A START-UP DISCHARGE PHASE IN A CASTOR TOKAMAK

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Abstract: It is shown experimentally, that during the inductive Tokamak breakdown strong overthermal plasma potential is generated. Simultaneously convective losses during the breakdown are measured. Mechanism of the losses and generation of electrostatic field is discussed.

Introduction: As is known, time delay between switching-on of the ohmic heating circuit and formation of the plasma with substantial density can be minimalized by a suitable external perpendicular magnetic field. During this time interval electron density rises due to avalanche ionization: $n_e \sim e^{\gamma t}$. Exponential rate is given by $\gamma = \beta - \tau^{-1}$, where lossless avalanche rate β is a known function [1] of reduced toroidal electric field E/n (n--filling atom density) and τ denotes loss time. During the avalanche a poloidal magnetic field is smaller than total perpendicular magnetic field $B_\perp$ (summ of external and stray fields). Several mechanisms of breakdown losses has been proposed. Geometrical electron losses [2] give $\tau = a/(v_D B_\perp / B_T)$, where $v_D = I_p/(\pi a^2 e n_e)$ is electron drift velocity, I_p- plasma current, a - plasma radius e-electron charge and B_T-toroidal magnetic field. Ambipolar toroidal drift for $B_\perp = v_D = 0$ leads to Bohm-like diffusion [3]. In the case $v_D = 0$, $B_\perp \neq 0$ and fully ionized plasma expression for τ is found in[4]. In [5] is considered breakdown between limiters as electrodes. Picture of the tokamak breakdown is not clear up to now. Present paper is a contribution to this problem.

Experiment: To investigate inductive breakdown we try to look simultaneously for losses and plasma potential. Measurements was performed on CASTOR tokamak with major radius R = 0.4m and plasma radius a = 85mm. Geometry of the experiment is shown on Fig.1. Net plasma current was measured by Rogowski coil inserted into

12th EPS Conference of Controlled Fusion an Plasma Physics, Budapest, september 1985 limiter shadow. Floating potential on the plasma edge was detected by a set of Langmuir probes. Toroidal magnetic field $B_T=1.3T$ and filling hydrogen atom density $n=2.5\times10^{19}m^{-3}$ was held fixed. Dynamics of the breakdown for $B_\perp= -1mT$, vertically oriented, is shown on Fig. 2. Plasma current exponentially rises up to the breakdown value I_B, corresponding to the transition into the fully ionized plasma conductivity. During the exponential phase electron drift velocity changes slightly and so the plasma current is proportional to the electron density. Floating potentials U_{FL} rise to high values and then relaxe after formation of rotational transform. It indicates generation of perpendicular electrostatic field, antiparallel to the perpendicular magnetic field. Floating potential is large comparing with the probe sheath potential (electron temperature $T_e= 10eV$). Since peak value of electrostatic field is approximately the difference of the floating potentials of the opposite probes: $2aE_\perp= U_{FL}(1)-U_{FL}(2)$. Further, we changed perpendicular magnetic field both in vertical and horizontal directions in the interval $|B_\perp| = 0 - 2mT$. Breakdown voltage rises with $|B_\perp|$ and is $U_B= 20-36V$. This interval corresponds to the electron drift velocity $v_D= (0.85-1.3)\times10^6 m/s$ and to the exponential rate $\beta= (0.95-1.5)\times10^5 s^{-1}$. On Fig. 3 is shown dependence of the electrostatic field, relative losses and breakdown current on $|B_\perp|$. A large scattering of points is caused by a space inhomogeneity and time modulation of magnetic field. Electrostatic field is proportional to $|B_\perp|$: $\vec{E}_\perp=-5\times10^3\vec{B}_\perp[V/m, mT]$. Losses λ are defined as the ratio of lost electrons to the all electrons born in the avalanche: $\lambda= 1 - \gamma/\beta$, where $\gamma = (1/I_p)\times(dI_p/dt)$. Losses are proportional to the magnetic field and reach more than 50%. Breakdown current is roughly independent on $B_\perp$. Corresponding electron density is $n_B= (1-2)\times10^{17}m^{-3}$.

