Groundwork for the Ignitor Experiment

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Introduction

The characteristic parameters of the Ignitor experiment are the high plasma currents ($\lesssim$ 11 MA), relatively small dimensions ($R_0 \cong 1.32$ m, $a \times b \cong 0.47 \times 0.86$ m^2), and magnetic fields up to 13 T [1, 2]. The operational life of the machine will include "preparatory" experiments at reduced machine parameters that are expected to access significant plasma regimes. In this context a careful analysis has been carried out to verify the consistency of the plasma parameters to be obtained, in particular the ideal ignition conditions in D-T plasmas, with the characteristics of the poloidal and toroidal field systems, and considerable pulse lengths. To this end many simulations were carried out with the JETTO code, that is capable of taking into account self-consistently the free-boundary plasma equilibrium evolution. Two scenarios with magnetic fields up to 9 T and appropriate levels of injected (RF) heating were investigated: "limiter" (no X-point) configurations with plasma currents up to 7 MA and double X-point configurations with plasma currents up to 6 MA. In all cases the compatibility of the poloidal flux consumption with the available flux was verified and the constraints on long pulse flat-tops related to the features of the toroidal magnet system were taken into account. The enhanced confinement properties of the H-regimes that can be attained in the presence of X-point configurations have not been examined yet. Thus only a kind of worst case scenario is included in this presentation. The results show that proper programming of the density evolution and of the RF injection lead to reach and to maintain steady state conditions with peak temperatures around 6 keV (ideal ignition for the considered profiles) and significant α-particle production. The required amount of injected power is up to 8 MW in the "limiter" configuration when the shortest confinement times are considered. The relevant pulse flat-top lengths can be about 9 seconds for the "limiter" configuration.

"Reduced" Scenarios

The present simulations were carried out, like the previous ones performed for the "standard" Ignitor scenarios (11 MA, 13 T), by means of the JETTO code. A BohmgyroBohm transport model was adopted for both electrons and ions represented by the expressions:

$$\chi_e = D_B[\alpha_{Be} q^2 f(s) + \alpha_{gBe}\rho^*](a/L_{Te}) \; ; \; \chi_i = D_B[\alpha_{Bi} q^2 f(s) + \alpha_{gBi}\rho^*](a/L_{Te}) + \chi_{i,neo}$$

where D_B is the Bohm diffusion coefficient; α_{Be}, α_{gBe}, α_{Bi}, α_{gBi} are numerical coefficients whose values are detailed later; $f(s)=H(s)[s^2/(1+s^2)]$ is a step function of the magnetic shear; q the local safety factor; a is the minor plasma radius; L_{Te} the characteristic temperature gradient length and $\chi_{i,neo}$ the neoclassical ion thermal diffusivity. Sawtooth oscillations are triggered by a critical peaking factor of the plasma pressure ($p_{kc}=p_0/<p>=2.7$), chosen on an empirical basis. The magnetic flux variation is evaluated by the Poynting method, choosing as reference point the inner edge of the plasma column [3]. The RF pulse is associated with a rather large deposition profile. The poloidal coil currents were evaluated so as to produce a flux matching the required value along the discharge evolution.

7 MA Scenario

In this “limiter” configuration scenario the toroidal magnetic field increases from 7.57 to 9 T during the current ramp (2.1 s) and the flattop lasts 9.4 s. Notice that the starting time in the simulations correspond to 0.3 seconds (1 MA plasma current). The working density along the flattop time is $<n_e> \approx 2 \times 10^{20} m^{-3}$ and the impurity content is such as to produce an effective charge ≈ 1.5, a higher value than usually observed at these densities, and slowly increasing during the flattop. The simulations reported here refer to:

$\alpha_{Be}=0.43 \times 10^{-3}$, $\alpha_{gBe}=0.10$, $\alpha_{Bi}=0.34 \times 10^{-3}$, $\alpha_{gBi}=0.10$ (Run A – on the left in the figures)

$\alpha_{Be}=0.13 \times 10^{-3}$, $\alpha_{gBe}=0.10$, $\alpha_{Bi}=0.10 \times 10^{-3}$, $\alpha_{gBi}=0.10$ (Run B – on the right in the figures).

