DEVELOPMENT OF 2D DISCHARGE INITIATION MODEL IN TOKAMAKS

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In this paper the increase of the region of the avalanche breakdown was taken into account while considering of the breakdown voltage as the function of gas pressure. The plasma column form is determined from the 2D equilibrium condition. Plasma conductivity was determined from 0D model particles and heat balance. The dynamics of transition of plasma configuration with the open magnetic surfaces to the closed one is demonstrated.
PACS: 52.55.Fa

1. INTRODUCTION

The study of breakdown physics and current ramp-up in tokamaks is still far from completion. Meanwhile, this issue is of a great importance because of its practical applications. Knowing the location of plasma column formation is crucial for development of tokamaks and accurate description of the process of current ramp-up.

The stage of transition from the avalanche breakdown to plasma column formation in the case of plasma being generated in the region of either closed or non-closed magnetic surfaces remains the most obscure. Currently the plasma column formation and current ramp-up at this stage is analyzed within the homogeneous (0D) model when the transverse column dimension ***a***, as well as the major radius ***R*** are derived from the avalanche breakdown condition and considered constant throughout the entire stage [1-3]. In [8] the early stage of plasma formation is considered in 1D model, where column dimension equals dimension of vacuum chamber.

After avalanche phase plasma minor and major radii can change. So, it will be more accurate to calculate all plasma parameters from condition of 2D plasma equilibrium in the external poloidal magnetic fields. Our work is devoted to this issue.

2. EQUATIONS FOR QUASINEUTRAL PLASMA

However, we firstly want to study the properties of this 0D model, i.e. analyze the regularities induced by the bulk processes accompanying current ramp during the early stage of plasma column formation. In this work we apply the approach developed in [1,2] following the original notation. The energy balance equations for electrons and ions in 0D approximation are written in the form:

$$\frac{3}{2}\frac{d}{dt}(n_e kT_e) = P_{\rm OH} - P_{\Delta} - P_{\rm ion} - \frac{3}{2}\frac{n_e kT_e}{\tau_E} \tag{1}$$

$$\frac{3}{2}\frac{d}{dt}(n_e kT_i) = P_{\Delta} - P_{\rm cx} - \frac{3}{2}\frac{n_e kT_i}{\tau_E} \tag{2}$$

Particle balance: electrons n_e and neutrals n_0 respectively:

$$\frac{dn_e}{dt} = n_0 n_e S_i - \frac{n_e}{\tau_p} \tag{3}$$

$$V_V\frac{dn_0}{dt} = \frac{n_0 V_p}{\tau_p} - n_0 n_e S_i V_p \tag{4}$$

Circuit equation for plasma current I_p:

$$L\frac{dI_p}{dt} + R_{\rm pl} I_p = U\ , \tag{5}$$

where L is column inductance and U is the loop voltage.

In (1-5) the following notations are applied: V_p is the volume of plasma region, V_v represents the vacuum chamber volume, T_e и T_i are the electrons and ions temperatures respectively, P_{OH} describes ohmic heating specific power, P_Δ is equilibration specific power between electrons and ions in plasma, P_{ion} is neutral gas ionization specific losses, P_{cx} describes charge exchange specific losses, τ_E and τ_P are the energy and particles confinement times. For simplicity we put $\tau_E = \tau_P$.

The value of breakdown voltage as a function of parameters under consideration represents our major interest [4]. Fig.1 shows that U_b increases linearly with the gas pressure.

Allowing for the fact that charge exchange represents the major energy loss channel during breakdown and assuming $T_i \approx T_e$ analytic expression for breakdown voltage can be found U_b [5]:

$$U_b = 10\sqrt{2}\frac{\sqrt{RV_V \ln L}}{aT_K^{0,1}} n_0^0 \tag{6}$$

In Fig. 1 one can see the comparison of numerical simulation results obtained for transient system (1-5) with formula (6) where a fairly good agreement is observed.

