*36th EPS Conference on Plasma Phys. Sofia, June 29 - July 3, 2009 ECA Vol.**33E**, P-4.161 (2009)*

Study of ITER Plasma Start-Up Conditions by ASTRA and DINA Codes

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1. Introduction. Development of the operational scenarios and analysis of conditions influenced the plasma performance in different discharge stages are the important aspects of the ITER design. This paper presents the recent results of complex study of conditions in the initial stage of the reference ITER inductive 15 MA scenario.

Preliminary multi-parametric investigation of scenarios was performed by the ASTRA transport code [1] with taking into account limiter sputtering in the limiter discharge stage, impurity transport and radiation simulated by the ZIMPUR code [2] and different methods of plasma fueling, heating and CD. Selected scenario was analyzed by the DINA code [3] comprising 2D free boundary plasma equilibrium, taking into account real properties of ITER poloidal field system, models of the power supplies and both feedforward and feedback control systems of plasma current, position and shape. The algorithm we used causes saturation of the coil currents when these are close to the design limits. In the divertor stage of considered scenario the separatrix strike points would be keeping all time on the divertor target plates.

To save the poloidal flux during the early phase of the plasma current ramp-up one need to increase the plasma current rise rate. In this case it is extremely important to consider the possible skin effect of the plasma parameters. It is important also to take into account the influence of boundary plasma parameters on limiter sputtering and estimate the impurity flux into the plasma in the limiter stage of scenarios under consideration. Last time a great attention is attracted also to the study of the initial discharge stage take account of possibility of Poloidal Field (PF) system to control the plasma column equilibrium and shape staying within the engineering limits.

The simulations were performed assuming the central-outboard plasma initiation without the limiter (plasma touches the outboard first wall till X-point formation with half aperture plasma of circular cross section). The ASTRA code was used for simulation of initial discharge stage from Ip =100kA and plasma minor radius a ~1.3m at t = 0.5s up to Ip= 1.5MA and a =1.8m at t =7.9s. Then the DINA code free boundary simulations were started.

The control scheme has two feedback loops acting on different timescales: the fast vertical stabilization (VS) loop with the time constant 7 ms and the slow feedback loop which provides control of the plasma current and shape (via control of the 6 gaps around the poloidal cross-section) with a time constant of 150 ms.

2. Dependence of parameters on plasma current ramp rate. To study the poloidal flux consumption and skin effects in plasma the simulations with the different plasma current rates during early phase of plasma current ramp-up were performed. Fig.1 demonstrates some schemes of parameter variations in these simulations.

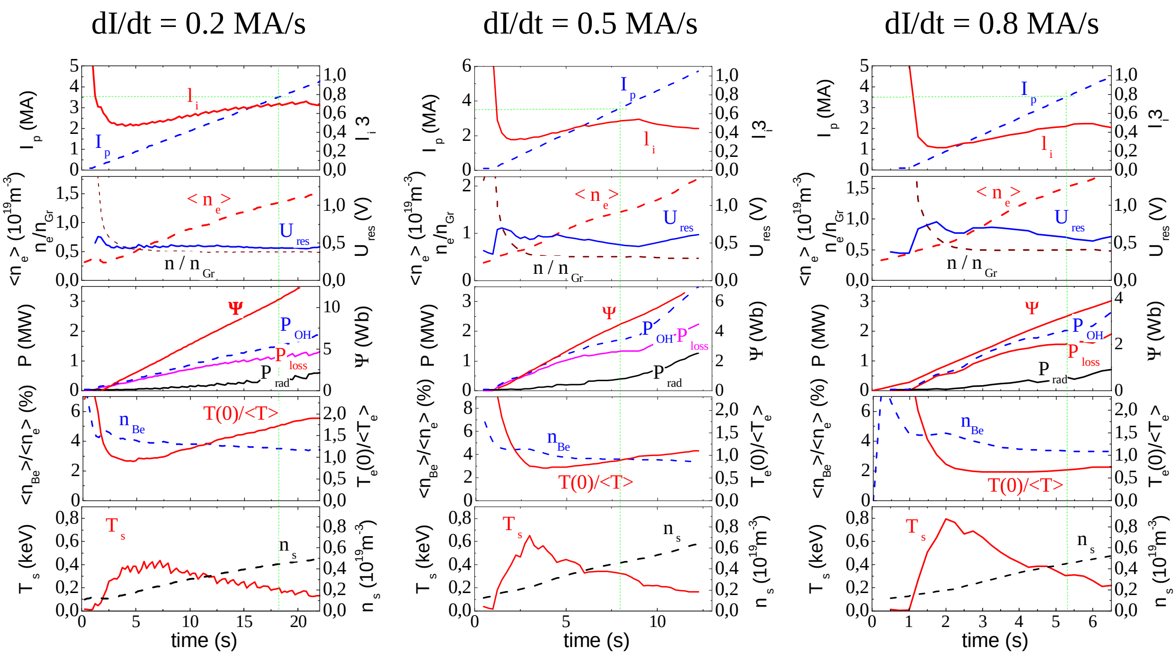

Fig.1 Plasma parameters dynamics at different current ramp-up rates.

