BURN CONTROL OF ITER-LIKE PLASMAS BY A COMBINATION OF AUXILIARY POWER HEATING AND DENSITY CONTROL

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Introduction

To reach ignition and to keep the ignited plasma in a steady-state regime is one of the most important goals of the tokamaks of the next generation. As well for the access from low temperatures to the ignited state (or to a driven state with high Q) as for the maintenance of a steady-state control systems are necessary. The feasibility of control systems must be demonstrated by numerical simulation of discharges. For realistic simulations computer codes with transport models of in one or 1-½ -geometry are necessary. Nevertheless in plasma control there are effects which can be investigated with half-dimensional models where the profiles of density and temperature are fixed during the simulation. The results of case studies with half-dimensional codes can be more easily interpreted and effects can identified to be investigated in the context of more sophisticated codes.

Physical model

The plasma is described by a ½-dimensional model. obtained by flux surface averaging and profile averaging of the transport equations as done in the PLASEVOL-code[1]. This means that the density and temperature profiles of electrons, fuel alphas, helium ash and fast alpha particles are prescribed by parabolas kept constant during the evolution., e.g. for deuterium - tritium density

$$n_{DT}(\rho) = n_{DT0}\left(1 - \rho^2/a^2\right)^{\nu_{DT}}$$

where ρ is the radial co-ordinate and *a* the minor radius. ν_D is the profile parameter. The profile parameters $\nu_\alpha, \nu_{He}, \nu_e, \ldots$ for fast alphas, helium ash, electrons, have been taken from higher dimensional calculations [2] as plausible as possible.

Of course in the ½ -dimensional model there is no transport model. Energy transport is modeled by the energy confinement time τ_E expressed by ITER-89P L-mode scaling [3] and related to the loss term in the energy balance equation P_L by $P_L = W_p/\tau_E$, where W_p is the

energy content of the plasma. The jump from L-mode to H-mode at the threshold power is considered. In this case the confinement time is multiplied by an H-mode factor. We have upgraded the PLASEVOL-code by adding continuity equations for fuel

$$\frac{dn_{DT}}{dt} = -2S_\alpha - \frac{n_{DT}}{\tau_D} + (v_{DT} + 1)S_{DT} \tag{1}$$

fast alphas

$$\frac{dn_\alpha}{dt} = S_\alpha \left(\frac{v_\alpha + 1}{v_{DT} + 1} \right) - \frac{n}{\tau_{sd}} - v_L n_\alpha \tag{2}$$

and helium ash

$$\frac{dn_{He}}{dt} = \frac{n_\alpha}{\tau_{sd}} \left(\frac{v_{He} + 1}{v_\alpha + 1} \right) - \frac{n_{He}}{\tau_{He}^*}. \tag{3}$$

The densities in Eqs. (1), (2) and (3) refer to their **central** value. S_{DT} is the fuel source and S_α the fusion rate. v_L denotes the loss factor of the fast alphas, τ_{sd} is the slowing-down time and τ_E^* represents the effective helium confinement time (including recycling). It is assumed that it is related to the energy confinement time by $\tau_{He}^* = k_{He}\tau_E$ [4] where k_{He} is referred to as helium confinement factor. This quantity is not well known. From experiments it is extrapolated that k_{He} has a value between 5 to 10.

Types of control systems

The PLASEVOL code has been also upgraded by a combination of control systems. It is composed of two actuators, i. e. auxiliary heating and the fuel injection. We have three control systems are working with PID algorithms. Furthermore the control systems take into consideration delay times due to the time passing between diagnostics and reaction of the control systems. In addition to the time periods elapsed by diagnostics physical delay times are accounted for physical delay times. These delay times take into consideration the fuelling time and eventually the equilibration time for hot ions if minority heating is applied. A detailed study will be described in a forthcoming paper. We have three control principles.

The Auxiliary heating control system (ACS) is used for heating up the plasma and for driven regimes. The Fusion power control by fuel injection (FIC) adjusts the ideal operation point in the $n_i - T$ POPCON diagram. This is the high temperature crossing point of the igni-

tion contour with the line for nominal fusion power P_f = 1500 MW. The Density control system (DCS) maintains a constant density by fuel injection.

