Investigation of the plasma density distribution in the "Tuman-2" installation by the method of active corpuscular diagnostics

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(Submitted January 28, 1974)
ZhETF Pis. Red. **19**, 283–287 (March 5, 1974)

The toroidal installation "Tuman-2" for magnetic adiabatic heating was used to measure the distributions of the plasma density over the small cross section of the plasma pinch for different instants of contraction and expansion. The measurements were made by sounding the plasma with beams of fast hydrogen atoms along different chords of the discharge chamber. It is shown that during the contraction time, the total number of charged particles in the plasma pinch increases by 60–90%, owing to the increase in their lifetime. The coefficient of plasma diffusion across the magnetic field, which coincides in the Ohmic heating regime with the Bohm value (8×10^4 cm^2/sec), decreases during the compression time to a value not exceeding 2×10^3 cm^2/sec.

The installation "Tuman-2" is intended for the study of adiabatic compression of plasma by a growing toroidal magnetic field.[1] Adiabatic compression is one of the possible methods of plasma heating in closed systems. The most important characteristic of the compression process is the time variation of the plasma density distribution, which makes it possible to assess the efficiency of the compression. During the time of compression, the diameter of the plasma pinch is not limited by a diaphragm, and the time variation of the density distribution is determined by the time variation of the magnetic field **H** and by the diffusion of the plasma across **H**. Measurement of the change of the density distribution with time makes it possible to determine directly the diffusion coefficient of the plasma.

The toroidal discharge chamber of the "Tuman-2" installation has a major radius 40 cm, a minor radius 10 cm, and a diaphragm radius 8 cm. The hydrogen pressure ahead of the discharge amounted to 2×10^{-4} mm Hg in our experiments. The plasma was preheated by a 5-kA discharge current. The compression was turned on 1 msec after the start of the discharge, when the current, the plasma density, and the electron tempera-

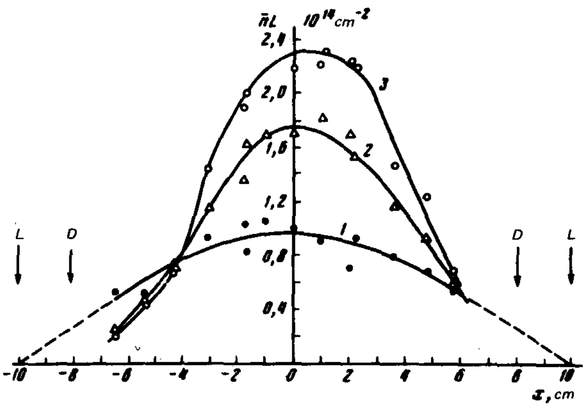

FIG. 1. Profiles of the linear density $\bar{n}l$, pertaining to different instants of time: 1) 0 μsec, 2) 50 μsec, 3) 125 μsec after the start of the compression; *D*- radius of diaphragm, *L*- radius of linear.

ture all flattened out. To compress the plasma pinch, the longitudinal magnetic field was increased from 3.2 to 11.5 kG within 125 μsec, and was again reduced to the initial value during the next 125 μsec.

The density distribution was determined by sounding with a beam of fast atoms along different chords of the minor cross section of the discharge chamber. A detailed description of the diagnostic setup for the sounding and of the method of determining the density from the attenuation of the atomic beam is given in [2]. In the present study, the sounding was with a beam of 8-keV hydrogen atoms. From the attenuation we calculated the plasma-target density, which was equal to

$$\bar{n}l(x,t) = \int_l n(y)\,dy, \tag{1}$$

where $l(x)$ is the length of the plasma-pinch chord located at a distance x from the chamber axis, $n(x,y)$ is the plasma density, and t is the time. Sounding along different chords was effected by parallel displacement of the atom beam along a discharge-chamber minor diameter located in the equatorial plane of the torus. The possible displacement was limited by the dimensions of the sleeves, and amounted to 13 cm (± 6.5 cm from the center of the chamber). From the values of $\bar{n}l$ obtained for different chords and pertaining to identical instants of time, we plotted the $\bar{n}l$ profiles, some of which are shown in Fig. 1.

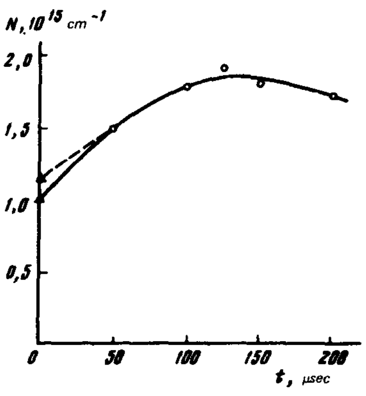

FIG. 2. Time variation of the total number of charged particle per unit length of the plasma pinch.

