Analysis of the initial stage of discharge in the T-15MD tokamak

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At present, the T-15MD tokamak is being modernized in NRC "Kurchatov Institute", Russia. This device should provide the ability to operate with a non-circular plasma shape, with a divertor, as well as with a more powerful system of additional plasma heating. This allows us to study issues related to the control of the plasma position and parameters in details, to develop the feedback systems and methods to control the level of impurities in the plasma and to optimize the tokamak operation modes. Researches on the T-15MD will solve a variety of tasks in support of the ITER project: to test various ITER subsystems, to investigate the different modes of operation.

At the present time, the tasks of preparing the physical start-up of the T-15MD, as well as a more detailed analysis of the base discharge scenarios assumed in experiments become important. In [1, 2], the stationary discharge stage was analyzed. It was shown that the vertical instability of the quasi steady state plasma can be suppressed by the feedback system. It was also shown that the system of magnetic plasma diagnostics can restore the plasma boundary with the tolerable error (less than 1 cm) if the magnetic field and the flux measuring errors do not exceed 1-3 %.

Meanwhile, the analysis of stationary states alone is not sufficient. An example of an "unsuccessful" (unrealistic) scenario was given in [3], in which, due to too early elongation of the plasma column, a vertically unstable configuration appeared, which could not be stabilized by the feedback system.

Today, all the elements of the T-15MD design have acquired their specifics [4], and it is possible to conduct a detailed analysis of the discharge scenario. The focus of this work is to analyze the initial stage of the discharge. Such calculations were performed earlier in [7] using the DINA code [8]. At present, new numerical codes TOKSCEN (equilibrium, vertical stability and plasma evolution) [5] and RPB (restoration of the plasma boundary) [6, 9] have been developed by a joint group of researchers from Russian Federation and the Republic of Kazakhstan. Using these codes, we conduct a more detailed analysis of the initial stage of discharge and the current ramp-up. At first, we study problem of the vertical plasma instability at this stage of discharge. At second, we find the error in restoring the plasma boundary caused by magnetic field errors. Calculations show that the considered stage of discharge can be realized in experiment.

We calculated the initial stage of discharge, preceding the vertical elongation of the plasma column (discharge time from 0.04 to 0.76 sec). Within this time interval, several instants were chosen, in which we determined the possibility to suppress the vertical plasma instability and to find the accuracy of plasma boundary calculation, taking into account the error in the magnetic signals.

Figures 1a-4a consistently reproduced the initial stage of the discharge (t = 0.04, 0.16, 0.46 and 0.76 sec.). In Figs. 1b-4b, the dotted line shows the accuracy of the restoration of the boundary and the separatrix, using a system of two-component magnetic sensors with the relative error of 1%. It is seen that measurement error less than 1% leads to the error in plasma boundary reconstruction less than 2 cm that is quite acceptable. The accuracy of determining the separatrix X-point is from 1 to 5 mm. This allows us to monitor the position of the "whiskers" of the separatrix for effective divertor operation. There are no vertical instability found up to t = 0.76 sec that is explained by the small elongation of the plasma cross section. In the following stage of the discharge [10], such instability arises, but its increment is small, and it can be suppressed by an active feedback system. The performed calculations show that the considered initial stage of the discharge can be realized in the full-scale experiment on T-15MD.

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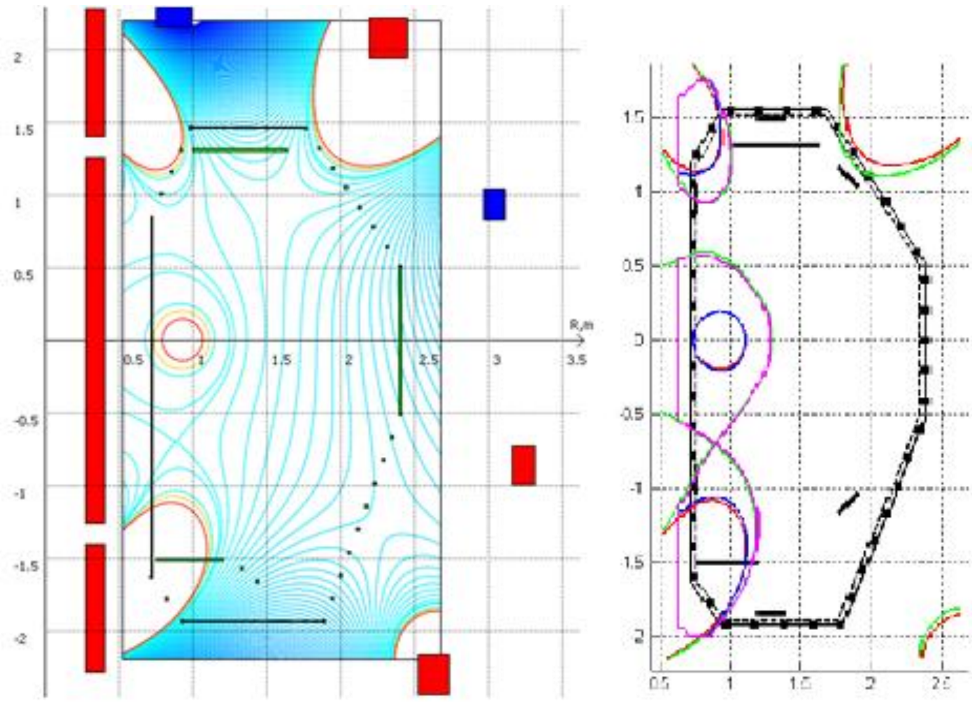

