Simulation of electromagnetic diagnostics system of the tokamak T-15M

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Abstract. We describe results of modeling the control of the plasma boundary and separatrix in the T-15M tokamak. In this paper, based on one of the possible scenarios projected discharge tokamak T-15M (Russia) shows the results of solving the inverse problem, obtained using the code RPB. Simulation of scenario discharge was conducted by numerical modules TOKAMEQ and DINA.

Introduction. The T-15M Tokamak is now on the stage of the design and construction. The main plasma parameters in the T-15M are given in Table 1 [1]. At present the most urgent problem is the analysis of Ohmic discharge scenario. Initialization occurs on the inner wall of the vacuum vessel for the following parameters R=1.2m, a=0.4m, k_{95} =1.02, Z_{axis} =0.0m. After that, plasma current rises with a plasma column, stretching it vertically and shifting it to the center of the vacuum vessel (R=1.2$\rightarrow$1.5m, a=0.4$\rightarrow$0.65m, k_{95} =1$\rightarrow$1.7). At the end of the current ramp-up stage a transition from limiter to divertor configuration takes place. The special attention is paid to the control of the vertical plasma position. This is due to the fact that the ground value of the elongation k_{95} =1.7 is greater than the neutrally stable to vertical displacements one for value k_{95} =1.2–1.3 and a given aspect ratio.

Plasma major radius, R(m)	1.2 – 1.5
Plasma minor radius, a(m)	0.4 – 0.65
Aspect ratio	~ 2.3
Plasma elongation, k_{95}	1.0 – 1.7
Triangularity, average	-0.01 – 0.4
Plasma axis vertical shift, $Z_{axis}(m)$	0 – 0.1
Plasma current,. $I_p(MA)$	0.15 – 1.1
Poloidal beta β_p	0.2 – 0.35
Internal inductance, l_i	0.5 – 1.0

To improve the modeling accuracy the baseline scenario of the discharge in the T-15M was calculated by different computer codes. Thus, in addition to DINA code [2], the script control points were also counted using TOKAMEQ code [3] and RPB code [4].

The system of magnetic measurements in the T-15M device. There is a set of 36 two-component sensors located on the inner surface of the vacuum vessel in the shadow of the diaphragm (set of squares on Fig. 1–3). These sensors measure the tangential and normal components of the poloidal magnetic field with respect to the contour of the chamber.

The problem of reconstruction of the plasma boundary is formulated as an inverse problem of the MHD equilibrium and described by Grad–Shafranov equation in the annular region with an additional Cauchy condition on its outer edge. The methods of solving of this problem are based on the following approaches: toroidal harmonics [5], filaments [6] and integral equations [7]. The method used in this paper is based on integral equations and had previously been used to simulate the installation KTM [8].

Analysis of reconstruction accuracy. We analyzed the influence of measurement error of the magnetic fields and the total number of sensors. MHD equilibrium configurations were modeled using TOKAMEQ code. The geometry of the coils, values of external currents and plasma parameters corresponded to the basic Ohmic scenario. Next, the calculated flux of the poloidal field was used to set signals on sensors. Additional disturbances were induced onto these signals by a uniformly distributed random variable for modeling measurement errors. These data were used as inputs in the problem of reconstruction.

t, mc	45	745	1445	2745
R(m)	1.41	1.44	1.48	1.46
a(m)	0.62	0.66	0.68	0.675
k_{95}	1.2	1.41	1.76	1.58
Δ_{aver}	-0.02	0.4	0.23	0.21
$Z_{axis}(m)$	0.0	0.13	0.1	0.05
$I_p(MA)$	0.064	0.68	1.09	0.91
β_p	0.35	0.2	0.2	0.26
l_i	0.5	0.79	0.9	0.8
(r_s, z_s)	(1.16,-1.1)	(1.08,-1,03)	(1.13,-1.23)	(1.15,-1.32)

The difference between the originally specified and reconstructed geometrical characteristics of the plasma makes it possible to analyze the accuracy of the reconstruction. We have selected a few scenario points of t=45, 745, 1445 and 2745ms, that corresponded to the evolution of discharge from the initial stage to plateau. Table 2 shows the parameters of the plasma for selected time moments. Our numerical experiment was based on the following requirements to the accuracy of determination of the plasma boundary: ~1cm for X-point of the separatrix and 0.5–1cm for the rest of the boundary. For the equilibrium No. 2 (t=745ms) accuracy of the determination of position of X-point separatrix $(r_s, z_s) = (1.08, -1.03)$ was estimated depending on the measurement error (Table 3a). It can be seen that at the stationary stage of discharge the error is about 1–2cm. The effect of reduction in the number of sensors from 36 to 30 is illustrated in Table 3b.

δ ,%	1	2	3	5	7
a) 36 sens. r_s , m	1.059	1.061	1.062	1.065	1.067
z_s m	-1.017	-1.019	-1.022	-1.026	-1.030
b) 30 sens. r_s , m	1.087	1.097	1.102	1.102	1.105
z_s m	-1.027	-1.029	-1.030	-1.030	-1.031

