Analysis of Magnetic Diagnostic in the KTM Tokamak

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Abstract. We describe results of modeling the control of the plasma boundary and separatrix in the KTM tokamak. The problems of the required measurement accuracy of flux and magnetic field are discussed.

Introduction. The KTM Tokamak is now on the stage of the start up operations. The main plasma parameters in the KTM are given in Table 1 [1]. At present the most urgent problem is the analysis of Ohmic discharge scenario. Initialization occurs on the outer wall of the vacuum vessel for the following parameters R=1.2m, a=0.2m, $k_{95}=1$, $Z_{axis}=0.3$m.

Plasma major radius, R(m)	0.9 – 1.2
Plasma minor radius, a(m)	0.2 – 0.45
Aspect ratio	~ 2
Plasma elongation, k_{95}	1.0 – 1.7
Triangularity, average	-0.01 – 0.1
Plasma axis vertical shift, $Z_{axis}(m)$	0 – 0.3
Plasma current,. $I_p(MA)$	0.15 – 0.75
Poloidal beta β_p	0.1 – 0.15
Internal inductance, l_i	0.98 – 1.4

After that, plasma current rises with a simultaneous increase in the size of the plasma column, stretching it vertically and shifting it to the center of the vacuum vessel (R=1.2$\rightarrow$0.9m, a=0.2$\rightarrow$0.45m, $k_{95}=1\rightarrow1.7$). 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.

To improve the modeling accuracy the baseline scenario of the discharge in the KTM was calculated by different computer codes. Thus, in addition to DINA code [2], the script control points were also counted using TOKAMEQ code [3–4, 7]. The vertical stability of the plasma was studied by PET [5] and TOKSTAB [6, 8] codes. The agreement of results is very good [7-8].

The system of magnetic measurements in the KTM 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 [9], filaments [11–12] and integral equations [10]. The method used in this paper is based on integral equations.

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	9	59	159	259
R(m)	1.2	1.02	0.95	0.95
a(m)	0.18	0.35	0.45	0.43
k_{95}	1.0	1.07	1.38	1.63
Δ_{aver}	-0.02	0.05	0.19	0.09
$Z_{axis}(m)$	0.3	0.3	0.3	0.3
$I_p(MA)$	0.15	0.175	0.35	0.75
β_p	0.1	0.1	0.25	0.15
l_i	1.36	1.32	1.11	0.98
(r_s, z_s)	0	0	0	(0.82,-0.55)

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=9, 59, 159 and 259ms, 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

δ ,%	1	2	3	5	7
a) 36 sens. r_s , m	0.817	0.807	0.8	0.748	0.709
z_s m	-0.527	-0.515	-0.504	-0.473	-0.468
b) 33 sens. r_s , m	0.808	0.791	0.787	0.757	0.739
z_s m	-0.537	-0.515	-0.502	-0.490	-0.502

boundary: ~1cm for X-point of the separatrix and 0.5–1cm for the rest of the boundary. For the equilibrium No. 4 (t=259mc) accuracy of the determination of position of X-point separatrix $(r_s, z_s) = (0.823, -0.55)$ 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 33 is illustrated in Table 3b.

Figure 1: t=159ms, the measurement error δ =1%

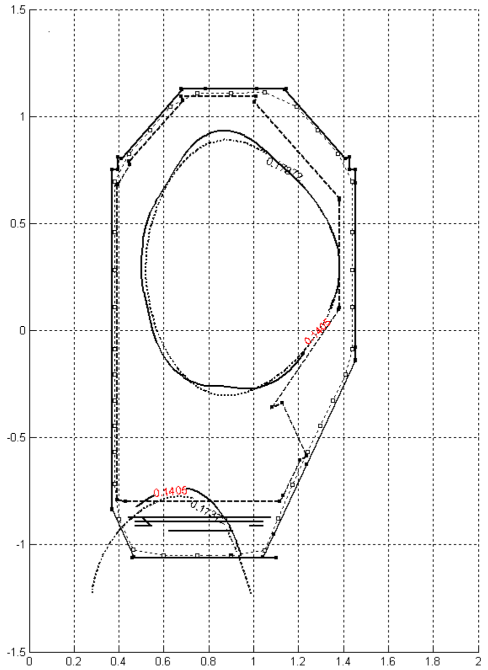


Figure 2: t=259ms, the mesurement error δ =1%

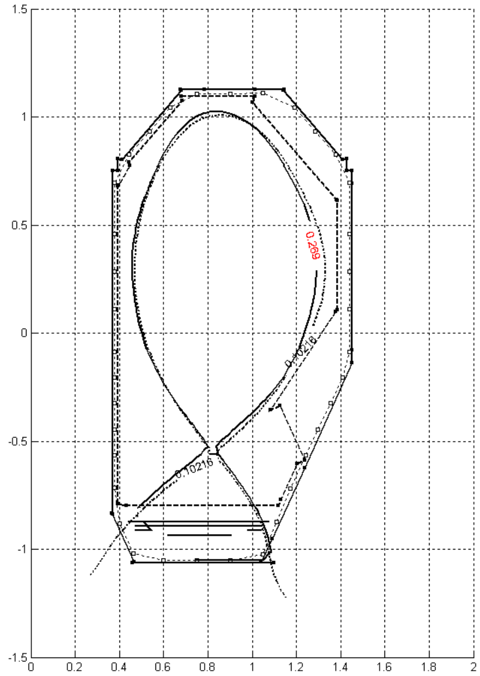
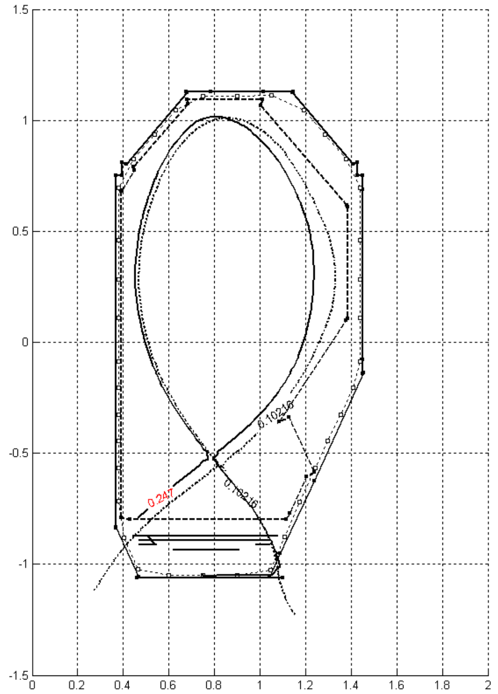


Figure 3: t=259ms, the measurement error δ =5%,
dots curve – exact shape, solid – reconstructed,
dashed - diaphragm



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=159ms, δ = 1% and t=259ms, δ =1, 5%). One can see that for the first three levels of error (δ =1, 2, 3%) both real and reconstructed separatrix are close on the surface of the table, and the levels of error 5% and 7% lead to the fact that the reconstructed separatrix on the table is not closed. This means that the levels of measurement error of the field more than 5% do not make it possible to control the separatrix effectively.

Conclusions. Based on the results of numerical modeling of the system of magnetic diagnostics of the boundary surface in the KTM facility we can draw the following conclusions: - the required accuracy for the effective control of the separatrix is 1–3% when forming divertor configuration; - replacement of magnetic probes on measuring the magnetic flux loops can improve the accuracy of the reconstruction of the boundary surface if the measurement error does not exceed 5%.

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