

Model of real time ITER plasma position, shape and current control on base of DINA code

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Poloidal field magnetic control in tokamak has the essential functions of stabilizing the vertical instability inherent in elongated cross-sections, and in keeping the plasma shape, position and current nearly reference even in presence of internal plasma disturbances such as sawteeth, minor disruptions, ELMs and other transients. Poloidal magnetic control comprises in adjusting of the tokamak equilibrium by use of the currents in the PF coils and must maintain the specified plasma current $I_{p\ ref}$, shape and position parameters during the full scenario including plasma current ramp up and shut down stages. Control of the plasma shape in ITER in the divertor configurations is realized by controlling the size of the gaps ($g1-g6$) between the separatrix and the plasma-facing components at six selected locations, as shown in Fig. 1 where a scheme of real time control of plasma position, shape and plasma current for ITER is presented. For that a real time reconstruction of plasma equilibrium (similar to real time XLOC [1]) with use of magnetic diagnostics (measurements of flux loops Ψ_l , poloidal magnetic fields B_p , currents in PF coils I_{PF} and plasma current I_p) is necessary to estimate plasma shape and include it in feedback control.

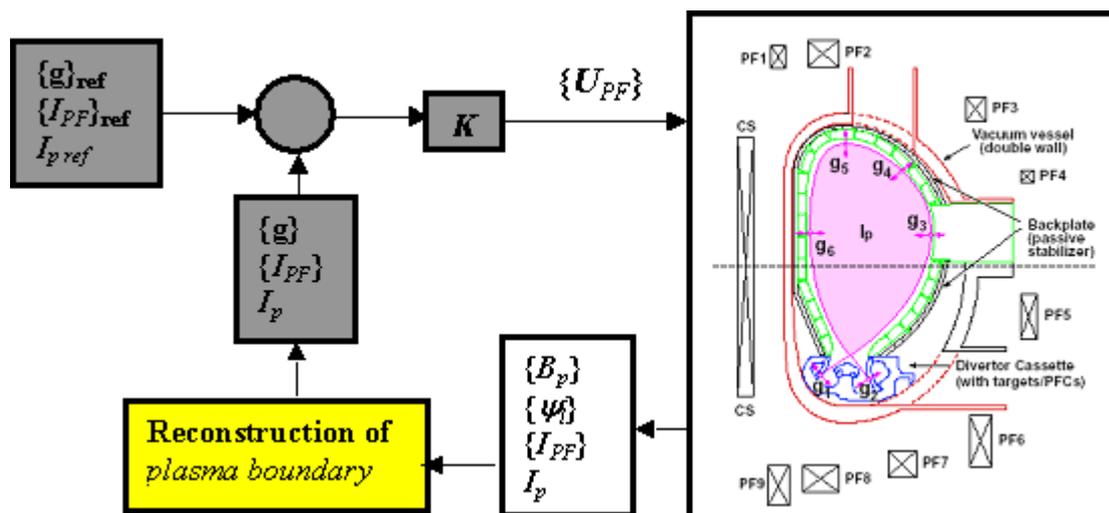


Fig.1 Scheme of ITER plasma current, position and shape control

Controller K produces the PF coil voltages U_{PF} to minimize a difference between the reference and controlled parameters.

In present work we are considering a version of filament reconstruction code which is used for predictive DINA code [2] modelling of real time control of current, shape and position of ITER plasma during ramp up stage in inductive 15 MA Scenario 2 [3]. Controllable plasma behavior with reconstructed equilibrium is compared with standard DINA scenario simulation results obtained without reconstruction [4].

Magnetic diagnostics in ITER and modeling scheme

Magnetic diagnostics for the plasma equilibrium reconstruction includes 24 inner flux loops and 48 normal B_{\perp} and tangential B_{\parallel} coils shown in Fig. 2 [5]. In Fig.3 the ITER modeling scheme on the basis of DINA code contained reconstruction module is presented. The code includes a two-dimensional free boundary plasma equilibrium solver in

