LIMITING PLASMA PRESSURE IN A TOKOMAK

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In spite of the general enthusiasm concerning the long containment of plasma in a Tokomak [1], it must be borne in mind that the heretofore performed experiments dealt with plasma of very low pressure ($nT < 0.01\ B^2/8\pi$) [2]. What are the limitations on the plasma pressure in the Tokomak? This question has been studied only within the framework of magnetohydrodynamics (MHD) (see, for example, [1]). At sufficiently high temperatures, when the separation of the plasma particles into "trapped" and "transiting" becomes significant (this is precisely the region of interest), MHD is not applicable. As is known from [3], the minimum of the "neoclassical" diffusion [4] and turbulent diffusion due to the development of instability of trapped particles [5, 6] lies in the following collision-frequency interval:

$$1 > \frac{\nu_{ii}\, a}{\sqrt{2}\, v_{Ti}\, \Theta\, \epsilon^{3/2}} > 0{,}2\left(\frac{m_e}{m_i}\right)^{1/3} \frac{T_e}{T_i}, \tag{1}$$

where $\nu_{ii} = 16\sqrt{\pi} n e^4 \Lambda / 3 m_i^2 v_{Ti}^3$ is the collision frequency and $v_{Ti} = \sqrt{2T_i/m_i}$ is the thermal velocity of the ions; $\Theta = B_I/B_0$, B_I is the self-field of the current I, B_0 is the toroidal magnetic field, a is the plasma-pinch radius, and $\epsilon = a/R$ is the toroidal ratio.

In such a rarefied plasma there flows besides the well-known Pfirsch-Schluter current

$$I_{PS} = -\frac{2rc}{B_I R}\frac{dp}{dr}\cos\theta, \quad p = n(T_i + T_e) \tag{2}$$

also an additional current whose magnitude is determined in the final analysis by the balance of the friction forces exerted on the transiting electrons by the locked electrons and by the ions [7] (the calculation of the numerical coefficients is given in [8]):

$$I_{GS} = -0{,}9\left(\frac{r}{R}\right)^{1/2}\frac{c}{B_I}\sum_j T_j\left(1 - 0{,}17\frac{d\ln T_j}{d\ln n} - 0{,}18\frac{T_e}{T_i}\delta_{ji}\frac{d\ln T_i}{d\ln n}\right)\frac{dn}{dr}. \tag{3}$$

Thus, the additional current turns out to be constant over each magnetic surface and consequently contributes to the magnetic field of the current B_I. As the plasma becomes heated, at $\beta_I = 4\pi p/B_I^2 \sim \epsilon^{-1/2}$ [9], this current exceeds the induction current and β_I stops growing. The distribution of the plasma and the distribution of the current (of the magnetic field B_I) are connected here by Maxwell's equation

$$\frac{1}{r}\frac{d}{dr} r B_I = \frac{4\pi}{c} I_{GS}(r). \tag{4}$$

We have neglected here the distortion, of the order of $O(\epsilon^{1/2})$, of the magnetic surfaces by the presence of the current I_{PS}.

Further increase of the plasma pressure leads rapidly to violation of the Kruskal-Shafranov criterion

$$q(r) = \frac{B_0}{B_I(r)} \frac{r}{R} > 1. \tag{5}$$

The numerical coefficients depend on the details of the distribution of the plasma pressure over the pinch cross section. The limiting value of $\beta = 4\pi p/B_0^2$. obtained by substitution in this criterion, was calculated by us for two different pressure and current distributions at uniform temperature:

$$1)\ p = p_0\left(1 - \frac{r^2}{a^2}\right),\quad B_I^2 = 0{,}81\left(\frac{r}{a}\right)^{5/2} 4\pi p_0 \epsilon^{1/2},\ q^2(a) = 1{,}23\epsilon^{3/2}/\beta > 1,$$

$$2)\ B_I = B_I(a)\frac{r}{a},\quad 4\pi p = 1{,}48 B_I^2(a)\left[1 - \left(\frac{r}{a}\right)^{3/2}\right],\quad q^2(a) = 1{,}48\epsilon^{3/2}/\beta > 1.$$

In the case of a non-isothermal plasma ($T_e \gg T_i$) with identical temperature and density profiles ($n(r) \sim T_e(r)$), the limiting pressure increases by a factor of three.

We note that the limiting values of β_I turn out to be lower than in the MHD equilibrium model (see [1]).

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CONCERNING ONE MORE METHOD OF MAGNETIC ENERGY PUMPING INTO A TURBULENT PLASMA

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1. If the intensity of plasma waves (plasmons) is sufficiently large, then interactions of the plasmons with one another can become more probable than interactions of plasmons with plasma particles. Under these conditions the plasma can be regarded as consisting of two weakly-interacting subsystems - particles and plasmons - between which a slow energy exchange takes place. The relaxation of the plasma will then have a two-step character - first quasistatic equilibriums will be established in the particle and plasmon subsystems