Magnetosonic heating of a two-component plasma in the T-4 tokamak

N. V. Ivanov, I. A. Kovan, and Yu. A. Sokolov

I. V. Kurchatov Institute of Atomic Energy

(Submitted August 9, 1976)

Pis'ma Zh. Eksp. Teor. Fiz. **24**, No. 6, 349–352 (20 September 1976)

PACS numbers: 52.55.Gb, 52.50.Gj, 28.50.Re

The possibility of developing a two-component tokamak-reactor has been discussed in the literature recently.[1-6] In this reactor, which has plasma parameters that do not differ greatly from those attained in the existing tokamaks, a positive yield of thermonuclear energy is obtained by artificially maintaining a non-Maxwellian velocity distribution of the ionic component of the plasma. Since the intensity of the thermonuclear reaction is quite sensitive to the form of the ion distribution function at a plasma temperature on the order of several keV, enrichment of the distribution with high-energy ions leads to an appreciable increase of thermonuclear yield. To obtain a non-Maxwellian plasma one can use either the method of injection of neutral atoms[1] or the method of magnetosonic heating at the ion cyclotron frequency in a plasma consisting of two sorts of ions (for example, a tritium plasma with a small admixture of deuterium, at the cyclotron frequency of which the heating is effected).[6]

The magnetosonic method, the experimental verification of which is the subject of the present paper, is based on the character of the dependence of the polarization of a magnetosonic wave on the ratio of the oscillation frequency to the ion cyclotron frequency. In a plasma consisting of one sort of ions, the magnetosonic wave has circular polarization at the frequency $\omega = \omega_i$, and the vector of the electric field rotates in a direction opposite to the Larmor rotation of the ions. In this case the cyclotron absorption is weak and is connected only with the finite spatial dispersion. In a plasma consisting of two sorts of ions, the magnetosonic wave propagating at one of the two cyclotron frequencies has elliptic polarization and should be effectively absorbed and transfer its energy to the resonant ions. Under these conditions the maximum absorption should be observed when the fraction of the resonant ions in the plasma is several percent.[6,7] The resonant ions, acquiring energy from the wave and giving it up subsequently as they are decelerated by the nonresonant ions and electrons, make up the "tail" of the ion distribution function, and in the case of a tritium-deuterium mixture they determine the increased thermonuclear yield.

The feasibility of obtaining a two-component tokamak regime was verified experimentally with a model of deuterium with a small admixture (several percent) of hydrogen. The plasma was heated with an RF generator operating at 23 MHz and connected with an exciting loop analogous in construction to that of[8]. The power input to the plasma was ~ 50 kW. The action of the RF oscillations on the ion distribution function was investigated by measuring the change of the energy spectrum of the charge-exchange neutrals emitted from

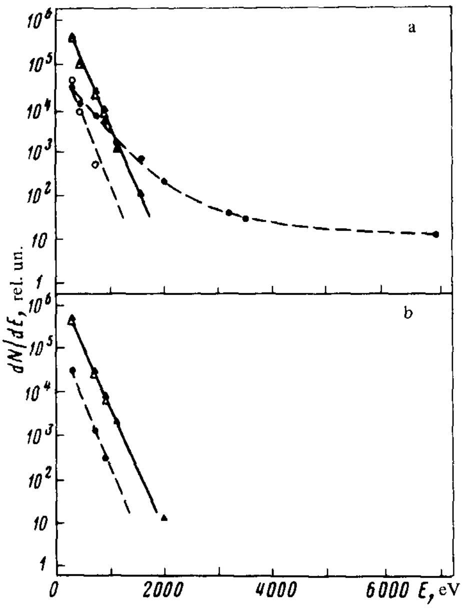

FIG. 1. Energy spectra of the charge-exchange atoms of hydrogen (dashed curve) and deuterium (solid curve) in a 15-kOe field (a) and a 21-kOe field (b). Symbols: ○—hydrogen, △—deuterium in the absence of RF heating; ●—hydrogen, ▲—deuterium during RF heating. The extension of the lines below the experimental points means that the reading for the succeeding values of the energy lies below the background level. The analyzer was located in a tokamak-chamber section diametrically opposite to the position of the RF exciter.

the plasma at 90° to the toroidal magnetic field. The analyzer made it possible to investigate separately the energy spectra of the hydrogen and deuterium.