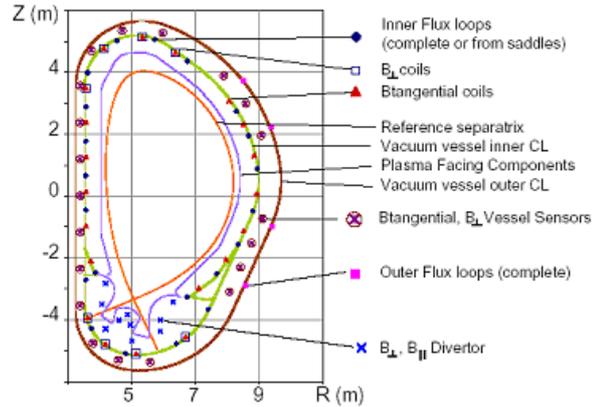


Fig. 3 Location of magnetic sensors in ITER

the external magnetic field and one-dimensional transport equations (averaged on magnetic surfaces) for poloidal magnetic flux and plasma (electron and ion) temperatures, taking into account the eddy currents in the vacuum vessel and models of the power supplies [4, 5].

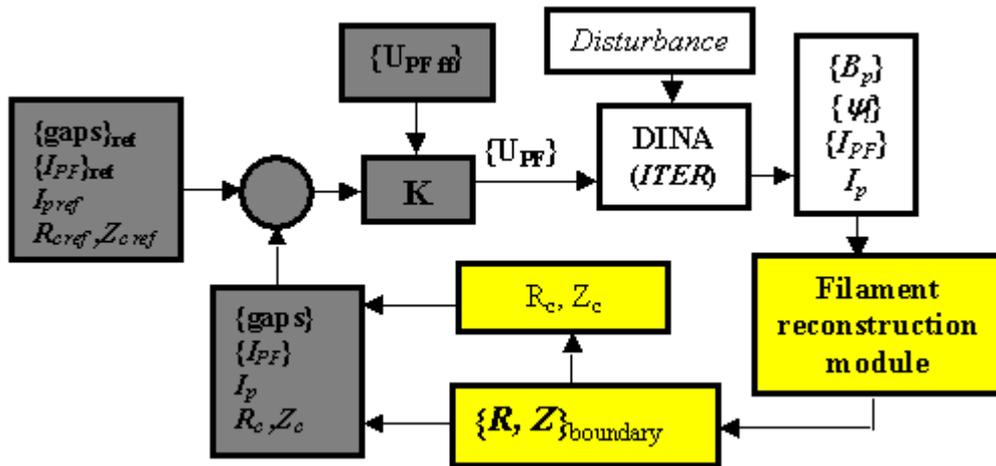


Fig. 3 Scheme of real time plasma control with DINA code

The code simulates the feedforward ($U_{PF\ ff}$) and feedback (U_{PF}) control of plasma current, position and shape. Reconstruction module provides the currents in the special distributed 4 filaments (Fig. 4) to obtain the best fitting between $\{\Psi_l, B_p\}_{rec}$ and $\{\Psi_l, B_p\}_{mes}$, where $\{\Psi_l, B_p\}_{rec}$ is magnetic data calculated with reconstructed plasma and $\{\Psi_l, B_p\}_{mes}$ is magnetic data calculated with plasma resolved by Grad-Shafranov equilibrium solver. Because of

extremely small number of filaments the reconstruction module is working very fast. The geometrical center (R_c, Z_c) is used for control of plasma position in limiter phase and plasma vertical velocity.

Problem definition

We are modelling the real time current, shape and position control of ITER plasma ramp up stage on base of LQG controller [4] and considering two irregular situations, in which a controllability is studied: 1) some magnetic sensors are producing incorrect signals at the time of scenario, 2) some magnetic sensors are broken from beginning of scenario. Relative weight of the each flux loop and magnetic probe sensor is taken the same at calculation of fitting error function.

Modeling results

Fig. 4 presents the ITER plasma position in one time moment where the blue colour magnetic surfaces are obtained with Grad-Shafranov solver and the lilac colour ones are produced by reconstructed 1÷4 filaments when

the all magnetic sensors shown in Fig. 3 are in perfect state. One can see that the quality of reconstructed plasma boundary is very high. As example Fig. 5 shows the time evolutions of R_c , Z_c and I_p behavior during plasma current ramp up for three cases of plasma control: 1) without reconstruction (these data have been obtained in [4]), 2) with 4 filaments reconstruction when the all magnetic sensors are in perfect state, 3) 6 Ψ_l loops and 7 B_p probes after time moment of $t_{ws}=50s$ are producing incorrect signals. One can see that the case 2 provides the good quality of control proceeding especially I_p and plasma position after formation of divertor plasma configuration. In case 3 turn the discharge terminates in hot VDE and following disruption.

