Modeling of plasma position and shape control during termination of T-15 discharges

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Introduction. The aim of the work is to simulate the magnetic control of the plasma position and shape of the T-15 tokamak currently being modernized [1] at the current ramp down stage using the plasma-physical code DINA [2] and the developed regulators [3]. At the stage of the current ramp down, additional heating is turned off, the temperature and density of the plasma drop rapidly. This leads to abrupt changes in the values of β_p, l_i, q_{95} [4], which directly affects the stability of the plasma and the possibility of its stabilization by the magnetic control system. During the whole period of current ramp down, the plasma should be in a limited area on the diagram l_i - q_{95} [5] to avoid the development of instabilities and disruption, and to maintain the divertor configuration to the minimum values of the plasma current. Several discharge termination scenarios that satisfy these criteria and take into account the actual characteristics of the poloidal magnetic field coil supplies are presented in the work. The results of the simulation are used to determine the maximum achievable current ramp down rate in the T-15 tokamak plasma.

Formulation of the problem. When the plasma current decreases, it is necessary to reduce its size and a plasma density value according to the formula

$$\langle n_e \rangle / n_{GW} < 1, \quad (1)$$

here $n_{GW}\,[10^{20}\text{м}^{-3}] = \frac{I_p\,[\text{MA}]}{\pi a^2 [\text{м}]}$ – the Greenwald plasma density limit, I_p – the plasma current, a – the minor radius. However, a decrease of the plasma size decreases the distances from plasma to the conductive elements of the tokamak, which play the role of passive stabilization of vertical instability. Due to the weakening of the confinement regime, a jump of poloidal beta β_p, which determines the equilibrium configuration of the plasma column, is possible. As a result the plasma radial displacements are possible. Because of the skin effect, the effect of the control windings of the magnetic system on the plasma for the purpose of the current output is applied mainly to the boundary part of it. This causes the current density profile in the plasma to peak (Fig.1) and, accordingly, the growth of the internal inductance of the plasma, which means an even greater distance from the plasma to the conducting structures. Although a decrease of the plasma elongation improves vertical stability, at current rampdown stage, it is desirable to maintain the divertor configuration of the plasma as long as possible in order to minimize the thermal load on the first wall of a tokamak. Significant effect on the control process is caused by restrictions on the voltage of power supplies, which worsen the theoretical possibilities of the regulator of the control system.

which worsen the theoretical possibilities of the regulator of the control system. In connection with above, the following requirements are imposed on the plasma current rampdown phase:

1. The possibility of stabilizing the magnetic configuration by the control system.
2. Plasma in the process of the current rampdown phase should keep the divertor configuration to minimum plasma current values to save the resource of the first wall.
3. The control of position and shape should be provided taking into account the real characteristics of the electric power supply system.

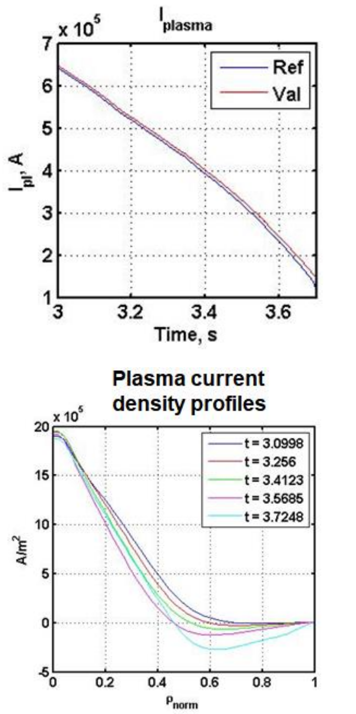

Fig. 1. Plasma current density profiles at different moments of T-15 current rampdown

Numerical modeling. Let us consider the numerical simulation of two scenarios with different current rampdown rates for estimating the effect of the current rampdown rate on the operation of the control system (Fig. 2). The current output