Fig.1: t=745ms, the measurement error δ =7%

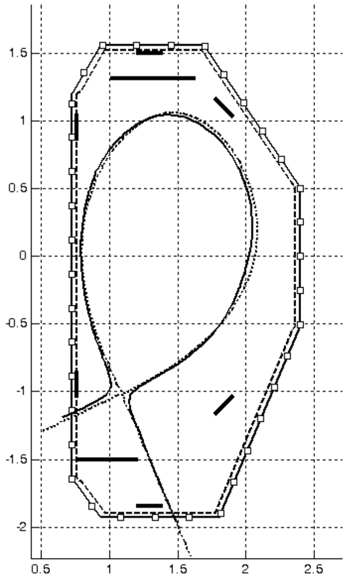


Fig.2: t=1445ms, the measurement error δ =5%

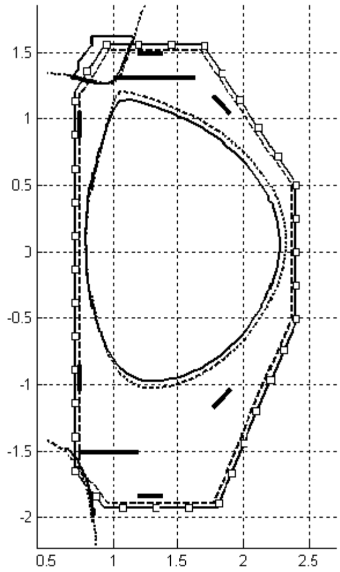
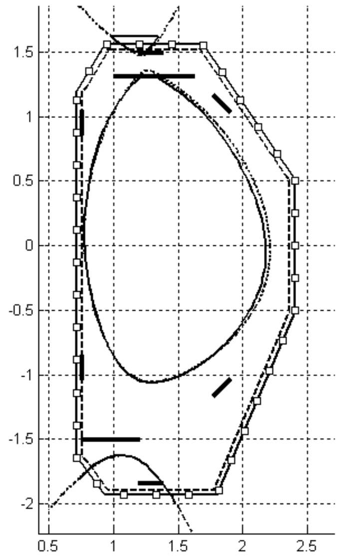


Fig.3: t=2745ms, the measurement error δ =1%, dots curve – exact shape, solid – reconstructed, dashed diaphragm



Next was the task to determine the required accuracy of measurement of magnetic fields, sufficient to control the contacting of whiskers of the separatrix with the divertor table, in order to assess the effectiveness of the divertor. Fig. 1–3 show the reconstruction of the boundary surface for different time moments and initial data errors (t=745ms, t=1445ms and t=2745ms, δ =1%, 5%, 7%). We see that for the above time points for the error level in the range of 1-7% have a good correspondence between the real and reconstructed separatrix. This means that the levels of measurement error of the field less then 7% do make it possible to control the separatrix effectively. Fig.4 shows a selection of the regularization parameter

Fig.4: t=745ms, the measurement error δ =1%, 7%

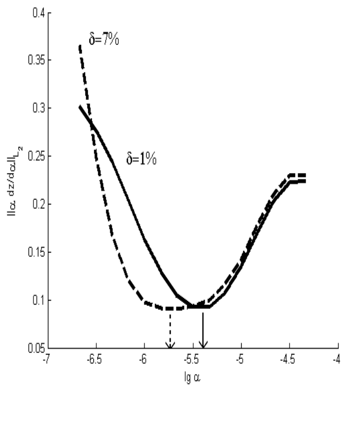


Fig.5a: t=2745ms, plasma current profile, γ=0, 1

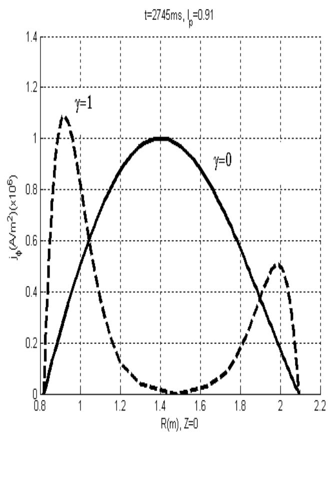
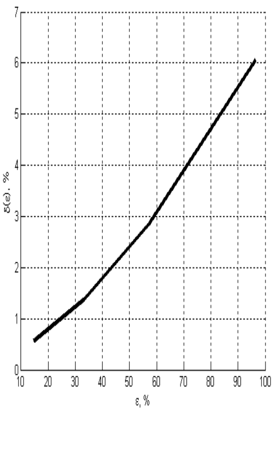


Fig.5b: t=2745ms, difference magnetic signals on Γ_p



using the quasi-optimal method. Arrows indicate the alpha value corresponding to the reconstructed plasma boundary (Fig.1).

The Fig.5a shows two possible very different current density inside the plasma $j_\varphi(r,\psi) = \lambda(\beta_p r/R + (1-\beta_p)R/r)g(x)$, $g(x) = x^\alpha(1-\gamma x^\alpha)$, $x = (\psi - \psi_p)/(\psi_{\max} - \psi_p)$, ($\gamma$ =0, 1) for t=2745ms. Fig.5b shows the difference between the magnetic signals on the plasma boundary $\delta = \left\| B_\tau^0 - B_\tau^\gamma \right\|_C / \max_{\gamma\in[0,1]} \left\| B_\tau^\gamma \right\|_C$ depending on the difference in current profiles $\varepsilon = \left\| j_\varphi^0 - j_\varphi^\gamma \right\|_C / \max_{\gamma\in[0,1]} \left\| j_\varphi^\gamma \right\|_C$. As can be seen from Figure 5a, b with an error greater than 6% two very different current profile by magnetic measurements can not distinguish.

Conclusions. Based on the results of numerical modeling of the system of magnetic diagnostics of the boundary surface in the T-15M facility we can draw the following conclusions: the required accuracy for the effective control of the separatrix is 1–7%; reducing the number of magnetic probes up to 30 leads to a drop in the accuracy in determining the X-point of the separatrix on 2 cm; in order to distinguish between the two essentially different current profiles required level of accuracy of magnetic measurements should not exceed 6%.

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