Drift motion in the scrape-off layer during hard disruptions

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1. Introduction

During hard disruptions, intense vaporization of the divertor plates takes place. The process is accompanied by the formation of a dense and partially ionized vapor layer over the plates, which significantly reduces the particle and heat fluxes reaching the divertor tiles and thus determines the evaporation rate of the surface. The energetic plasma particles moving along the skewed magnetic field lines are stopped inside the layer at different depths. Hence, in order to produce a return current that compensates the current carried by the plasma particles, a self-consistent electric field is generated (ambipolarity constraint). Since the temperature of the vapor plasma is of the order of some eV-s, the electrical conductivity is rather low and the resulting electric field is of considerable strength. In a tokamak with conducting divertor plates, the local electric field has to be normal to the plates, thus creating plasma drift across the flux surfaces. This electric field and the resulting drift motion are modelled in a self-consistent manner. In the code applied, the deceleration of hot particles of different energy groups is calculated, while the cold layer is described by means of resistive MHD equations by taking into account all important elementary processes taking place in the plasma [1]. In the present 1-D model, the electric field is calculated from the condition of zero net current through the plates. The analysis shows that drift velocities of the order of 10^3 to 10^4 m/s may be expected, which may notably impair the shielding characteristics of vapor layers and may thus increase the erosion rate of the divertor plates. Under analogous conditions, this type of drift may become relevant also for detached divertor plasmas in normal tokamak regimes.

2.Model

The 1D geometry is considered, Fig. 1, $\partial/\partial z = \partial/\partial x = 0$, B_x is assumed to be zero. The current of hot particles $e\Gamma_i(y)$-$e\Gamma_e(y)$ is parallel to $\vec{B}$, and its projection on y direction is $e(\Gamma_i-\Gamma_e)\sin\alpha$. It is calculated by tracing the depletion of particle groups of different energies [1]. The potential drop between the cold and the hot plasmas [2], [3] is also taken into account.

The current has to be balanced by the return current created by the self-consistent electric field E_y. The return current j_y is the sum of the projections of the B-parallel current $j_{||}\sin\alpha$ and the B-perpendicular current $j_\perp\cos\alpha$. The parallel current is primarily the electron current driven by the parallel projection of electric field $E_{||}=E_y\sin\alpha$. The perpendicular current $j_\perp$ is associated with $E_\perp$. The condition of vanishing net current in the y-direction throughout the vapor layer can be written as

$$j_{||}\sin\alpha+j_\perp\cos\alpha+e(\Gamma_i-\Gamma_e)\sin\alpha=0. \qquad (1)$$

It differs from the corresponding condition discussed in [3] by the second term. The component $j_{||}$ is determined from the parallel projection of the electron momentum balance equation

$$j_{||}=\sigma_{||}\sin\alpha(E_y+eT_e\partial\ln n_e/\partial y+g_T e\partial T_e/\partial y), \qquad (2)$$

where $\sigma_{||}$ is the electrical conductivity which depends both on Coulomb and electron-neutral collisions [3], the coefficient g_T is larger than unity due to the thermal force. From the perpendicular component of the electron momentum balance equation (neglecting the perpendicular thermal force), we have

$$\vec{j}_\perp+\beta_e[\vec{j}_\perp\times\frac{\vec{B}}{B}]=\sigma_\perp(\vec{E}_\perp+[\vec{V}\times\vec{B}]+\frac{\nabla_\perp p_e}{en_e}), \qquad (3)$$

where the Hall parameter $\beta_e=\omega_{ce}/\nu_e$; ω_{ce} is the electron cyclotron frequency, ν_e is the electron collision frequency, and $\vec{V}$ is the ion velocity, $\sigma_\perp=\mathrm{const}\,\sigma_{||}$. Due to high collisionality, the ion and neutral gas velocities are assumed to be equal.

Another relation between the perpendicular current and plasma velocity is given by the x-component of the momentum equation

$$\frac{\partial\rho V_x}{\partial t}+\frac{\partial(\rho V_y V_x)}{\partial y}=[\vec{j}_\perp\times\vec{B}]_x. \qquad (4)$$

The velocity component V_y is calculated from the y component of the momentum equation by solving simultaneously the complete set of resistive MHD conservation equations, thus determining the evolution of the vapor layer. The electric field component E_x is assumed to be zero.