Fig. 6 presents the results with different number of available magnetic sensors. One can see that the I_p control is not sensitive to the number of magnetic sensors but the plasma position is changing with decrease of available magnetic sensors.

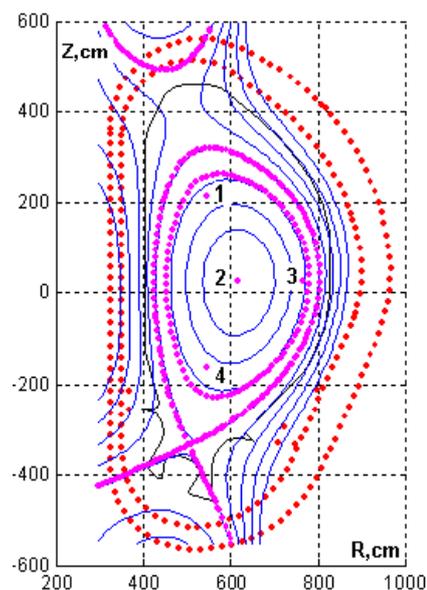


Fig. 4 Reconstructed (lilac) and Grad-Shafranov (blue) equilibrium of ITER plasma; (1÷4) are the filaments to reconstruct the plasma

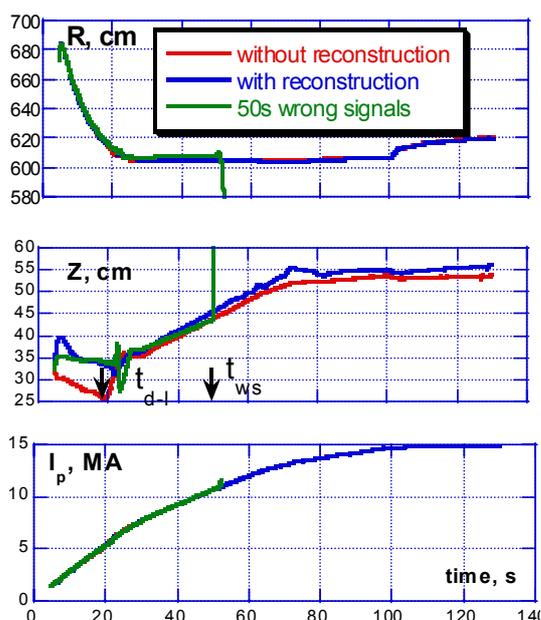


Fig. 5 R_c , Z_c and I_p time evolutions for cases without and with reconstruction; $t_{d-l}=19$ s is time moment from limiter to divertor transition, $t_{ws}=50$ s is a time of wrong sensors beginning

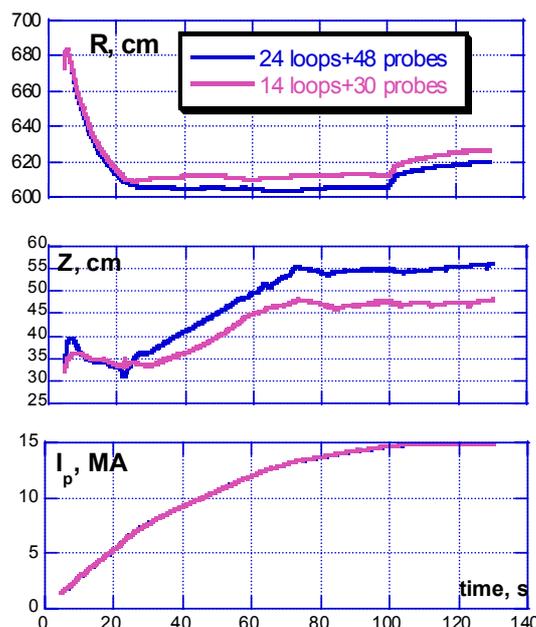


Fig. 6 Time evolutions with different number of available magnetic sensors

Conclusion

On base of DINA code the very fast scheme of plasma current, position and shape control with use of LQG controller and filament reconstruction module is demonstrated. Such scheme one can consider as a model of real time plasma current, position and shape control for ITER. It is shown that the only 4 special located filaments inside the reconstructed plasma are enough to control the current, position and shape plasma parameters. Demonstrated DINA modelling results for such kind of the real time control of the plasma current ramp up in ITER inductive scenario seem to be very encouraging.

References

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