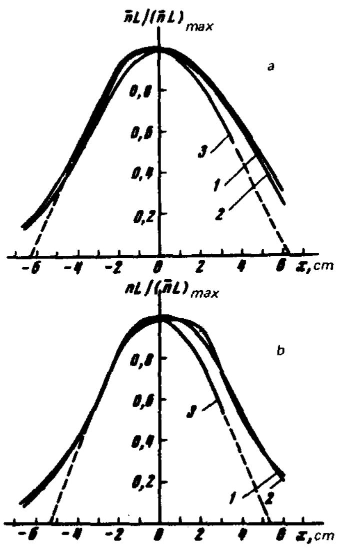

FIG. 3. Comparison of the shapes of $\bar{n}l$ profiles corresponding to the same magnetic field intensity: a) $H = 8$ kG, curves 1 and 2—50 and 200 μsec after the start of compression, respectively; b) $H = 11$ kG, curves 1 and 2—100 and 150 μsec after the start of compression.

By integrating the $\bar{n}l$ profiles with respect to x we could determine the total number N of charged particles, per unit length of the plasma pinch. The results of such an integration within the limits of x "seen" by the beam are represented by the points in Fig. 2. We see that N increases during the course of compression from 1×10^{15} to 1.9×10^{15} particles/cm. The increase of N can be due, first, to the influx of charged particles from the peripheral sections of the plasma pinch, "not seen" by the beam ($|x| > 6.5$ cm), second, to the increase of the flux of neutrals from the walls during the time of compression, and finally, to the increase of the lifetime of the charged particles in the compressed pinch. To estimate the possible contribution of the peripheral particles to the increase of N, we extrapolated the $\bar{n}l$ profile corresponding to the start of the compression (shown by the dashed line in Fig. 1). The result of the integration of the extrapolated profile, designated by a triangle in Fig. 2, shows that the contribution of such particles to the increase of N does not exceed 0.15×10^{15} particles/cm. From the results of the investigation of the plasma light emission[3] it follows that the flux of atoms entering the plasma from the walls is not increases by the compression. Thus, the observed growth of N is evidence of an increase of the lifetime of the charged particles in the compressed pinch.

An analysis of the balance of the charged particles in the plasma pinch enables us to determine the difference between the plasma diffusion coefficients in the Ohmic heating regime and under compression, $D_{\mathrm{o.h.}}$ and D_{comp}, if it is assumed that the flux of atoms from the walls does not change when the compression is turned on. The already mentioned constancy of the plasma density immediately before the compression means that in the Ohmic heating regime the increase of the

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number of charged particles, due to ionization of the incoming flow, is offset by their outflow from the pinch via diffusion. This outflow slows down after the start of the compression, and the ionization of the flux of atoms from the wall leads to an increase of N. From this we can determine the difference between the fluxes of the charged particles before and after the compression is turned on, and consequently the difference between $D_{\text{o.h.}}$ and D_{comp}. Calculations show that

$$D_{\text{o.h.}} - kD_{\text{comp}} \approx 8 \cdot 10^4 \text{ cm}^2/\text{sec}, \qquad (2)$$

where k is a numerical coefficient on the order of several units.

To determine the coefficient in the compressed pinch we have compared the shapes of the $\overline{n}l$ profiles for compression and expansion instants of time corresponding to the same intensity of the longitudinal magnetic field H. We note that the ionization of the hydrogen atoms coming from the walls cannot influence noticeably the shapes of the $\overline{n}l$ profiles, since the mean free path of the hydrogen atoms in the plasma with respect to ionization is comparable with the pinch radius. To compare the profiles, they were normalized to unity at the maximum. The normalized profiles for two values of H are shown in Fig. 3 (curves 1 and 2), which gives also the profiles obtained by recalculating curve 1 of Fig. 1, which pertains to the start of the compression, to the corresponding values of H assuming that the plasma is frozen into the magnetic field (curves 3). It is seen from the figure that the $\overline{n}l$ profiles pertaining to identical values of H in the case of plasma compression and expansion coincide in shape within the limits of the measurement errors. This means that during the time interval between 50 and 200 μsec the plasma diffusion does not broaden the $\overline{n}l$ profile by an amount exceeding the measurement error. From this we can determine the upper bound of the plasma diffusion coefficient in the compressed pinch. Calculations have shown that $D_{\text{comp}} \lesssim 2\times10^3$ cm²/sec. It follows then from (2) that $D_{\text{o.h.}} \approx 8\times10^4$ cm²/sec. It is also seen from Fig. 3 that the experimental profiles pertaining to the instants of time 50 and 200 μsec ($H = 8$ kG) and 100 and 150 μsec ($H = 11$ kG) are broader than the calculated ones. This indicates that the plasma is not fully frozen into the magnetic field during the initial stage of contraction.

Thus, the present results indicate that the coefficient of plasma diffusion across the magnetic field decreases during the time of compression when the plasma pinch becomes detached from the diaphragm. As noted in [3], the absolute value of the plasma diffusion coefficient in the Ohmic heating regime is close to the Bohm value (4×10^4 cm²/sec), and for the compressed pinch it does not exceed the values obtained from the pseudoclassical calculations (3×10^3 cm²/sec).

In conclusion the authors are indebted to M. G. Kaganskii and the entire crew of the "Tuman" installation for help with the experiments and useful discussions. The authors are grateful to Professor V. V. Afrosimov for constant interest.

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