The combined control system (CCS):

The CCS finds the prescribed operation point (driven or ignited) by an appropriate combination of the control systems. .If the density approaches 140% of the Greenwald limit the density is fixed by DCS and at the same time the ACS shifts the operation point towards to the nominal fusion power curve. If the temperature falls down the plasma is held by auxiliary power in the ignited region. If this region is not accessible (Greenwald limit, beta limit) the plasma is run in a driven state. The control system runs in three regimes: The **standard operation**, the **low temperature operation** and the **high density operation**.
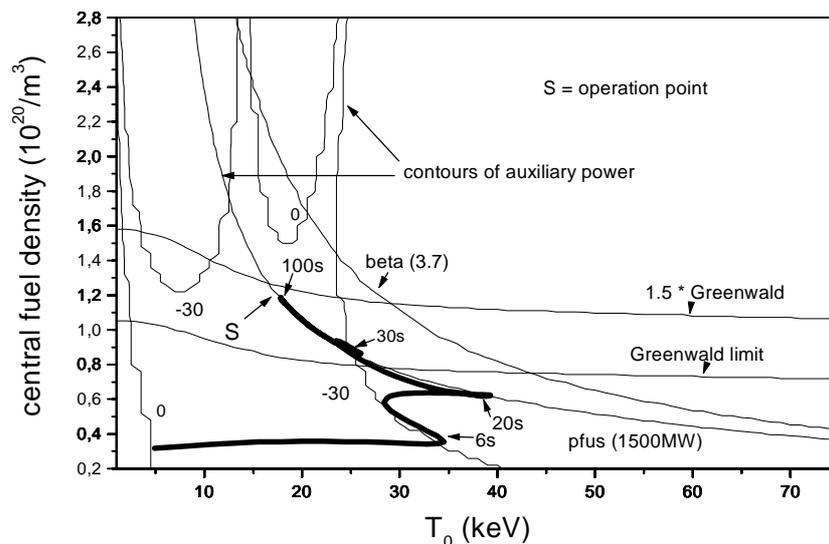

Fig. 1: The way to a driven operating point by means of the CCS

Examples

Fig. 1 is a POPCON diagram showing the contours of constant auxiliary heating for 30 MW and the ignition line characterized by the index zero. We have limited the density by 1.5 times the Greenwald density. Both curves are traced in the POPCON diagram. Furthermore the beta limit curve and the nominal fusion power curve are contained in the figure. The strong line is the trajectory of access to the operation point. S we have chosen a driven state with high Q-factor. The time (s) by reference of the staring point is marked.
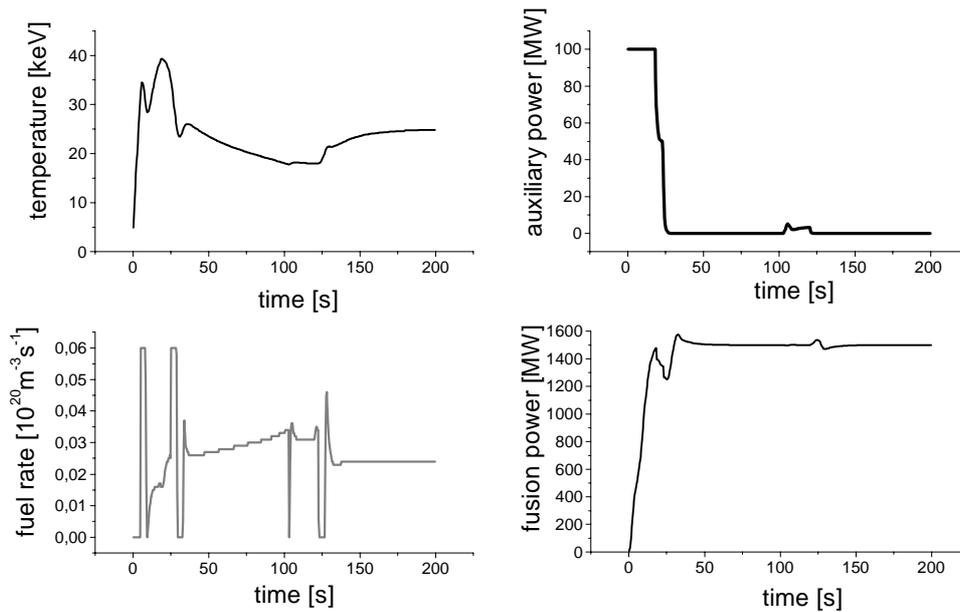
Fig. 2: An ignited Iter plasma is perturbed by a sudden enhancement of the H-factor

The second example (Fig. 2) shows the evolution of central temperature, auxiliary power, fuel injection rate and fusion power of a plasma heated to ignition. The quasi equilibrium plasma has been perturbed by a sudden increase of H-mode factor from 2 to 2.5 .

Conclusion

It is concluded that the proposed combined control system manages plasmas with Iter-parameters as well in access to power operation as well as in the cases of perturbation of equilibrium states. The results give an orientation for investigations with 1 ½ -dimensional models.

Acknowledgement

References

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