<u>Discussion</u>: Observed electrostatic field is strongly overthermal $eE_\perp a \approx 60T_e$. Field is generated by a charge separation of electrons and ions (fixed). Velocities of gradient and centrifugal drifts are negligible and then plasma polarizes only due to directed flow of electrons along lines of force. Theoretically electrostatic field can rise up to the steady state value $E_\perp = E\,B_T/B_\perp$, when electron current vanishes. In experiment steady state is not reached because time of equilibration of space

charge $a/(v_D B_\perp/B_T) \approx 0.1$ms is comparable with the duration of the avalanche. Thus the value of electrostatic field in our experiment is about one half of value $E x B_T/B_\perp$.

Charge deficit is much more smaller than the relative losses:

$$\delta n_e/n_B \approx 2\varepsilon_o E_\perp/(e a n_B) \approx 10^{-5} \ll \lambda$$

(ε_o- vacuum permittivity), and then mechanism of individual escape of electrons [2] can not be accepted. Measured losses can be explained by $\vec{E} \times \vec{B}$ drift. If we assume homogeneous profiles for electrostatic field and electron density, the loss time is

$$\tau = (2/\pi) B_T a/E_\perp \approx 5 \times 10^{-5}\ s,$$

for $B_\perp = 1$mT. This value is in a good agreement with the time determined from the exponential rates: $\tau = (\beta\lambda)^{-1} = 2x10^{-5}$s. It must be noted, that the rate of current rise γ may be partially affected by a "reverse" effect of electrostatic field.

Generally described mechanism can take place if the toroidal current exists but poloidal magnetic field does not yet prevail perpendicular one. Then it may appear in non-inductive current-rise experiments as well. Finally note that energy flow on the limiter is negligible during the breakdown (1kW comparing with 100 kW in the developed discharge in our experiment). But more danger rises from enhanced arcing probability due to the large plasma potential.

References:

[1] Buffa A. et al.: Phys. Rev. A3 (1971) 955
[2] Papoular R.: Nucl. Fusion 16(1976) 37
Prinzler H. et al.: Czech.J.Phys. B34(1984) 665
[3] Abramov V.A. et al.: Fizika Plazmy 1(1975) 536
[4] Parail V.V. et al.: in Plasma Phys. and Contr. Nucl. Fusion Res. (Proc. 10th Int. Conf. London 1984), Vol. 1, IAEA Vienna (1985) 605

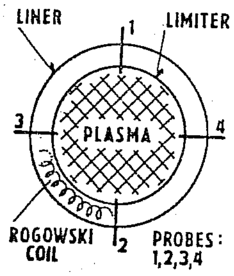

Fig.1: Geometry of the experiment.

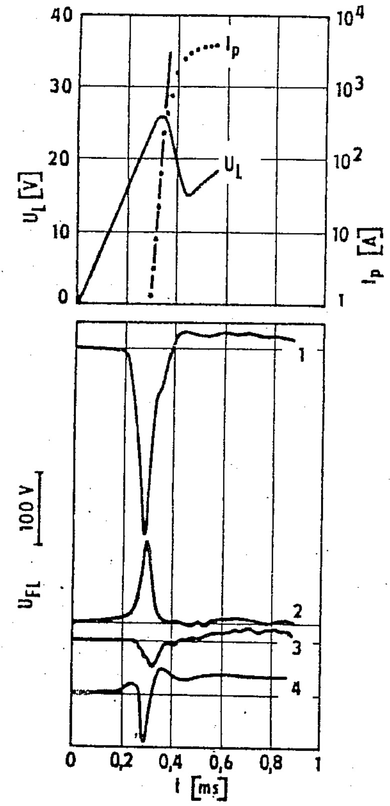

Fig.2: Temporal evolution of loop voltage U_L, plasma curent I_p (logarithmic scale) and floating potentials U_{FL}. Numbers 1-4 reffers to the probes on Fig.1 .

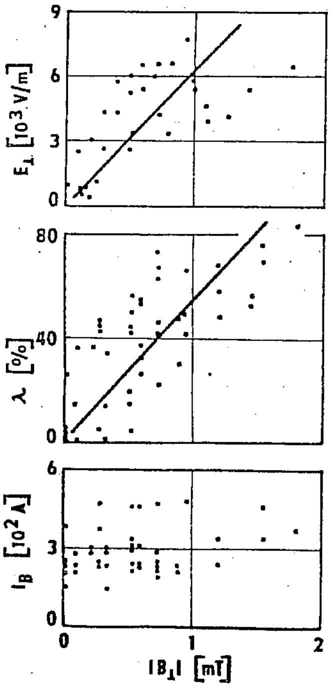

Fig.3: Dependence of electrostatic field, losses and breakdown current on perpendicular magnetic field.