NUMERICAL SIMULATION OF THE DYNAMICAL PLASMA EVOLUTION OF THE ASDEX-UPGRADE TOKAMAK

R.Weiner, O.Gruber, S.C.Jardin*, K.Lackner, U.Seidel

Max-Planck-Institut für Plasmaphysik
Boltzmannstraße 2, D-8046 Garching bei München
Federal Republic of Germany

*) Princeton University, Plasma Physics Labaratory
Princeton, N.J. 08544, U.S.A.

Abstract:

The dynamical behavior of plasma in ASDEX-Upgrade, which is now being constructed, has been studied using the free boundary axisymmetric tokamak- simulation-code (TSC) [1, 2], which models the resistive time evolution of toroidal plasma, including its interaction with poloidal field coils and other nearby conductors. The code is applied to model the passive and active feedback system of ASDEX-Upgrade needed to control the axisymmetric instabilities of vertically elongated plasmas. Calculations concerning the resistive evolution of plasma configurations with Single- and Double- Null crossectional shape are performed for high and low poloidal β. Active control coils inside and outside the toroidal field coils are used to control the radial and vertical position of the plasma. Calculations showing the plasma evolution during the start-up phase, where the plasma evolves from an inside limiter bounded circular plasma shape to a final divertor configuration, are presented.

Passive stabilization of vertically elongated ASDEX-Upgrade equilibria:

Plasmas in tokamaks having elongated cross sections are unstable with respect to vertical displacements. The growth rate of the vertical displacement instability is slowed down from the Alfvén time scale to a moderate resistive time scale by passive stabilization coils.

To calculate the growth times of the resistive instability, the asymmetric passive conductor system of ASDEX-Upgrade is modeled on a rectangular grid between $0.8\,m \le r \le 2.6\,m$ and $-1.5\,m \le z \le 1.5\,m$. The resistance of the grid conductors is treated as a parameter which is adjusted to yield an L/R-time of $\approx 400\ ms$ of the system without the plasma present. To calibrate, the coil currents of the grid conductors are initialized with equal and opposite currents, applying the constraint that the sum of currents is equal to zero. As time advances the coil currents decay and from flux measurements of observation pairs symmetric to $z = 0$ the L/R-time of the whole set of conductors in vacuum can be determined.

Calculations of the resistive instability with the plasma present have been performed for Single- and Double- Null equilibria at low ($\beta_p \approx 0.1$) and high poloidal β ($\beta_p \approx 2.0$) and at a plasma current of: $I_p = 1MA$. A vacuum toroidal field strength of $B_t = 2.7\ T$ at $R_0 = 1.65\ m$ in the Single-Null- and $B_t = 2.35\ T$ in the Double-Null- case was assumed.

At low poloidal β ($\beta_p \approx 0.1$) the resulting resistive growth times of Double-Null-equilibria τ_r, determined from fits to the flux difference of obeservation pairs symmetric to $z = 0$ and from the time dependent movement of the magnetic axis, comes out to be: $\tau_r \approx 50\ ms$. The ratio of stabilizing to unstabilizing forces is therefore given by: $\frac{F_{stab}}{F_{unstab}} \approx 1.125$. Single- Null- equilibria at the same β_p indicate a somewhat larger value.

In stability calculations at high β ($\beta_p \approx 2.$) a neutral beam injection model [3] has been utilized to provide an additional heating power of $\approx 15\ MW$. For Double-null- equilibria the flux measurements indicate here a resistive growth time of $\tau_r \approx\ 100\ ms$ which correspond to a ratio of $\frac{F_{stab}}{F_{unstab}} \approx 1.25$ or to a stability margin of 0.25. In the Single-Null- case the resistive growth time is again somewhat larger.

Active feedback control of ASDEX-Upgrade equilibria:

Passive conductors with finite conductivity are capable of surpressing the fast mode growth of the vertical instability on the Alfvén time scale but cannot ensure full stability. In ASDEX-Upgrade, the residual instability will be controlled by active control coils both inside and outside the toroidal field coils.

