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SUPPRESSION OF THE BALLOONING MODES INSTABILITY OF THE PLASMA STREAM BY RADIAL CURRENTS

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Introduction

In our previous experiments [1,2] we found that the hollow cylindrical plasma stream in a not uniform axial magnetic field is unstable against ballooning modes driven by and localized in a region of bad curvature with the least plasma beta limit (Fig. 1,a). The grossly stability against flute/interchange modes is due to the stabilizing influence of the cathode end arc discharge.

In order that to suppress these ballooning modes the metallic nets of different types had been placed in corresponding plasma stream cross section. The idea of these actions consisted in the possibility of the demolishing of azimuthal polarizable electric fields driven by the difference in drift velocities of ions and electrons.

Experimental results

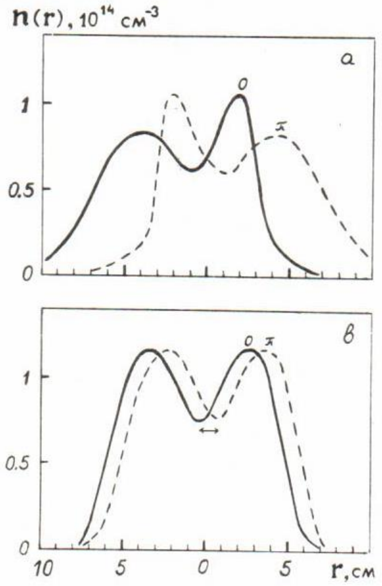

Fig. 1. Radial profiles of the plasma density at midplane of the trap without a net (a) and with the copper radial net (b). The solid and dashed curves are concerning to the opposite phases of the stable plasma column oscillations with $f_0 \sim 30$ kHz.

At first sight it may appear that the net shown on Fig. 2(a) would be more convenient to suppress the instability. However, if this net had been placed in plasma stream, any effects of stabilization were absent. For the nets shown on Fig. 2(b,c) the stabilization effects were very small.

The best effect of stabilization had been achieved for the radial net (Fig. 2,d) consisting of 48 copper wire-radii of 0.35 mm diameter every. Corresponding to this effect the radial plasma density profiles are given in Fig. 1(b).

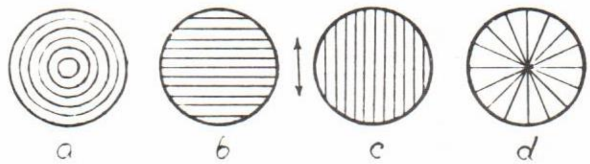

Fig. 2. Types of used nets: (a) concentric; (b),(c) chord; (d) radial. The arrow shows the direction of the plasma column oscillations.

It is necessary to note that the net with closed wires with respect to each other stabilizes just effective as one with isolated. This fact utterly excludes the possible influence of the demolishing of the azimuthal electric fields. Efficiency of the instability suppression decreases with increasing or decreasing the number of wires or with increasing the diameter of wires. For further decreasing of the wire diameter one is fusing. If one changes the copper wires on the nichrome wires, stabilization effect disappears.

It is found that the most part of the plasma stream longitudinal electron currents driven by arc discharge at the plasma source has closed on these wires. The electron current got on the wires at inner radii of the plasma stream corresponding to the cathode end of plasma gun and flowed from ones on the outer radii corresponding to the anode end of plasma gun due to the development of the electrical arc. Possibility of the beginning the radial currents follows from the plasma potential distribution (Fig. 3) too. The estimation of these currents magnitude gives near 500 amperes for one wire.

Discussion

The analyses of experimental data for suppression of the ballooning modes by copper radial net presented in this paper show that the suppression is determined by the geometry of net and by the magnitude of currents along the wires, i.e. by the geometry and magnitude of currents. There are several alternative explanations of this feature. In particular, it can be explained by making the such system of currents which provides a stable cylindrical shell of the magnetic field at region with primary bad curvature.

Here we shall consider the easy model of such system only. In Fig. 4 the distribution of primary uniform magnetic field H_0 disturbed by the cross currents is presented for the plane case. There are three different regions of the disturbed magnetic field H. First region, where the magnetic field magnitude decreases and the length of the force lines increases. This region contents to the condition

$$\int \frac{d\ell}{H} > \int \frac{d\ell}{H_0} \qquad (1)$$

Second region, where $H > H_0$, but the condition (1) is satisfied by large increase of the force lines length. At last, the third region, where $H > H_0$ too and the condition (1) is not satisfied.

If we shall draw the cross currents, then the curvature of the force lines in region 3 will increase and the magnetic field magnitude will decrease so with the some step between the currents the region 3 will has vanished. Thus, we shall have the magnetic field layer satisfying to the condition (1). Therefore, the all flux tubes of this layer satisfy to the condition of stability on going out into the undisturbed magnetic field region

$$\delta \int \frac{d\ell}{H} < 0 \qquad (2)$$

where the variation of the integral is taken along a normal to this plane.

The detailed numerical analysis in case of the real cylindrical geometry of these radial currents gives the distance between them $S \approx 1$ cm for $H_0 = 1$ kG and $I = 500$ A when the condition (2) is satisfied. Comparisons of experimental data ($H_0 \approx 1$ kG, $I \sim 500$ A and the step between wires at the radius of the maximum plasma stream potential gradient $S \approx 0.7 \div 1.2$ cm) and the data obtained from this model show the good agreement.

This model allows to explain the observed dependency of suppression effects from the further decreasing of step between wires and from the diameter of wires. The condition (2) can be rewritten (for $dP/d\Phi < 0$) as

$$dU^*/d\Phi > 0$$

where $U^* = -\delta \int \frac{d\ell}{H}$ is the "potential energy" of the magnetic shell disturbed by radial currents; Φ is the magnetic flux enveloped by this shell; P is the plasma pressure. In case of the undisturbed magnetic field with bad curvature one has $dU/d\Phi = -\gamma < 0$ and so that to the suppress the ballooning modes it is necessary to satisfy next conditions

$$\Delta U > \gamma \Delta \Phi \qquad (3)$$

where $\Delta U = U - U^*$ is the "depth of potential well" determined by number N of wires in the net, by value of current I along a wire and by diameter of these wires. Since the maximum contribution of ΔU is determined by a regions with strong distortion of the magnetic field near the wires then that increase with decreasing of wire diameter. It is increasing also with I or N. However, if N is aspiring to the infinity (for conservation of full current, i.e. $N \cdot I = const$) the ΔU is aspiring to zero. Therefore, the optimum number of the radial currents is equal that when all force line on the considered shell only is beginning to satisfy the condition (2).

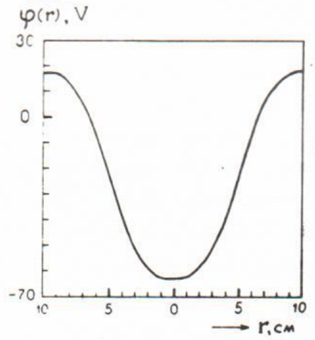

Figure 3

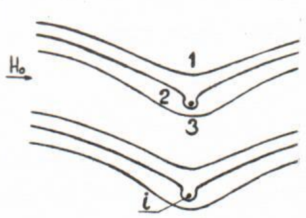

Figure 4

Fig. 3. Radial space potential profile.
Fig. 4. Distortion of the uniform magnetic field H_0 by the cross currents .

[1] Kabantsev A.A., Taskaev S.Yu. Fiz. plasmy (in print).
[2] Kabantsev A.A., Taskaev S.Yu. 1989, XIX ICPIG, Belgrade, Contributed papers.