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INTENSE PLASMA STREAMS TRANSPORT IN NON-HOMOGENEOUS MAGNETIC FIELDS

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One of the most widespread methods of filling open magnetic traps with "warm" plasma is an injection of plasma streams along the magnetic field. Plasma sources are located usually in the outside-the-trap region at a more or less considerable distance from the magnetic mirror where the own magnetic field is relatively low.

Four plasma guns [1] were placed on the "AMBAL-U" device (a classical mirror with minimum B [2,3]) for the creation of target plasma, where the high energy neutral beams are captured.

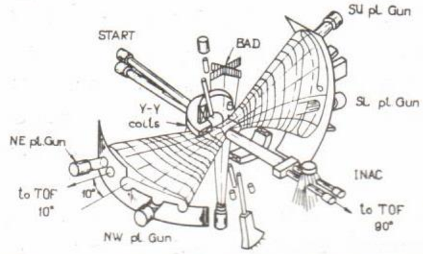

Fig. 1. Schematic diagram of the "AMBAL-U" device.

The guns were located near the plasma receiver plates (Fig.1) at a distance ℓ =2.95 m along the magnetic force line from centre of device. The own magnetic field strength in these points is 0.01 T (when the field in the centre is 0.7 T). Each gun generates a hollow cylindrical stream with the initial outer diametr 13 cm and thickness 1 cm. The initial plasma density is $1\div3\cdot10^{14}$ cm^{-3}, mean electron and ion energies are 10-20 eV and 40-50 eV respectively. Discharge duration is 1.5ms. In order to match the magnetic field flux outgoing from the gun with the given plasma shape in the midplane of the trap each gun was installed inside a pulse solenoid with a field up to 0.6 T. Fig.2 shows the horizontal and vertical cross sections of the magnetic field tube, which transports the plasma stream. Such a stream configuration can result in a number of effects that might reduce the quality of plasma target.

The measurements performed on "AMBAL-U" have shown a strong instability of the plasma

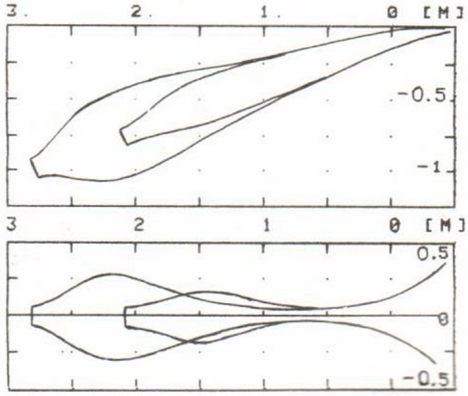

Fig. 2. Calculated cross sections of plasma stream (ℓ =2,95 m , ℓ =2,15 m).

stream. The plasma density was more then ten times less than the calculated one (Fig.3a). The ring structure of the stream was completely destroyed not only in trap but also in transport region between the gun and the mirror. On the Lengmuir probes high level oscillations as a frequency of $\leqslant 100$ KHz were observed, and near the boundary of plasma stream the level of oscillations was 100%. The total positive current > 1 kA was measured on the grounded plasma reciever plates located near the operating gun (in case of one gun operation). A negative current of the same quantity flew on the opposite plasma receiver plates. The high electron current flowing along the plasma stream from the gun to the opposite plasma receiver was registered by diamagnetic loops. We also observed high level oscillations with a frequency of $\leqslant$ 100 KHz in the currents on plates with an area of ~ 1 m^2. This fact indicates the macroscopic character of the instability.

As it has been proved more then once flute oscillations in such plasma streams do not occur because of the electrical contact with plasma sources along the field lines (stabilisation by a conductive end face). The most probable explanation of the plasma stream instability is the balloon-mode development in transport region. Computer estimations performed according to the method discribed in [4] show that criterion of the development of this instability is well satisfied. The threshold value of β for the balloon mode development calculated for the plasma stream near the gun is $\beta_{gc} \simeq 10^{-3}$. In our experiments β_g is 10^{-2}.