To study the control of these instabilities, the inner control coils (COI) have been modelled by single grid conductors in the upper and lower plane, having an L/R-time of 535 ms. The feedback has been performed on the flux difference of observation pairs as well as on the deviation of the magnetic axis from the equilibrium position, and feedback voltages (u) have been calculated. A new feedback model has been proposed, shown in *Fig.*1, which is now implemented in the TSC-code. It consists of two PID-control systems where the first feedback system acts on the deviation of the magnetic axis from the predefined position (**r**) whereas the second feedback system responses on the difference between desired and actual currents ($\mathbf{j}_w$,**j**), where the quantities shown in *Fig*.1 are to be considered deviations from equilibrium values.

Start-up calculations:

Calculations of the evolution of ASDEX-Upgrade- equilibria during the start-up phase, where the plasma evolves from a inside limiter bounded plasma shape to a final Double-Null- divertor configuration, have previously been done using an iteration between a network simulation code, which models the plasma as a rigid loop with a variable inductance, and the MHD-equilibrium code [4].

In accordance with this former calculation, we applied the TSC-code to model the plasma evolution between 40 $ms \leq t \leq 280$ ms taking into account passive stabilization and active feedback control. The currents in the plasma as well as in the poloidal field coils have been preprogrammed and active control has been carried out using the shaping- coils for vertical and radial feedback. The density is raised from $0.25 \cdot 10^{19} \frac{1}{m^3}$ to $2.5 \cdot 10^{19} \frac{1}{m^3}$ with a resulting increase of β_p from 0.05 for the inside limiter equlibrium to $\beta_p \approx 0.25$ for the final Double-Null- configuration. The time dependent evolution of the 95% - equilibrium surfaces is shown in ***Fig*.2** with the divertor equilibrium formed after ≈ 130 ms.

References:

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

[2] S.C.Jardin; "Multiple Time-Scale Methods in Tokamak Magnetohydrodynamics"; Computational Physics; Academic Press; edited by B.Cohen & J.Brackbill (1985) 185

[3] S.C.Jardin et al.; "Post Disruptive Plasma Loss in the Princeton Beta Experiment (PBX)"; Princeton University, Plasma Physics Laboratory PPPL-2358 (July 1986); to appear in Nuclear Fusion (1987)

[4] O.Gruber and ASDEX-Upgrade Project Group; "ASDEX-Upgrade, Start-up and Operation"; From: Tokamak Start-up, Plenum Publishing Corporation; edited by Heinz Knoepfel (1986)

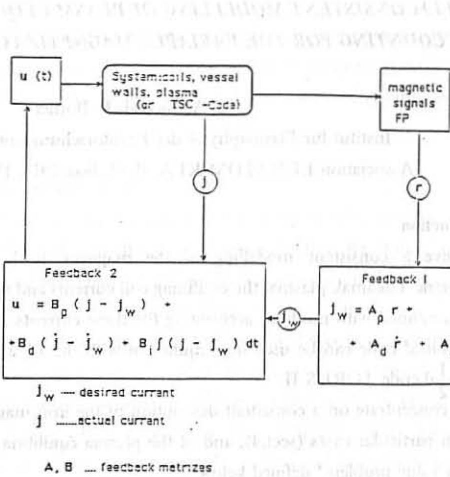

Fig.1:
Proposed ASDEX-Upgrade feedback system now implemented in the TSC-code. In equilibrium state, voltages (**u**)*, currents* (**j**, $\mathbf{j}_w$) *and the position of the magnetic axis* (**r**) *are to be considered deviations from equilibrium values.*

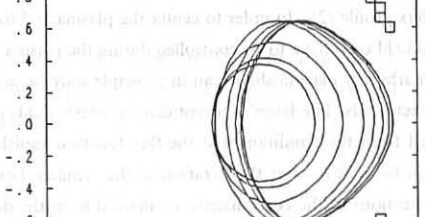

Fig.2:
Time dependent evolution of the 95%- surface of ASDEX-Upgrade equilibria from an inside limiter shape to a final Double-Null- divertor configuration within 240 ms. Conductors used to model the the passive stabilization coils of ASDEX-Upgrade are also shown.