SIMULATION OF ASDEX UPGRADE SHOT SCENARIOS WITH POWER SUPPLY CONSTRAINTS

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1. Introduction

ASDEX Upgrade, presently under construction at IPP Garching, is a divertor tokamak allowing experiments with elongated plasmas of Single and Double Null shapes. For this tokamak, we have performed a series of dynamical simulations during the start up, the flat top and the shut down phase, using the Princeton Tokamak Simulation Code (TSC) [1]. In the simulations, we have included all coil groups, i.e. the ohmic heating system, the poloidal field coils external to the TF magnets, the inner control coils as well as passive structures such as passive conductors and the vacuum vessel. The feedback control of the plasma position by the inner control coils and the external poloidal field coils, both during regular shot scenerios and for disruption simulations under realistic power supply constraints, is studied. In the following we describe in somewhat more detail two applications, the simulation of a complete discharge including the start up phase and a plasma disruption. Although in both cases of the simulation, model assumption are required for the thermal energy transport, the emphasis is here on the aspects of plasma position and shape control and the electrodynamics of the poloidal field circuits.

2. Complete Discharge Simulations

Numerical simulations of complete Single Null discharges including start up, flat top and shut down phase during 10 sec have been performed. The interaction of the plasma with the poloidal field coil system and passive wall structures have been taken into account by modelling the vacuum vessel, the top - bottom unsymmetric passive conductors and the poloidal field coils as illustrated in Fig.1. In the simulations plasma current and poloidal field coil currents as determined from the Garching equilibrium code, have been preprogrammed and correction currents have been determined by position and plasma current feedback systems. The desired currents consist of preprogrammed and feedback currents. By comparing desired and actual currents the feedback voltages have been determined. For energy transport, a model by Coppi and Tang [2] was taken which describes the L-mode scaling and consequently underestimates the expected β and τ values during additional heating by a factor of order 2.

In an example, the simulation of a Single null shot is started with a plasma current of 100 kA. Due to power supply limitations, the current ramp rates in the poloidal field coils are not sufficient during the initial plasma current rise for obtaining divertor configurations. Therefore the discharge is started as a limiter plasma at the torus inner wall needing less PF currents compared to those of divertor plasmas. Additional precharging of PF coils is necessary and the resulting stray field is compensated by the inner control coils. After break down a divertor equilibrium is provided as soon as possible, in our example at time $t \approx 80\ msec$. During the expansion phase the major radius increases to about 1.65 m and the plasma is displaced vertically by $\approx$ 15 cm. The evolution of the 99% surfaces of equilibria from the inboard limiter to a divertor plasma during 80 msec is shown in Fig.1. The final cross sectional shape is obtained after $\approx$ 200 msec. During the pure ohmic heating phase up to 1.5 sec, the plasma current is raised to 1.2 MA as shown in Fig.2a and the poloidal beta evolves to about $\beta_p \approx 0.2$ (Fig.2b). The auxiliary heating of $\approx$ 10 MW is started during the plasma current ramp up phase as the necessary changes in the PF currents going from low to high β_p help to save Vsec. The flat top is reached after 2.5 sec with a plasma current of 1.6 MA, a poloidal beta of ≈ 0.7 and a density of $\approx 1.5 \cdot 10^{20}\ m^{-3}$. At the end of the flat top and auxiliary heating phase (t = 7 sec) the plasma current is ramped to the initial value within 3 sec and the plasma is moved to the inside limiter again.

Presently we are optimizing the Single Null shot scenarios by readjusting the preprogrammed quantities especially the plasma position, the currents of the external shaping coils and of the OH coils, where we take into account also the actual voltage supply restrictions. We are trying to optimize also the feedback coefficients for the plasma current control and the control of the radial plasma position in order to avoid radial overshoots which would cause the plasma to touch the outboard limiter (the ICRH antenna) during the start up phase.

3. Simulation of Single Null Plasma Disruptions

Several scenarios for plasma disuptions in ASDEX Upgrade have been simulated to assess the limits up to which - with the foreseen power supplies - discharges can be sufficiently controlled to avoid strong wall contact and terminal current quench after a partial disruption. As one result of such simulations we show the time trajectory of the magnetic axis position in the R - z plane for the case of a high - β_p Single Null disruption in ASDEX Upgrade (Fig.3). For such a simulation we distinguished three phases:

- A short stable discharge phase which serves to produce reasonable initial conditions for the plasma configuration. During this period (which corresponds to the first 4 msec in Fig.3) the plasma position is controlled by the feedback system acting on the interior control coils. With proper choice of initial parameters, heating power and energy transport model, the radial and vertical plasma excursion during this phase are kept to less than 3 mm.
- Plasma disruption phase (from 4 msec to 5 msec). We simulate the consequences of the thermal quench phase of a minor disruption by transiently increasing the factor in front of our heat conductivity expression from 1 to 500. The plasma loses its equilibrium position, the plasma current decreases from 1.6 MA to 1.58 MA and the β_p value reduces from 1.6 to 0.7.
- Recovery phase (from 5 msec to 30 msec). After the thermal quench phase the heat conductivity enhancement factor is reset to the original value. Due to the action of the feedback systems, the plasma position and the current converge back to their original values.

Acknowledgements

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References

[1] S.C.Jardin, N.Pomphrey, J.DeLucia; JCP **66** (1986) 481

[2] S.C.Jardin et al.; Nuclear Fusion Vol.27, No.4 (1987)

Fig.1: Evolution of the 99% flux surfaces during the start up phase of a Single Null discharge. Also shown the modelling of passive structures and the poloidal field coils.

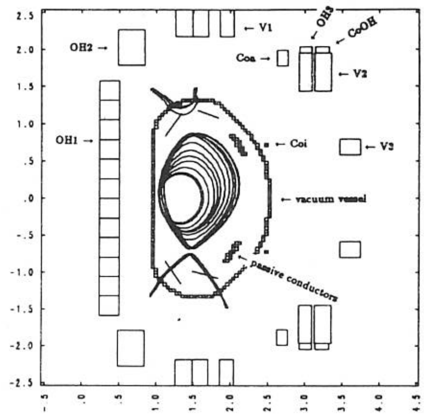

Fig.2a: Plasma current in kA of a Single Null discharge: 2.5 sec current ramp up, 4.5 sec flat top, 3 sec shut down.

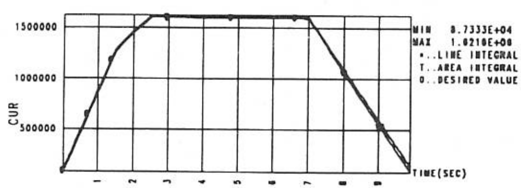

Fig.2b: Poloidal beta and internal inductance during a complete discharge. Auxiliary heating is applied at time T = 1.5 sec.

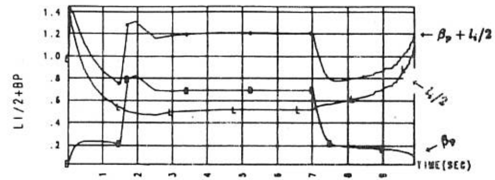

Fig.3: Trajectory of the mag. axis position during a minor disruption (Time: 0 sec → 0.03sec)