Development and inclusion of Iron Model into evolution codes.

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There are exist several tokamaks, which has Iron Core Transformer, such as JET, TOR-SUPRA, T15. Usual evolution codes can not be used directly to model physical processes at these devices and serious modification of them is required to describe a plasma column behavior and carry out discharge simulations.

New Iron model for simulation of plasma evolution in tokamaks has been developed and included into DINA[1] and SPIDER[2] codes. Two methods of Iron representation, such as Full domain and Surface Currents model were studied and tested. Benchmark calculations of test model problem with commercial package ANSYS were carried out. Preliminary results of the test simulations for ramp-up and flattop scenarios of T15 tokamak [3] with divertor plasma are presented.

Full domain Iron model, comparison with ANSYS [4]

To test a numerical algorithm of poloidal flux distribution produced by magnetic iron we apply a 2D iron model approach (Fig. 1) and distributed source of plasma current.

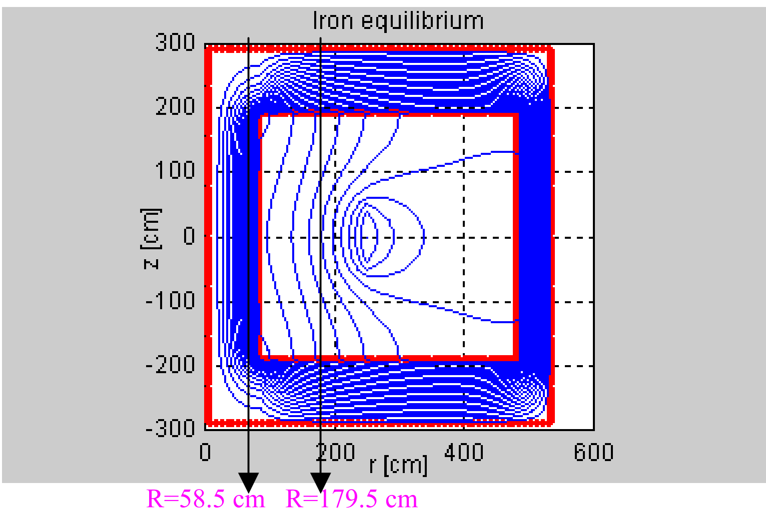

Fig. 1. 2D iron model approtch in rectangular grid

Poloidal flux $\tilde{\Psi}$ one can present as $\tilde{\Psi} = \Psi_{Fe} + \Psi_j$ where ψ_{Fe} is poloidal flux produced by iron and Ψ_j is poloidal flux produced by plasma current distributed source. Equation for plasma equilibrium one can present as:

- in the area of current source: $r\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial\tilde{\Psi}}{\partial r}\right)+\frac{\partial^2\tilde{\Psi}}{\partial z^2} = -r\mu_0 j$

- in the iron and air: $\frac{\partial}{\partial r}\left(\frac{1}{\mu\ r}\frac{\partial\tilde{\Psi}}{\partial r}\right)+\frac{\partial}{\partial z}\left(\frac{1}{\mu\ r}\frac{\partial\tilde{\Psi}}{\partial z}\right)=0$, μ=1 at air,

With $\tilde{\Psi}$=0 in the outer boundary of iron. The task of $\tilde{\Psi}$ calculation is a very non-linear because of big changing of iron magnetizability μ. The 2D modeling of $\tilde{\Psi}$ distribution in rectangular grid has been used to obtain the Ψ_{Fe} value as function of μ and external magnetic flux B_{ext} in the boundary of central core of iron. Results of such modeling for B_{ext}=18 kG are presented in the Table where $H_{ext=}$ B_{ext}* α(μ), B_{Fe}= μ* H_{ext} and B_{ext}=0.18 kG. This data are obtained for the current source I=50kA located in R=250cm. In Fig.1 the two sections are shown where the distribution of magnetic field obtained with full domain iron model are compared with ANSYS modeling.

μ	H_{ext}, kG	B_{Fe}, kG	Ψ_{Fe}, Vs	α(μ)
1000	0.1	100	3.4	0.556
500	0.12	60	2	0.667
100	0.14	14	0.48	0.778
50	0.15	7.35	0.25	0.833
10	0.16	1.6	0.055	0.889
5	0.173	0.86	0.029	0.961
2	0.18	0.31	0.012	1.
1	0.18	0.18	0.006	1.