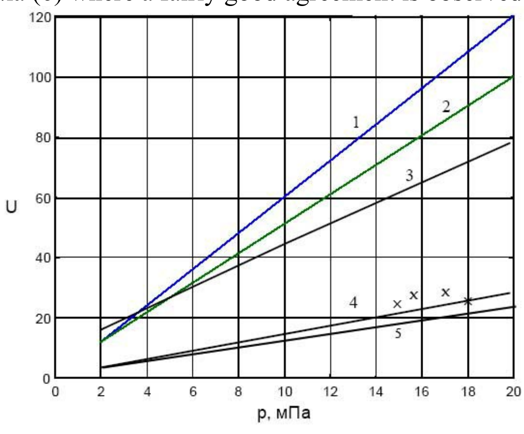


Fig. 1. Comparison of simulation results for breakdown voltage depending on hydrogen pressure: 1 – theory, 2 – simulation, 3 – simulation with taking into account dependence of plasma radius from pressure (KTM); 4 – theory, 5 – simulation, × – experiment (T-11M)

Problems of Atomic Science and Technology. Series: Plasma Physics (11). 2005. № 2. P. 14-16

Fig.1 demonstrates pressure dependent linear growth of breakdown voltage similar to that during the avalanche breakdown (high pressure limit [6]). However, the breakdown voltage at quasi-neutral stage is substantially higher (within an order of magnitude) than the corresponding value at the avalanche.

With increase of gas pressure breakdown conditions become easier, because Taunsend coefficient α rises with pressure. It is known that with increase of pressure the permissible value of poloidal field increases, and consequently, the area where conditions of breakdown are fulfilled is broadened. Accurate consideration of electrons movement along magnetic line let us to obtain detailed shape of this region (Fig. 2).

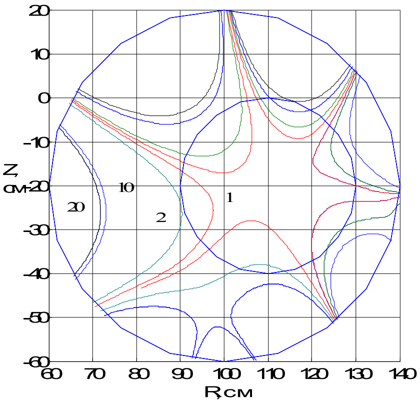


Fig. 2. Boundaries of region for avalanche breakdown at KTM tokamak for different pressures: p =1, 2, 10, 20mPa

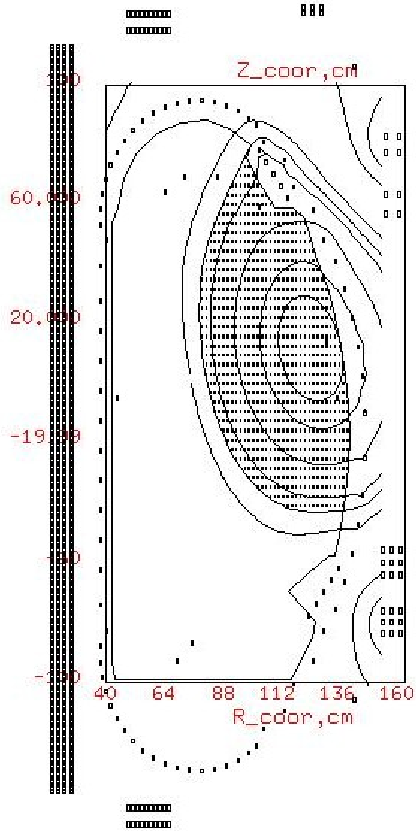
It is seen that with increase of pressure the region, favorable for breakdown is widened. If we determine the size of plasma column through the size of this area and substitute it's value into formula (6), then we obtain correlated value for breakdown voltage (see Fig. 1).

3. 2D MODEL OF PLASMA COLUMN FORMATION

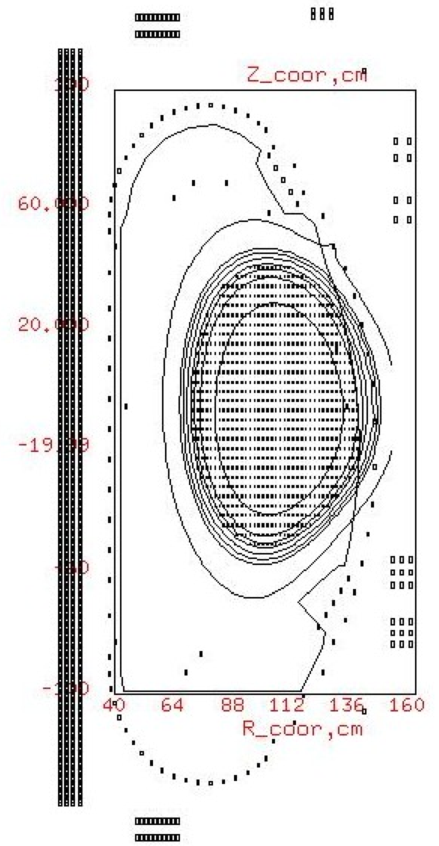
In 0D model major and minor plasma radii are required, which can be determined from equilibrium conditions for plasma column at external poloidal magnetic fields. Plasma equilibrium in tokamaks is described by Grad-Shafranov equation. At our case part of magnetic field lines where plasma flows are closed and part of them are opened and they end at the vessel walls. This situation is similar to the picture of Halo-currents formation during disruption [7].