Figure 1(a, b). (a) Stage of current breakdown in the T-15MD. At the time moment t = 0.04s, I_p = 0.017 MA, R_{mid95}=0.924 m, a=0.185 m, k = 1.04, β_p=0.35. **(b)** Reconstruction of the plasma boundary (red and blue lines) and separatrix (green and yellow lines), 44 two-component magnetic sensors (squares), measurements error 1%.

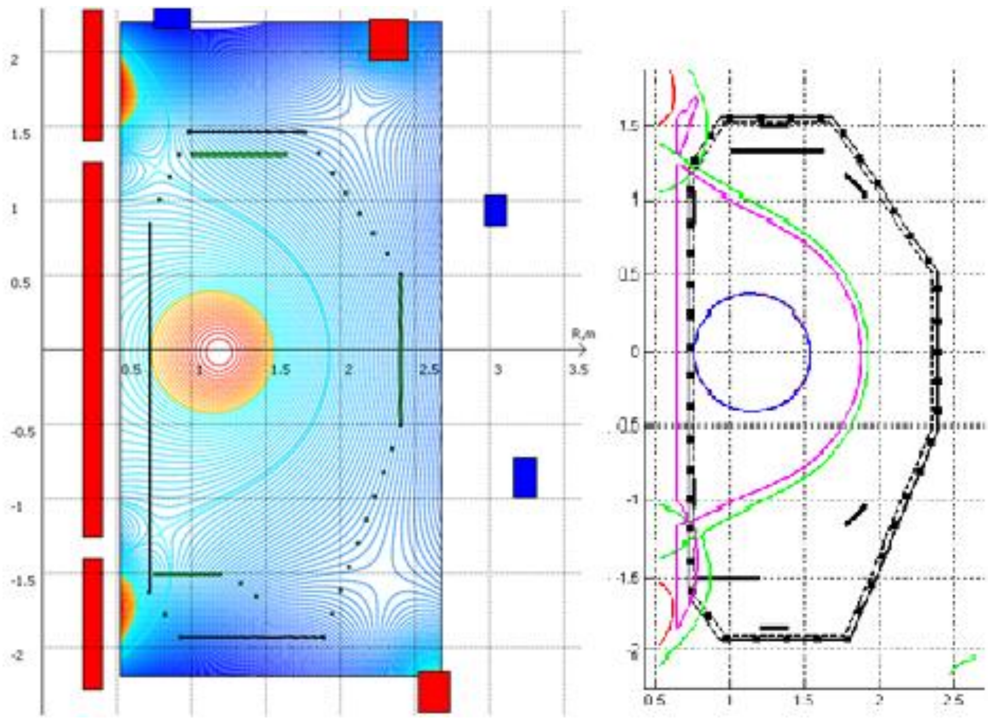

Figure 2(a, b). (a) The magnetic configuration of the T-15MD at the time moment t = 0.16 s, I_p = 0.105 MA, R_{mid95} = 1.15 m, a = 0.39 m, k = 1.0, β_p =0.33. **(b)** Reconstruction of the plasma boundary (blue and red lines) and separatrix (green and purple lines), measurement error 1%, 44 two-component magnetic sensors (squares).