Table. Dependence of Ψ_{Fe} value on μ with B_{ext} =0.18 kG specified

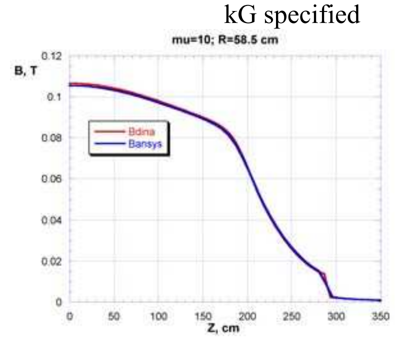

Fig.2 a (μ=10, R=58.5 cm)

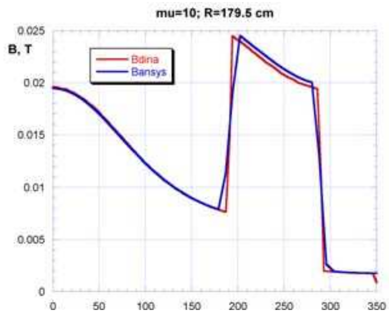

Fig.2 c (μ=10, R=179.5

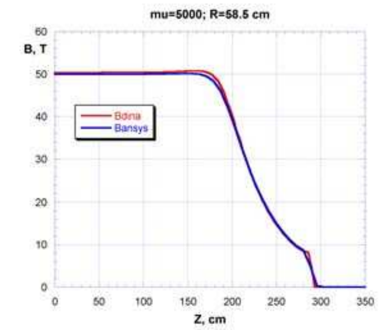

Fig.2 b (μ=50000, R=58.5 cm)

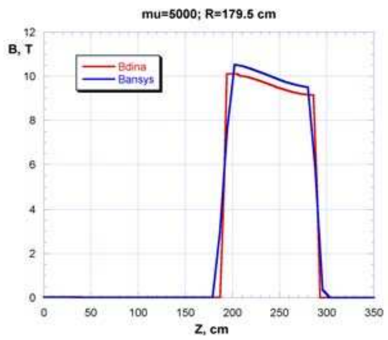

Fig.2 d (μ=5000, R=58.5

The results of comparison for the values of μ=10 and 5000 in each of this sections are presented in Fig. 2 (“red” color is Full domain of iron model, “blue” is ANSYS model). One can see that the difference results between the two methods no more than 1%. The function of Ψ_{Fe} = f_Ψ(B_{ext}, μ) presented in the Table has been used to model T15 scenario in present work.

Surface currents Iron model

In the first approximation iron magnetization core currents are approximated by currents flowing in the interface iron-air surfaces. In the poloidal cross section these interfaces are presented as two close loop lines, internal, which surround plasma and passive structure and external, which surround iron core, plasma and passive structure. Curves are divided into segments with uniform current density in each. The boundary condition that the tangential component of the magnetic intensity at each i^{th} segment are continuous across the interface is used to derive a system of equation for surface currents:

$B_t^{iron}(\gamma_i) = \mu_r(B_i) B_t^{air}(\gamma_i)$ or as system:

$$[\mu_r(B_i)-1][\,B_t^e(\gamma_i) + \sum_j b_\tau(\gamma_i,\gamma_j) I_j\,] - [\mu_r(B_i)+1]\,\frac{\mu_0 I_i}{2L_i} = 0,$$

the singularity at i=j is avoided by using integral relation [5]. To take into account the volume magnetisation currents inside core it is divided into segments by curves which separates regions with the different magnetic permeability and the additional relation is used: $\mu_1(B_i) B_t^{iron\_2}(\gamma_i) = \mu_2(B_i) B_t^{iron\_1}(\gamma_i)$

Preliminary results of T15 plasma ramp-up modeling

New developed iron model has been tested for simulation of scenario with diverted plasma in T15 tokamak. In Fig. 3 the poloidal magnetic field system of T15 tokamak [3] is presented together with three additional PF divertor coils located inside of vacuum vessel.

