Confinement of a hot plasma with $\beta \sim 1$ in an open confinement system

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Effective confinement of a hot plasma with $\beta \sim 1$ in a gasdynamic confinement system has been demonstrated experimentally.

Mirnov and Ryutov[1] have suggested that a fusion reactor might be developed from a gasdynamic confinement system consisting of a mirror system of length $L_s > \lambda \ln K/K$, where λ is the mean free path of the particles, and $K = H_m/H_s$ is the mirror ratio. This condition differs from that in a classical mirror system, $L_s \ll \lambda \ln K/K$, another difference is that the confinement time in a gasdynamic confinement sys-

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tem is not very sensitive to loss-cone instabilities and increases linearly, rather than logarithmically, with increasing K. A plasma with $\beta \sim 1$ results in a reduce field at the center of the system and thus an increased effective mirror ratio. In order to reach the maximum possible confinement time it is necessary to increase β to the highest possible value. However, there has been no study of the stability of a plasma with $\beta \sim 1$ in a gasdynamic confinement system. The regions with an unfavorable force-line curvature may give rise to a flute instability or to the appearance of ballooning modes, and they break up the plasma.

In this letter we report experiments on the confinement of a hot deuterium plasma with $\beta \sim 1$ in a gasdynamic confinement system.

The hot plasma is produced by colliding streams from electrodynamic accelerators. The possibility of producing a hot plasma during the collision of streams in a uniform longitudinal magnetic field under conditions such that the Coulomb stopping length is much greater than the longitudinal dimensions of the plasmoids was demonstrated theoretically in Ref. 2 and experimentally in Ref. 3. In this case the effective randomization of the directed energy of the plasmoids results from a firehose instability. The lifetime of a hot plasma in a uniform longitudinal magnetic field with transverse thermal insulation does not depend on the field strength; it is determined by the characteristic time of the longitudinal outflow.

The experiments on plasma confinement in a gasdynamic system were carried out in the 2MK-200 test facility which consists of two electrodynamic accelerators with pulsed gas injection, installed 7 m apart and pointed at each other. The accelerators are powered by 1150-μF capacitor banks. The working voltage in these experiments is 20 kV. The accelerator chambers are connected by a thin-walled metal plasma duct 30 cm in diameter, in which a quasisteady magnetic field of special profile is produced by multiturn solenoids. The magnetic field configuration is that of an axisymmetric mirror system 2 m long (Fig. 1) with a field $H_m^{(0)} = 14.4$ kOe at the mirrors. The plasma streams are transported in a uniform longitudinal magnetic field of 7.2 kOe over the distance of 2.5 m from the accelerator to the confinement system; they are injected into the confinement system through the magnetic mirrors. A partial reflection of the stream was observed in the course of the interaction with the magnetic field of the mirror; the injection efficiency was $\sim 50\%$. The field at the center of the confinement system, $H_s^{(0)}$, was varied from 0 to 12.6 kOe, while the field at the mirrors was held

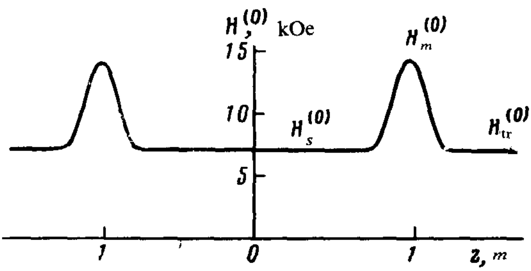

FIG. 1. Field profile in the confinement system.

constant. In this manner we were able to study the plasma confinement efficiency as a function of the mirror ratio $K^{(0)} = H_m^{(0)}/H_s^{(0)}$ at a constant energy of the plasma in the confinement system.

The collision of the streams in the confinement system resulted in the production of a plasma with a temperature $T_i \approx 2$ keV, a number density per unit length $N \approx 1.5 \times 10^{17}$ cm^{-1}, and an energy $W \approx 15$ kJ. The value of β, given by

$$\beta = \frac{P}{P + H_i^2/8\pi}$$

(P is the plasma pressure, and H_i is the internal field), was approximately unity. This is a gasdynamic confinement system, since the effective ion scattering length is smaller than the longitudinal dimensions of the system because of the well-developed turbulence.[2,3]

Figure 2a shows the plasma confinement time vs $H_s^{(0)}$. The maximum confinement time is $\tau = 40$ μs. A comparison shows that τ does not exceed 18 μs in collisions of streams in a uniform field.[3] This result is testimony to the effective operation of the system at these plasma parameters.

The plasma lifetime depends on the longitudinal and transverse confinement times:

$$\frac{1}{\tau} = \frac{1}{\tau_\perp} + \frac{1}{\tau_\parallel}.$$

At small values of $H_s^{(0)}$, τ is determined by the rate of the transverse energy loss. With increasing $H_s^{(0)}$ and with improved magnetic thermal insulation, the transverse loss Q falls off slowly (Fig. 2b). A decrease in the mirror ratio H_m/H_s, however, reduces the

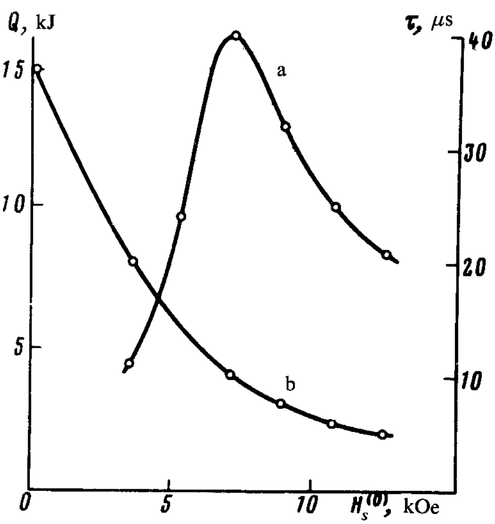

FIG. 2. Dependence of the plasma lifetime (a) and the transverse energy loss (b) on the magnetic field $H_s^{(0)}$.

confinement efficiency, because particles escape along the field. The maximum lifetime is reached at $K^{(0)} = 2$, at which we have $\tau_{\|} \sim \tau_{\perp}$. In this case the actual mirror ratio measured with the plasma in the system is $K = 6$. We see that the confinement time found here corresponds to the estimate in Ref. 1: $\tau = KL_s/v_T \approx 30\ \mu s$.

These experiments demonstrate that it is possible to confine a plasma with $\beta \sim 1$ in a gasdynamic confinement system. A plasma with a product $n\tau \approx 5 \times 10^{10}$ s/cm^3 and $T_i \approx 2$ keV has been produced. No large-scale instabilities of any sort which would lead to a rapid breakup of the plasma were detected.

[1]V. V. Mirnov and D. D. Ryutov, Voprosy atomnoĭ nauki i tekhniki, Seriya Termoyadernyĭ sintez No. 1 (5), 57 (1980).

[2]V. M. Alipchenkov, I. K. Konkashbaev, and V. B. Lopatko, Preprint IAÉ-3793, I. V. Kurchatov Institute of Atomic Energy, Moscow, 1983.

[3]A. M. Zhitlukhin, I. V. Ilyushin, V. M. Safronov, and Yu. V. Skvortsov, Fiz. Plazmy **8**, 509 (1982) [Sov. J. Plasma Phys. **8**, 287 (1982)].

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