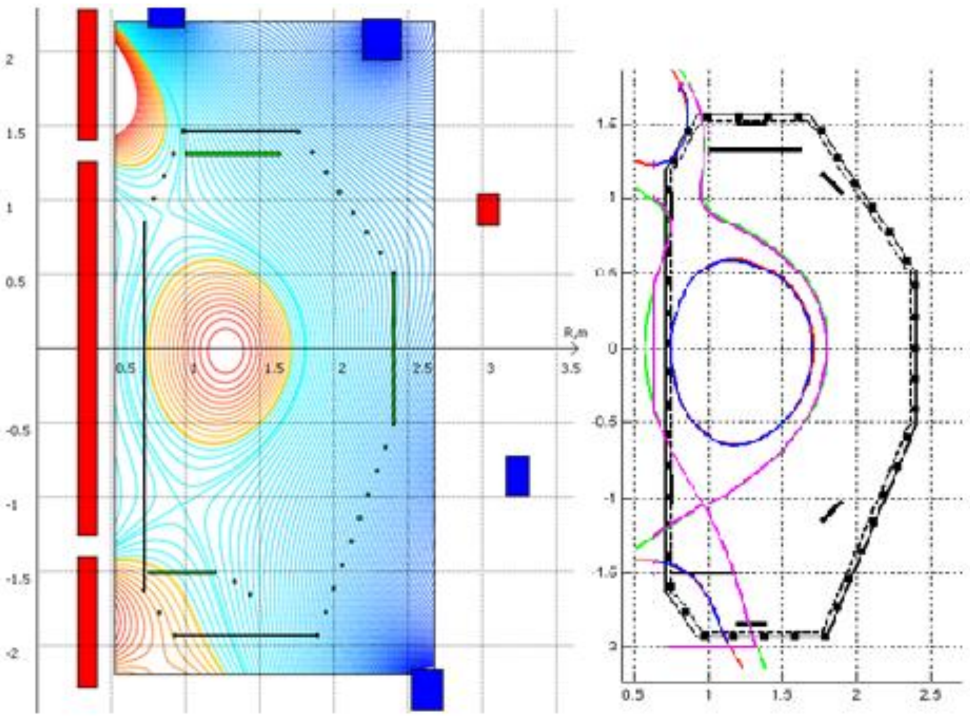

Figure 3(a, b). (a) The magnetic configuration of the T-15MD at the time moment t = 0.46 s, I_p = 0.3055 MA, R_{mid95} = 1.23 m, a = 0.48 m, k = 1.3, β_p = 0.22. **(b)** Reconstruction of the plasma boundary (blue and red lines), and separatrix (green and purple lines), measurement error 1%, 44 two-component magnetic sensors (squares).

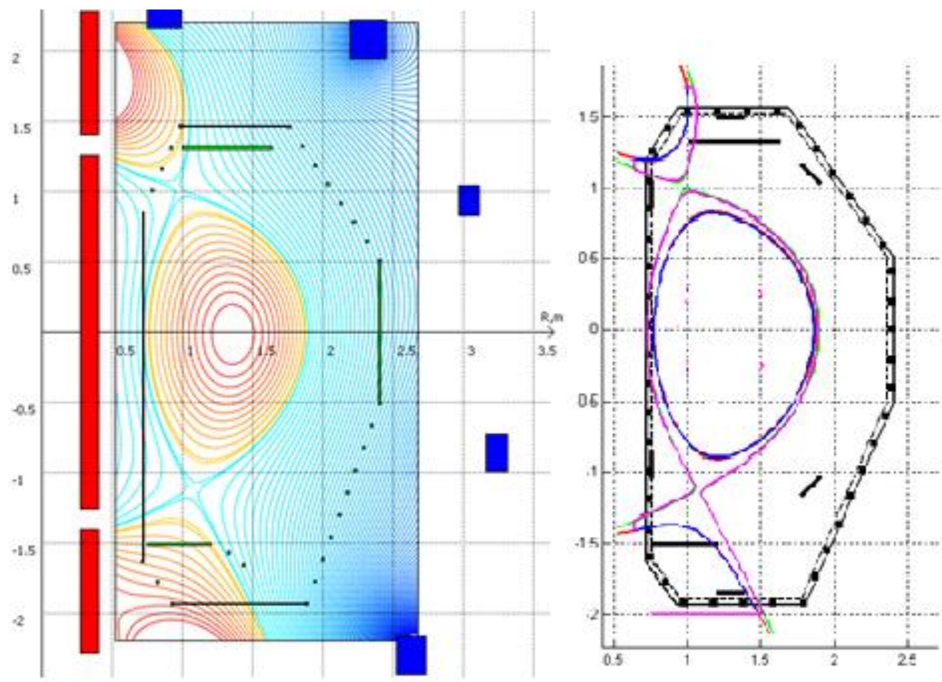

Figure 4(a, b). (a) The magnetic configuration of the T-15MD at the time moment t = 0.76 s, I_p = 0.5059 MA, R_{mid95} = 1.32 m, a=0.55 m, k = 1.58, β_p = 0.18. **(b)** Reconstruction of the plasma boundary (blue and red lines), and separatrix (green and purple lines), measurement error 1%, 44 two-component magnetic sensors (squares).