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Status of the RFX-mod2 Reversed Field Pinch upgrade

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The RFX-mod experiment (R/a=2m/0.459m) was a Reversed Field Pinch device, encompassed within a matrix of 48x4=192 independently controlled saddle coils, which characterized plasma current regimes up to 2MA. Based on RFX-mod results, an upgrade of the boundary is being designed and implemented (RFX-mod2), which will start the operation in 2021. The main change compared to the RFX-mod device is the removal of the Inconel vacuum vessel, whose high electrical resistance was discovered to negatively influence the plasma performance. The new first wall will be the copper stabilizing shell, protected with graphite tiles. The external Stainless Steel support structure will be modified in order to ensure vacuum tightness [Peruzzo2019]. This new boundary implies an increased minor radius leading to a shell to plasma ratio decrease from 1.11 to 1.04. The change of the conductivity of the first continuous conducting wall and the reduction of the plasma shell distance are predicted to open new plasma scenarios. In particular, a reduced non axisymmetric deformation of the Last Closed Magnetic Surface (due to phase locked Tearing Modes), a higher plasma current threshold for wall locking and a reduction of mode energy, will allow a further exploration of the high current regimes. [Zuin2017].

Status of the design The external stainless steel toroidal support structure will be modified with the integration of 150 vacuum-sealed ports, interfaced with existing machine sub-systems (diagnostics, pumping and fueling). The new vacuum vessel requires the implementation of two poloidal and two toroidal vacuum-tight electrically-insulated gaps, necessary to allow suitable penetration of electromagnetic fields. This layout is challenging because it creates vacuum tight crossed triple joints. The designed solution implies the use of high-performance polymers combined with acrylic based syntactic foam materials, which provide proper vacuum tightness and electrical insulation, with suitable viscoelastic characteristic that guarantees the compensation of thermal deformations expected during operation. While tests on a previous solution, presented at the last IAEA conference [Cavazzana2018, Peruzzo2019], were not encouraging, those performed in the present one have been reproducibly successful: the final test on a suitable mock-up is on going.

The RFX-mod2 conductive shell will be vacuum, exposed to low gas pressure and to the low temperature plasma, a condition which can potentially lead to dangerous arcing phenomena in presence of the intense electric fields at the gaps. Several experimental tests on a mock-up exposed to a weakly ionized Helium plasma have been performed, confirming that alumina ensure a good insulation. On the other hand, arcs between exposed metal regions even at relatively long distances have been observed, strongly suggesting that the entire surface of the copper shell needs to be insulated. Among the different deposition techniques, such as magnetron sputtering, detonation gun and plasma spray, the latter has been chosen. Moreover two poloidal gaps in the copper shell will be implemented, because a uniform alumina coating over the entire RFXmod2 shell cannot be guaranteed and the expected worst case electric fields are comparable with those leading to arcs in the tested samples.

The RFX-mod2 plasma edge is near to the shell eddy currents and can be significantly affected by magnetic field errors at the shell gaps, which are key ingredients in the wall locking of Tearing Modes [Marrelli2019a]. The plasma current threshold for MHD modes wall-locking can in fact be significantly lowered by increasing errors, whose amplitude depends on the geometry of the gaps and on the time scale. Previous studies were focused on the effect of the copper shell during the plasma startup phase [Marrelli2019b], when the main source of error field is the slow vertical field variation required for plasma position control and are not well suited on faster time scales, such as sudden variations during reconnection events. The code CAFÉ-hVI overcomes such a limitation, by implementing an integral formulation to solve for eddy currents on a polyhedral mesh of generic topology [Bettini2017]. Preliminary simulations confirm that error fields in the overlapped poloidal gap concept are significantly reduced compared to the butt-joint design also on the faster time scale. Simulations with more realistic geometries are ongoing.

RFX-mod2 scientific program. The exploration of achievable experimental scenarios with the new boundary is the first issue to be addressed. Key aspects to investigate are the effect of the improved plasma boundary on the RFP plasma confinement, temperature, particle and energy transport, loop voltage, MHD modes dynamics, Quasi Single Helicity formation, high density regimes. It will require an adaptation of RFX-mod MHD Mode Control algorithms, in order to characterize the effect of the shell on the current threshold for spontaneous mode rotation. A milder Plasma Wall interaction, related to the reduced deformation of the LCMS, is expected to decrease the uncontrolled particle release affecting the high current operation in RFX-mod [Puiatti2013], thus allowing to obtain Quasi Single Helicity regimes at high density and in an extended the range of the Lundquist number. Energy and particle transport will be investigated too: the predicted reduction of the mode energy will favor the study of the effect on energy transport of microturbulence (in particular ITG and

microtearing modes) when magnetic chaos is not the main drive of transport. Specific transient experiments, including tracer impurity pellet (TESPEL [Carraro2019]) and edge impurity injection by Laser Blow Off, will be planned since the first campaigns to study the impurity transport. Edge properties of RFX-mod have been found to depend on MHD spectrum [Scarin2019], with a particular role played by m=0 modes and wall-locking of m=1 modes: the 3D characteristics of RFX-mod2 will be therefore investigated by means of new insertable probes and improved spatial resolution magnetic [Marconato2019] and electrostatic [Spagnolo2019] sensors. RFX-mod can also be operated as a low current circular ohmic Tokamak, without divertor, obtaining H-mode through insertable electrode [Spolaore2017]. Due to the flexibility of the poloidal field shaping coils, it is possible obtain tokamak plasma equilibria with DEMO-like shape conditions (i.e. $\delta>0.3$, $\kappa>1.5$) can be produced, including the possibility of either single or multiple X-points also with negative triangularity.
Finally, we expect that RFX-mod2 can improve and assess the current scaling extrapolation [Piovan2018] opening the possibility of a further step in RFP research [Piovan2019]. Indeed, in principle, the RFP configuration could offer several appealing features as an alternative fusion device: the self-organized plasma is relatively easy to produce and is not prone to disruptions; the toroidal coil system is inherently simple and does not require superconducting technology; fusion condition can be reached, in principle, only by ohmic plasma heating, without additional systems.

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