For a more detail investigation of this instability and search of ways of its stabilisation the same plasma gun was placed on a test stand "MAL" [5] with an adequate geometry of the magnetic field. The measurements performed on this device completely confirm our assumptions. The first mode of balloon oscillations with a frequency of 30 KHz developed in the plasma stream [6]. The contribution of higher modes was insignificant perhaps due to the stabilizing effects of the finite larmor radius. The effect of oscillation stabilisation by a radial conductor system was discovered and explained [6].

The posibilities of an increased plasma flow to the mirror were investigated on the "AMBAL" device. It is seen, from the calculations, that with the plasma gun approach to the mirror the value of β_{gc} increases considerably due to the quick growth of the mirror magnetic field. Thus, if ℓ=0.8 m, then $\beta_{gc} \simeq 5.6\,10^{-3}$. Experiments confirmed this assumption. The plasma flow to the trap grew proportional to β_{gc} (Fig.3a) though the high level of oscillations remained.

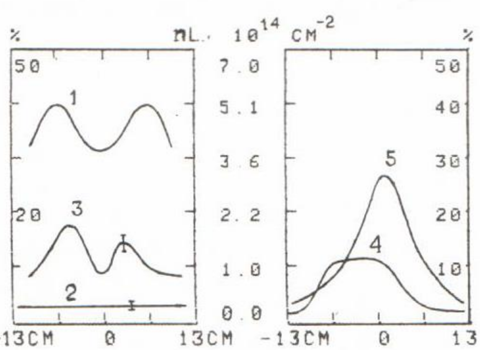

Fig. 3. Horizontal distribution of line density of plasma stream from ring guns in the midplane of trap.
a) The gun magnetic strength is 0.43 T
1.ℓ=2,95 m (calculated), 2.ℓ=2.95 m,
3.ℓ=2.15 m (2. and 3. -measured)
b) gun solenoid is switched off
4.ℓ=2.15 m, 5.ℓ=1.75 m.

In this position and in case when the plasma gun was located on the axis of the divice at a distance ℓ =1,75 m, the flow of a plasma stream with a switched-off solenoid, i.e. a MHD-stable configuration of the magnetic field was investigated. No large-scale oscillations were observed in these experiments. The cross dimentions of streams were slightly in excess than the calculated ones, that can be explaned by the classicals diffusion in the mirror area. A considerable portion of plasma stream penetrates into the trap (Fig.3b).

We have investigated also another type of plasma gun[7]. The initial stream diameter was 4.6 cm. A hollow in stream was absent. This plasma source was located on the axis of the device at distances ℓ =2,55 m and ℓ =1,75 m from the center, respectively. A plasma stream behaviour was the same as described above. But interesting results were obtained when the gun solenoid was switched on with a magnetic field contrary to that of the mirror (cusp configuration). In this case the plasma from the gun cannot penetrate into the trap along the magnetic field lines. But a stable and dense enough plasma stream with clear boundary was observed (Fig.4). The investigations at the test stand "MAL" showed that the plasma flew throuth the area near the zero point of magnetic field [8].

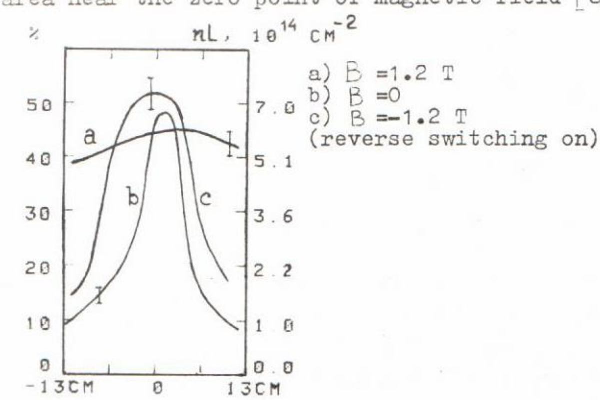

Fig. 4. Horizontal distribution of line density plasma stream from cylindrical gun at ℓ =1,75 m versus magnetic field direction in gun solenoid.

Thus we investigated the dense plasma streams transport in non-homogeneous magnetic fields. The balloon instability was discovered and identified. The possibility of the plasma stream transport through the zero region of a cusp configuration of magnetic field was shown. Regimes of satisfactory plasma stream flow in the "AMBAL-U" -device were found.

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