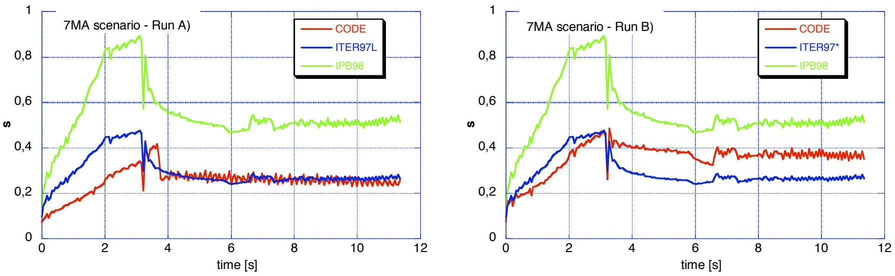

Fig.1. *Energy confinement time, in seconds, given by the code compared with the ITER97L and IPB98 global scalings. Run A on the left-hand side and Run B on the right.*

The first set of parameters is the same used in previous simulations, for which the resulting energy confinement time comes close to the one estimated with the ITER97L scaling. The second set produces a τ_E, during the current flattop, that is about 1.5 times the

ITER97L, compatible with the results of the FTU machine in the presence of ECRH heating. The RF pulse (7.7 MW absorbed by the plasma) is maintained from 3.5 s until the end of flattop. It is worth noting that Run A presents a stability trajectory, in the (q_ψ, l_i) plot, more stable than the one of Run B. The transport properties influence the magnetic flux consumption during the discharge, as shown in Fig.2.

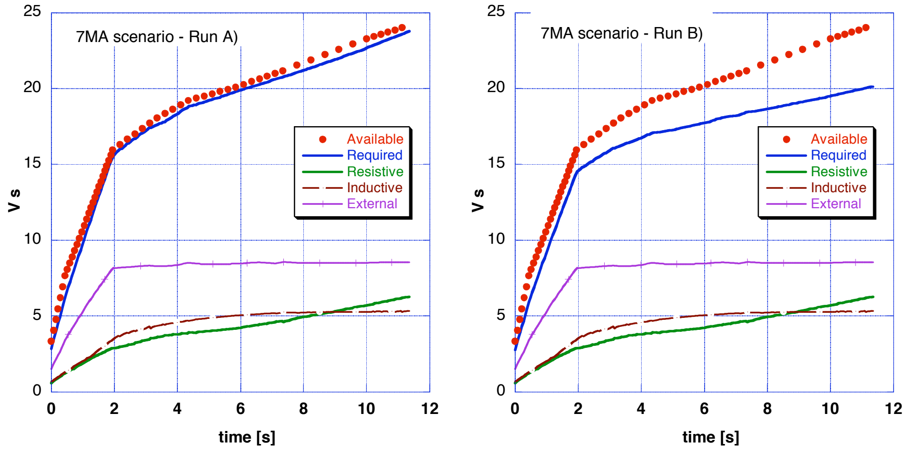

Fig.2. *Flux evaluations for Runs A (on the left-hand side) and B.*

These evaluations point out that, even with a pessimistic choice for the transport model, such as the ITER97L scaling, the peak temperature can be over 6 keV (see Fig. 3). Any more realistic assumption will ensure much higher performances.

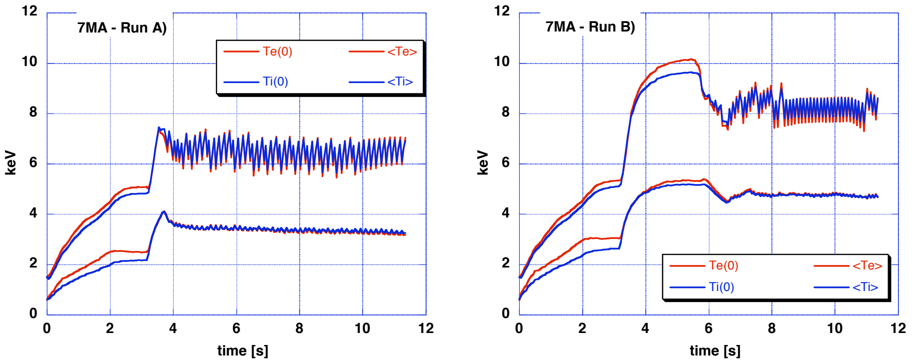

Fig. 3 *Peak and volume averaged temperatures for Runs A (on the left-hand side) and B.*