It has been found that for plasma current ramp-up rate higher than 0.5 MA/s the strong skinning of plasma current ($l_i \leq 0.4$-0.5) and temperature ($T(0)/\langle T\rangle \leq 1$) are observed what results in a deterioration of plasma column controllability, increases the boundary temperature and limiter sputtering what can result in enrichment of plasma core by impurities which cool the plasma. From the other side V-sec consumption slightly increases at the smaller current rise rate. Using of the auxiliary plasma heating helps to decrease the V-sec consumption in this stage, to control boundary temperature and prevent plasma boundary cooling by gas puffing and impurity fluxes.

3. Simulation of reference ITER scenario. Fig.2 demonstrates the evolution of plasma parameters for scenario with current ramp rate ~ 0.2 MA/s which satisfies the PF system technical limits (voltages, coils currents, magnetic fields, forces) and the accuracy of plasma shape and separatrix location control. In this case current ramp-up stage should lasts ~ 70 s. Minimum average plasma density after the discharge initiation is ~ $0.5{\cdot}10^{19}\text{m}^{-3}$ and then

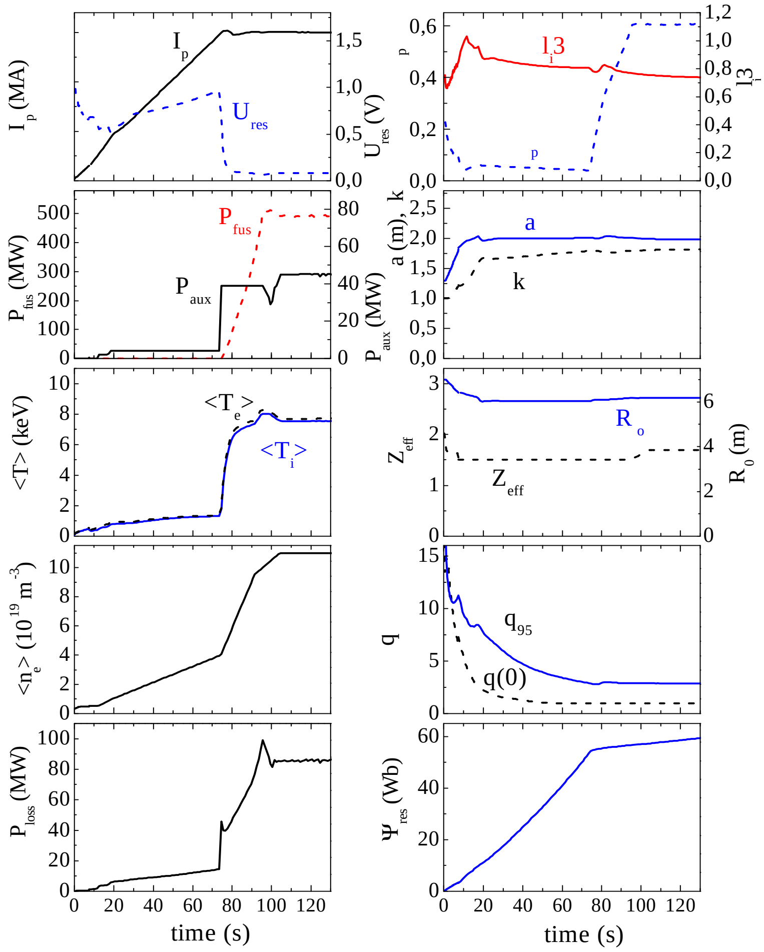

Fig.2 Evolution of plasma parameters in the current ramp-up phase of 15MA ITER reference scenario.

increases when normalized value <*ne*>/*nG* reaches ~ 0.5. Simultaneously with the density rise the ECR plasma heating with P = 2MW starts to prevent excessive periphery plasma cooling. After divertor configuration formation ECR power is increased to 4MW. Boundary temperature after discharge initiation is ~ 300 eV and then decreases to ~100 eV together with the density rise. In this time beryllium relative concentration drops from 7 to ~2%. The divertor configuration is formed at about 13-14s (X-point formation), when the plasma current is ~ 3.5-4 MA. Plasma density increases to 0.4×10^{20} m^{-3} at the SOF (70 s) and at this time ~ 50 MW of the main auxiliary heating starts and triggers L to H mode transition. In this scenario the phase of burn