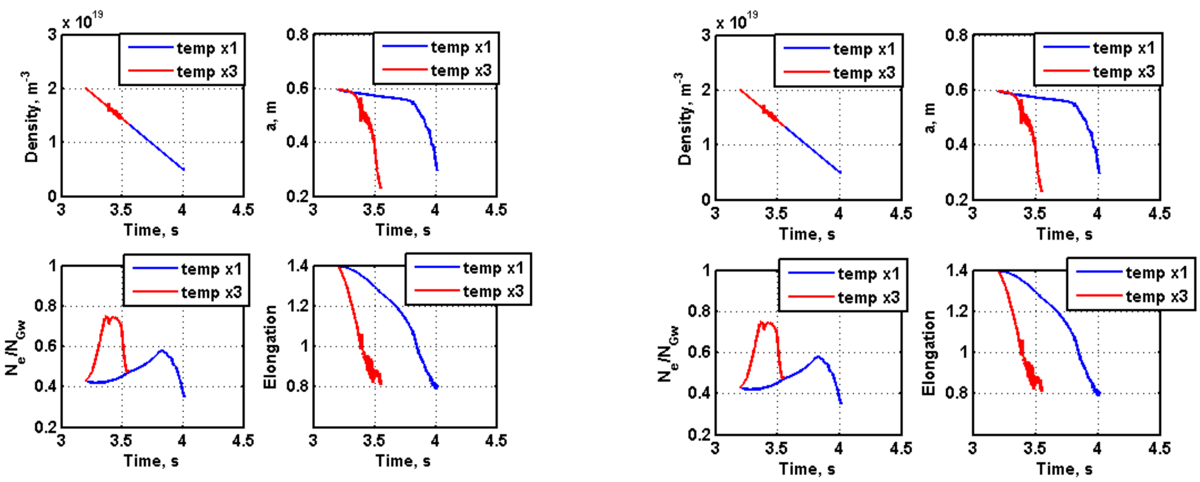

Fig. 2. Graphs of scalar values for scenarios of current rampdown at a speed of 660 kA/s (blue) and 2000 kA/s (red)

rate was 660 kA/s and 2000 kA/s, taking into account the limitations of the maximum supply voltages of the control windings. The figure shows that at higher current output speeds, higher values of the internal inductance

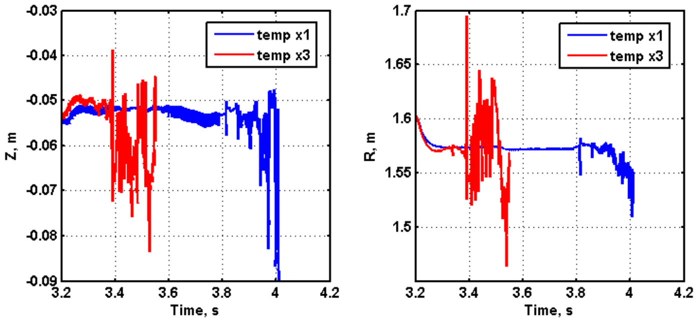

Fig. 3. The vertical and radial coordinates of the plasma column for current rampdown scenarios at a rate of 660 kA/s (blue) and 2000 kA/s (red)

$l_i(3)$ actually appear, as well as smaller values of the stability margin at the plasma boundary, and the plasma density value is closer to the Greenwald limit. The remaining values on the graphs differ only in the rate of change, which corresponds to the overall acceleration of the change in scenario values. Increasing $l_i(3)$ leads to a more difficult control process, as can be seen in Fig. 3. Oscillations of the plasma position are noticeably amplified.

Fig. 4 shows that the faster current output, the higher voltages for control windings are required to suppress the development of unstable plasma displacements.