Double X-point Scenario

In this scenario the plasma reaches 6 MA and a configuration with double X-points inside the first wall. The current ramp lasts 3.8 s and the flattop is limited to 4.2 s while the complete thermomechanical analysis of the involved coils is being carried out. A RF pulse (5 MW absorbed by the plasma) is injected from 3.3 s until the end of the flattop. The possibility of accessing an H-mode confinement regime in the presence of an X-point configuration has not been examined yet. The density conditions are the same of the previous scenario and the two sets of transport coefficients are very similar. The slower rate of the current ramp improves the current penetration. The peak temperatures oscillate around 5.5 keV and 6.5 keV in the two confinement conditions, here indicated as C and D (see Fig.4). In this scenario the less favorable confinement gives a (q_ψ, l_i) trajectory always included in the stability region; the alpha power relevant to the better confinement increases up to 2 MW (see Fig. 5).

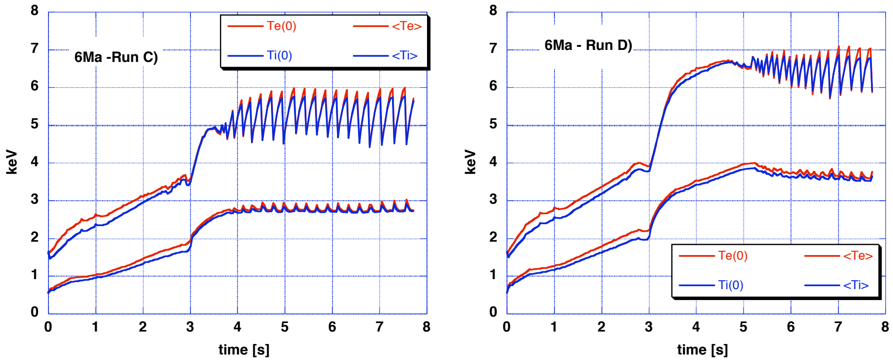

Fig.4 *Peak and volume averaged temperatures for Runs C (on the left-hand side) and D.*

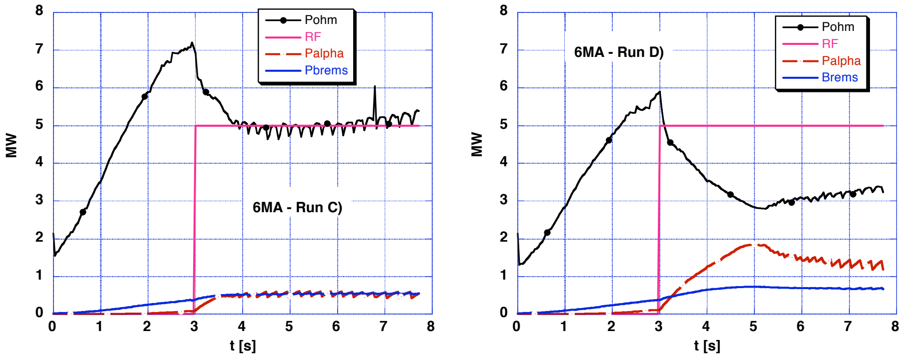

Fig.5 *Ohmic, RF and alpha powers forRuns C (on the left-hand side) and D.*

The comparative analysis of the simulations assures that significant performances can be reached in both scenarios even with pessimistic hypotheses on the confinement properties. The amount of injected heating power can be adjusted to compensate for the different transport conditions. In the 7 MA scenario a flattop as long as 9 s is compatible with the characteristics of the poloidal and toroidal field magnet systems.

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References

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