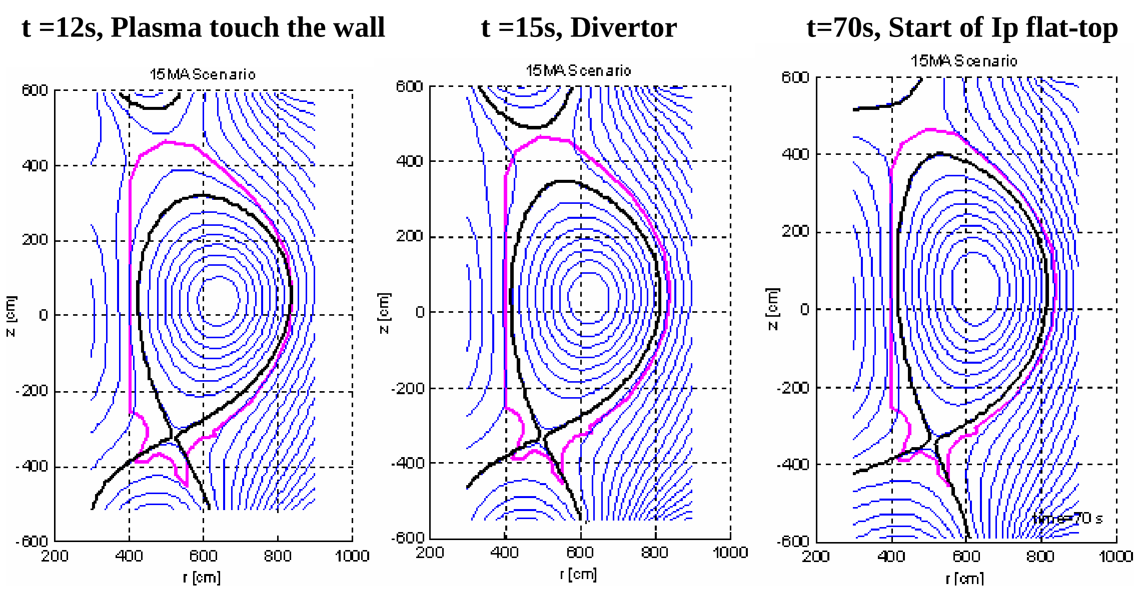

Fig.3 Plasma shape evolution during current ramp up phase of 15MA reference ITER scenario.

starts (SOB) at t =100 s, when the plasma density increases to 1.1×10^{20} m^{-3} and the value of $_p$ increases to about 0.61. The burn duration in this scenario is ~ 400 s. Value of l_i in this scenario is ~ 0.75 - 0.9.

Plasma shape evolution during considered scenario is shown in Fig.3. Time t = 12s corresponds to the plasma shape before the divertor configuration formation (plasma touch the wall). Plasma shapes after the divertor configuration formation (t =15s) and at the plasma current flat-top (t = 70s) are shown in this picture too. As one can see in the divertor stage of the considered scenario the separatrix strike points can be keeping all time on the divertor target plates.

4. Conclusions. Recent results of complex study of conditions in the initial stage of the basic ITER inductive 15 MA scenario are presented. The main goal was to demonstrate the capability of the PF system to support this scenario with selected parameters.

Simulations were performed with use of ASTRA and DINA codes taking into account of the limiter sputtering (in the limiter discharge stage), the limits imposed on the PF system (coils currents, voltages, magnetic fields, forces) and the accuracy of plasma shape control including the separatrix strike points location on the divertor target plates.

It has been found that for the plasma current ramp-up rate higher than 0.5 MA/s the strong skinning of plasma current and temperature radial profiles (li ≤ 0.4-0.5; T(0)/<T> ≤ 1) are observed. This effect can be minimized by use of current layer accretion method (when current increases simultaneously with the plasma size).

The plasma current ramp up stage of the 15MA ITER reference inductive scenario with the current rise rate ~ 0.2 MA/s which satisfy the PF system limits and the accuracy of plasma shape control is presented. This scenario is characterized by early formation of divertor magnetic configuration (t ≈14s, Ip ≈3.5-4MA) and preliminary auxiliary heating plasma. The plasma current ramp-up time is ~ 70s and value of $l_i(3)$ at the start of the current flattop is ~ 0.75. The possible burn duration in this scenario is ~ 400 s.

The authors wish to thank Dr. A.A. Kavin for the development of the algorithms for the ITER plasma current, position and shape control in this analysis. This work was supported by contract H.4a.52.03.09.1035 between State Corporation Rosatom and RRC "Kurchatov Institute" and grant SS-371.2008.2.

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