At the Grad-Shafranov equation the condition that plasma pressure is constant along magnetic surfaces is used. In our case plasma pressure is small, so this requirement is not important. Plasma conductivity was determined from 0D model, electric field was calculated from solution of 1D diffusion of magnetic field equation self-consistently with shape of magnetic surfaces. Poloidal current function F is calculated using averaged Grad-Shafranov equation and it is used further as part of toroidal current density to solve 2D equilibrium and to find structure of magnetic surfaces.

At the Fig. 3 examples of magnetic field structure at different plasma currents are shown. It is seen that at small value of plasma current significant part of it flows along opened field lines. With the increase of plasma current practically all current flows inside closed magnetic surfaces. Plasma columns in both cases are in equilibrium state. Thus, for studying of initial plasma column formation, the hybrid 0D-2D model can be used.



a



b

Fig. 3. Magnetic surfaces cross section of KTM tokamak during breakdown (a) - 3 кА, (b) – 60 кА. Dark region corresponds the plasma column

4. CONCLUSIONS

At the 0D homogeneous model it was shown that value of voltage to overcome radiation barrier increases with the increase of hydrogen pressure and decreases with the increase of minor plasma radius. The self-consistent model of initial plasma formation with 2D equilibrium and 0D transport is presented. The dynamics of transition of plasma configuration with opened magnetic surfaces to closed one is demonstrated. Next stage will consist of in developing 2D transport and 2D equilibrium and use scenario for Null formation and PF coils current waveforms from TRANSMAK code.

REFERENCES

1. B. Lloyd, G.L. Jackson, T.S. Taylor et al.// *Nuclear Fusion* (31). 1991, № 11.
2. B. Lloyd, P.G. Carolan, C.D. Warrick.// *Plasma Phys. and Controlled Fusion* (38). 1996, p. 1627.
3. V.A. Belyakov, V.I. Vasiliev, K.I. Lobanov et al.// *Proc. of VII Int. Conf. Engineering Problems of Termonuclear Reactors*, *Oct. 28-31, 2002, St.Petersburg.* p. 178.
4. E.A. Azizov, Yu. S. Cherepnin, V.N. Dokouka et al.// *Proc. of the 21-st Symp. on Fusion Techn*, *Madrid, Spain, Sept. 11-15, 2000*.
5. E.A. Azizov, A.D. Barkalov, G.G. Gladush, R.R. Khairutdinov // *Proc. of the Int. Conf. and School on Plasma Phys. and Controlled Fusion*, *Alushta, Ukraine, Sept. 16 – 21, 2002*.
6. Von Engel. *Ionized gases (2-nd ed.).* Oxford: Claredon Press, 1965.
7. V.E. Lukash, R.R. Khayrutdinov // *Fiz. Plasmy* (22). 1996, p. 99.
8. Yu. N. Dnestrovsky, D.P. Kostomarov, G.V. Pereverzev, K.N. Tarasyan: Preprint 2980. Moscow: RRC Kurchatov Institute, 1978.

РАЗВИТИЕ 2D МОДЕЛИ ИНИЦИИРОВАНИЯ РАЗРЯДА В ТОКАМАКЕ

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В работе учитывается влияние увеличения области лавинного пробоя на величину напряжения пробоя с ростом давления газа. Форма плазменного шнура определяется из условия двумерного равновесия, проводимость из 0-мерных уравнений баланса тепла и частиц. Показана динамика перехода от плазменной конфигурации с разомкнутыми магнитными поверхностями к конфигурации с замкнутыми поверхностями.

РОЗВИТОК 2D МОДЕЛІ ІНІЦІЮВАННЯ РОЗРЯДУ В ТОКАМАЦІ

Е.А. Азізов, А.Д. Баркалов, Г.Г. Гладуш, Р.Р. Хайрутдінов

У роботі враховується вплив збільшення області лавинного пробою на величину напруги пробою з ростом тиску газу. Форма плазмового шнура визначається з умови двовимірної рівноваги, провідність з 0-мірних рівнянь балансу тепла і часток. Показано динаміку переходу від плазмової конфігурації з розімкнутими магнітними поверхнями до конфігурації з замкнутими поверхнями.