3. Results of calculations

A set of typical results is presented for a scenario in which a carbon (or carbonized) divertor plate is exposed to a thermal disrupting plasma at t=0. The following input parameters were assumed: T_{e0}=5keV, $n_{e0}=5.5\times10^{18}m^{-3}$, B=6T, $\alpha=5^0$. A cold and dense shielding layer is evolving at the surface. The temperature (electron temperature being equal to the heavy particle temperature) and the density distributions, monitored at t = 50μs , are shown in Figs. 2

and 3. At this time instant, ionization degrees significantly less than unity only exist in a narrow vapor layer adjacent to the surface (y less than 2 cm) in which the neutral atom density is of the order of $10^{24}m^{-3}$. The corresponding potential distribution is shown in Fig. 4. The divertor plate as well as the vapor layer are biased negatively with respect to the rest of the SOL. The potential difference is of the order of the energy of the incident hot electrons. In Fig. 5, the calculated velocity component V_x is displayed for three different time instants. As can be seen, large lateral velocities may exist. Outside of the weakly ionized region the value of V_x practically coincides with the drift velocity $V_{drift}=E_\perp/B \approx E_y/B$. In another scenario calculations with $T_{e0}=1keV$, $n_{e0}=6x10^{19}m^{-3}$, which correspond to larger Hall parameter values β_e, lateral velocities of the same order of magnitude were obtained. Within the ionized part of the vapor layer, the values of V_x are found to be close to the values of V_{drift}.

4. Conclusions

Drift velocities of the order of 10^3 to 10^4 m/s may be expected during hard disruptions. This effect may notably impair the shielding characteristics of the vapor layer and increase the erosion rate of the divertor plates.

Acknowledgment
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References.

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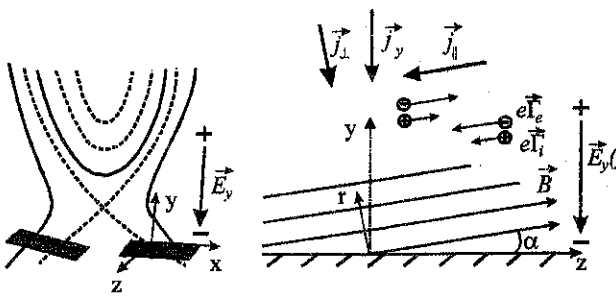


Fig.1 The geometry considered

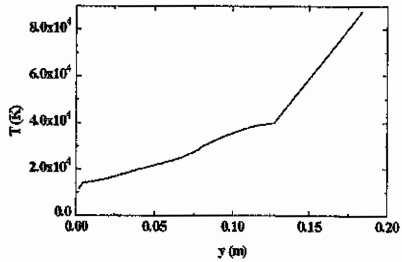


Fig.2 5 keV disrupting plasma: temperature distribution in the vapour layer 50 μs after plasma-wall contact.

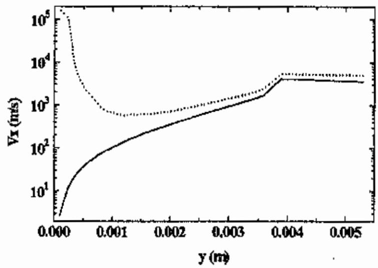


Fig.5 5 keV disrupting plasma: distributions of V_x (solid lines) and and $E_\perp/B$ (dotted lines) in the vapour layer

a) t = 3 μs.

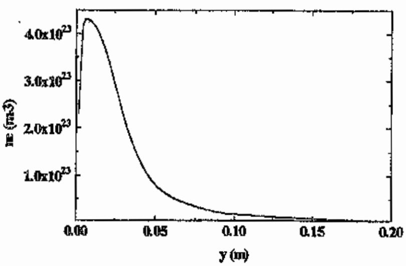
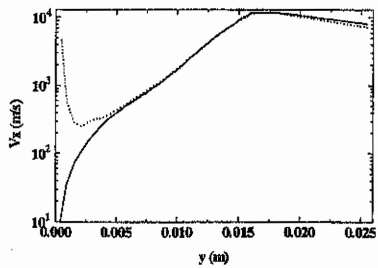


Fig.3 5keV disrupting plasma: density distribution in the vapour layer 50 μs after plasma-wall contact.



b) t = 10 μs.

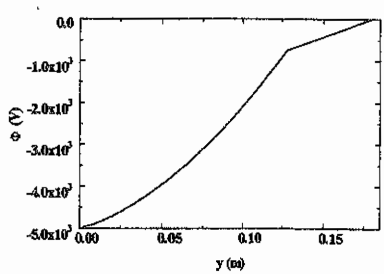
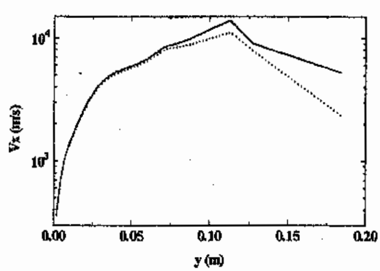


Fig.4 5 keV disrupting plasma: potential distribution across the vapour layer, t=50 μs



c) t = 50 μs.