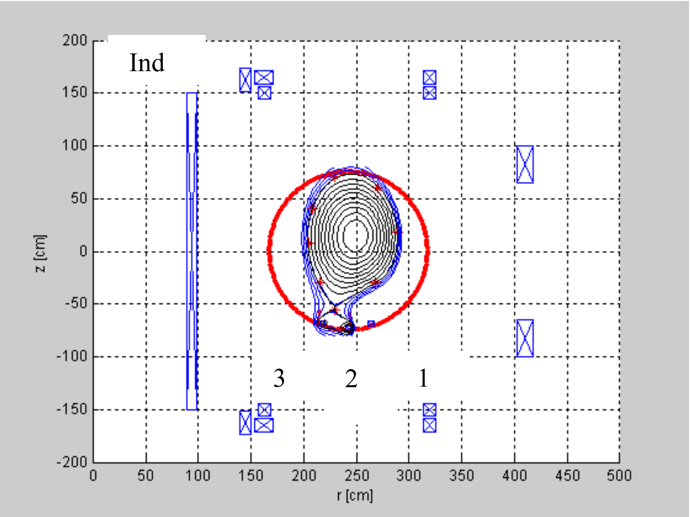

Fig.3 Poloidal field system of T15 with divertor

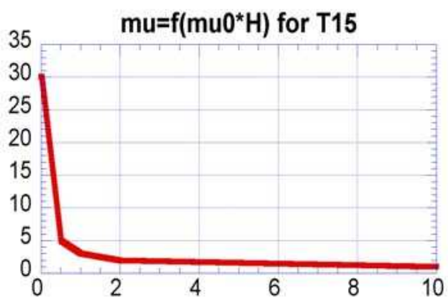

Fig.4 Dependence of μ(H)

In present simulations an influence of Ψ_{Fe} to plasma shape and position is neglected, calculation of poloidal flux consumption from inductor with iron is carried out with taking into account of $\Psi_{Fe} = f_{\Psi}(B_{ext}, \mu)$ function, obtained above. Function of $\mu(H)$ is shown in Fig.4. Energy transport equations are calculated for T_e and T_i with Aclator scaling for electrons and neo-classical for ions. The ohmic plasma is assumed to be during plasma current ramp-up, the plasma density is specified to be $n=(0.2+0.3t)10^{20}$ m^{-3} for $0 \le t \le 0.3s$ and $n=0.5 \cdot 10^{20}$ m^{-3} for t>0.3c. In Fig.5 time evolutions of plasma current I_p and I_{ind} are shown. One can see that the divertor configuration is formed up to 480 ms time moment. In Fig.6 the

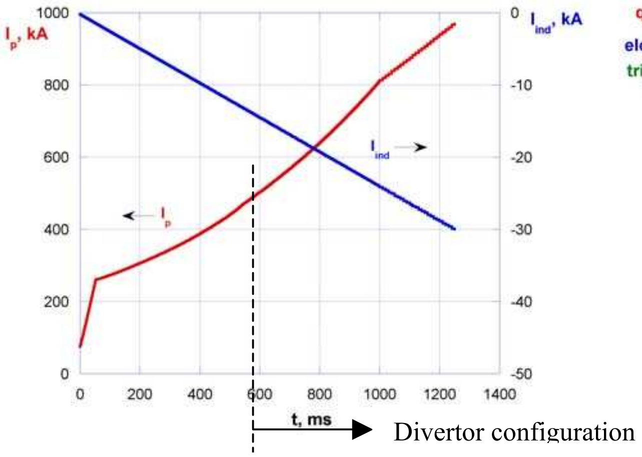

Fig.5

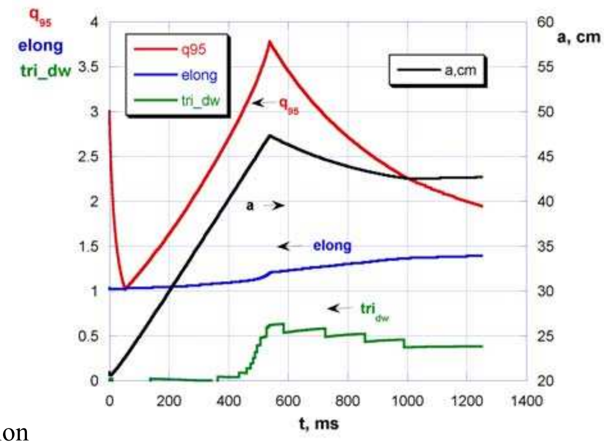

Fig.6

time evolutions of some plasma parameters are presented (elongation, triangularity, q_{95}).

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Conclusions

Full domain model for tokamak iron is developed and included in DINA code. This model has been compared with ANSYS simulation results. The preliminary results of plasma current ramp-up modeling in tokamak T15 with iron core are presented. It is shown that it is possible to obtain the divertor plasma with $I_p \approx 1$ MA and elongation around 1.5.

References

1. V.E. Lukash, R.R. Khayrutdinov, Plasma Physics Reports 22 (1996), p. 99
2. A. Galkin, V.V. Drozdov, A.A. Ivanov, S.Yu. Medvedev, Yu.Yu. Poshekhonov, GA Report, GA-A23045, May 1999
3. Beliaev V.P., Gluhich B.A., et al., Rus. Atom. Energy, v.52 (1982) p.101
4. ANSYS Workbench 8.1, 2004
5. L.E. Zakharov , C.V. Atanasiu., Vopr. Atomnoj nauki I tekhniki, Ser. Termoyadernyj sintez 3 (1986) 25 (in Russian)