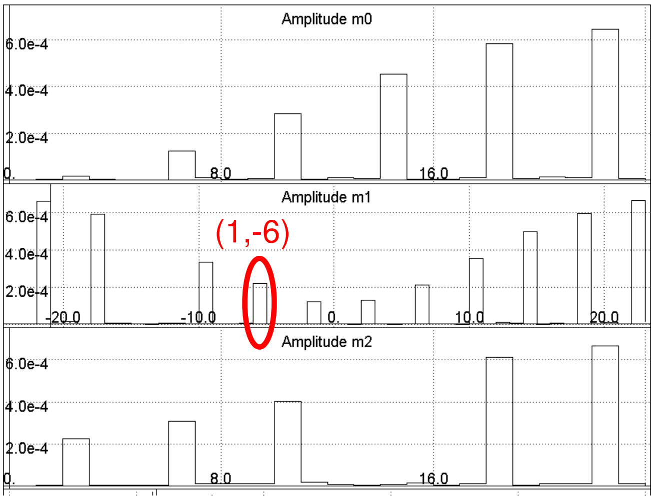

Figure 4: measured Br harmonics produced for a pure (1,-6) harmonic request in the 8x1 configuration

In figure 4 the measured field produced by a 8x1 configuration is shown; note that the requested waveform was a single, constant (1,-6) harmonics, while all the remaining measured components are due to the finite size of the coils and to the aliasing in space of the external field. These results can be compared to the ones routinely obtained with the full system where the high precision of the externally produced field is evident [3].

When feedback control is applied in plasma experiments, these effects have clear consequences in the control effectiveness. To test the control under reproducible conditions, it was decided to apply the reconfiguration algorithm to the control of one or more unstable Resistive Wall Modes (RWMs). We just recall that in Reversed Field Pinch plasmas, RWMs are mainly current driven instabilities and that their growth rate can be kept constant just by controlling the plasma flat top average configuration, providing in this way an excellent physics background for control optimization studies [4].

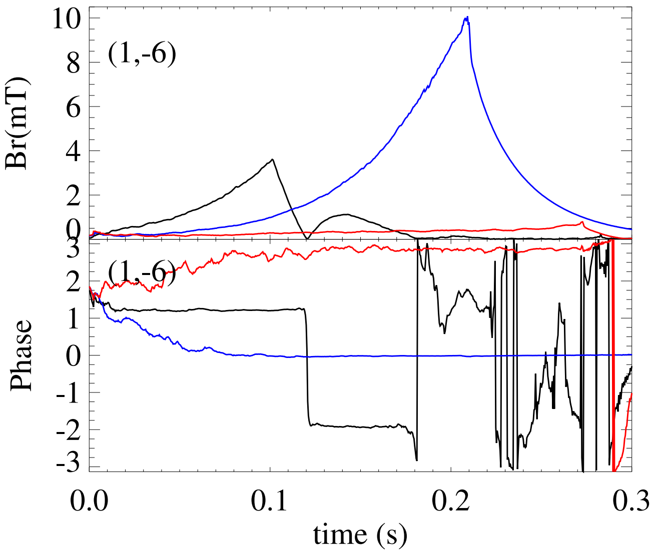

Figure 5: control experiments with full system (black, control on from 0.1s), and downgraded 12x1 (blue for evenly spaced coils and red for unevenly spaced ones).

Tests of single and multiple unstable RWM feedback control with reduced active coil coverage as shown in Fig. 3 were executed on RFX-mod. First results clearly indicate that unwanted sidebands can be very deleterious for MHD control. At the same time the effect of coil positioning proved to be essential under certain configurations for complete mode stabilization. In Fig.5 an example is shown for the 12x1 configuration where, due to the specific mode periodicities, evenly spaced coils were not able to stabilize the mode: in fact during the control the mode changed its phase in order to place amplitude nodes over the active control position (blue lines). Full control in this case was recovered without increasing the number of active coils, but simply by using an uneven coil distribution (red lines).

Plasma experiments were performed in collaboration with JAEA association with the explicit intention of supporting the design of RWM control system for the JT-60SA new device, which aims at producing and sustaining high β_N AT plasmas [5]. A more complete review of RWM control experiments under different configurations is given in [6], where issues such as mode rigidity and resonant field amplification are discussed as well.

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References

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