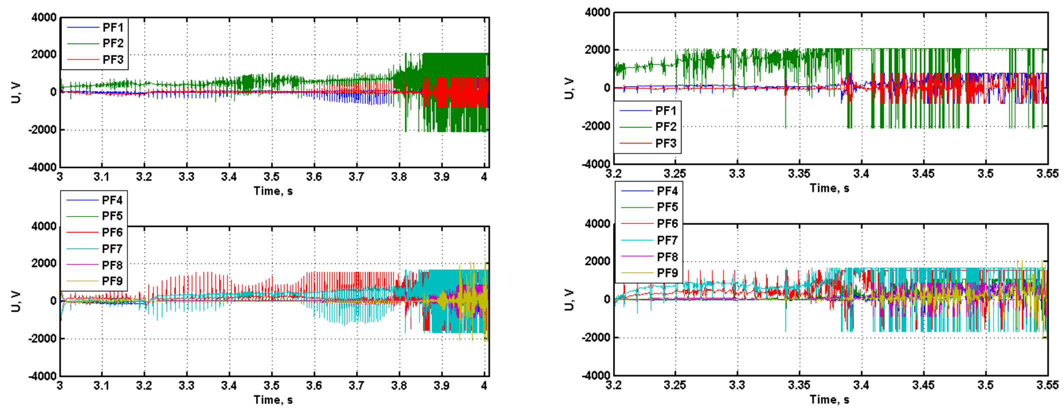

Fig. 4. Voltages on poloidal field control windings for current rampdown scenarios at 660 kA/s (left) and 2000 kA/s (right)

This affects the power consumed by the power supplies of the magnetic control windings. Fig. 5 shows the power estimation graphs for the scenarios under consideration. Because of the higher applied voltages with the rapid current rampdown, the power consumption is greatly increased. When the control voltages reach the limits, the efficiency of the corresponding coils for control drops sharply. The quality of control not only in the vertical and radial positions of the plasma (Fig.3) suffers, and the shape of the plasma deteriorates. At a high

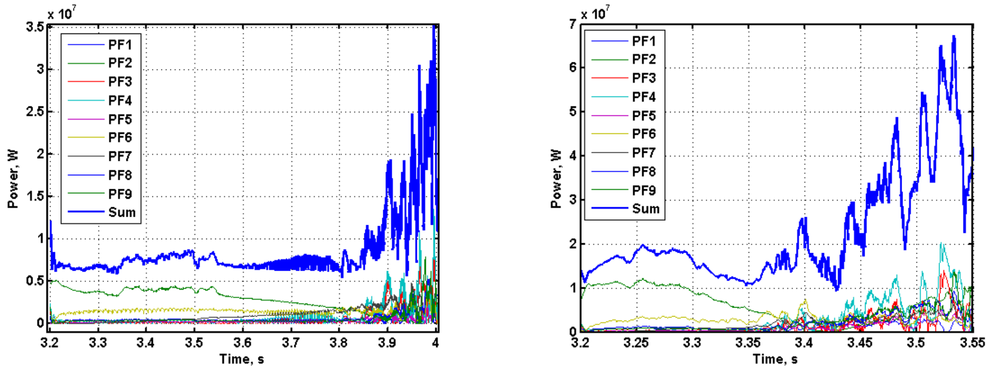

Fig. 5. Estimates of the power consumed by the control system for current rampdown scenarios at 660 kA/s (left) and 2000 kA/s (right)

current output speed, considerable currents are induced in the vacuum chamber, which interact with the plasma and can lead to distortions in the configuration of equilibrium and displacement of the plasma column. Destruction of the divertor configuration and the transition of the X point to another location is possible. In T-15 with a 2000 kA/s current rampdown rate this occurs at a plasma current of 226 kA, and correspondently at a 600 kA/s at a current of 136 kA.

Conclusion. As a result of comparing the T-15 scenarios with different current rampdown rates, it was obtained that at a higher current output rate:

1. The quality of control of the position and shape of the plasma deteriorates due to the deterioration of the plasma stability and the influence of engineering limitations on the power supply voltage of the control system;
2. The change in the divertor configuration of equilibrium occurs with a greater plasma current value, which can cause an increased thermal load on the first wall of the tokamak;
3. The power consumed by the magnetic control system is significantly increased.

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