For the comparison we used two tokamak discharge regimes, with different values of the toroidal magnetic field intensity, $H_z = 15$ kOe and $H_z = 21$ kOe. In these two regimes, the plasma concentration was the same, 10^{13} cm^{-3}, at the instant when the RF generator was turned on. At $H_z = 15$ kOe, when the frequency of the oscillations coincides with the cyclotron frequency for hydrogen and with its second harmonic for deuterium, turning on the RF generator excited the natural magnetosonic oscillations of the plasma pinch and was accompanied by an appreciable change of the hydrogen distribution function (Fig. 1a). The quality factor of the plasma, determined from the shape of the resonance curves,[9] was $Q \approx 3\times10^2$, in satisfactory agreement with an estimate of Q based on[6]. It should be noted that according to the calculations under our conditions absorption in a pure deuterium plasma corresponds to $Q = 3\times10^3$, while the quality connected with the absorption in the chamber walls is $Q = (2-5)\times10^3$.

It is seen from Fig. 1a that RF heating leads to an appreciable increase of the energy content of the small hydrogen admixture, especially in the "tail" of its distribution function. This effect is not observed in the $H_z = 21$ kOe regime, when the condition of cyclotron resonance is not satisfied and natural magnetosonic oscillations are not excited in the plasma as a result of the operation beyond cutoff (see Fig. 1b).

It is seen from Figs. 2a and 2b, which show the energy spectra of the charge-exchange neutrals in the tokamak-chamber section where the RF exciter is located, that in addition to heating the hydrogen admixture, which occurs only under cyclotron resonance conditions, a change takes place here also in the

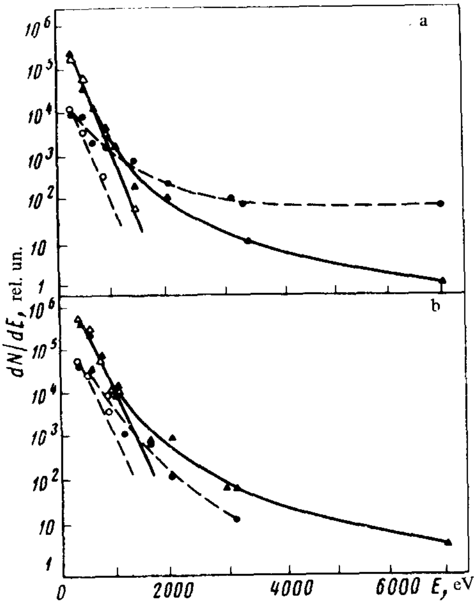

FIG. 2. Energy spectra of the charge-exchange atoms in a 15-kOe field (a) and in a 21-kOe field (b) in the section where the RF exciter is located. All the symbols are the same as in Fig. 1.

distribution functions of the deuterium and hydrogen, which do not depend on the satisfaction of the resonance conditions. This change is connected with local heating of the plasma on the periphery of the pinch under the influence of the RF field of the loop. This explanation was confirmed by the particle-lifetime data shown in Fig. 3. The observed lifetime of the protons with energy 1 keV agrees with the estimate of the time of their deceleration by the deuterium ions, which yields a value $\tau \approx 1$ msec, whereas the "tail" on the distribution function of the deuterium disappears ~100 msec after the RF generator is turned on.

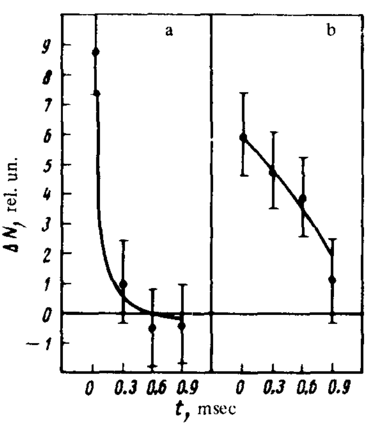

FIG. 3. Time dependence of the intensity of the charge-exchange flux of the deuterium (a) and hydrogen (b) atoms with energy 1 keV after turning off the RF generator. The zero level is taken to be the intensity in the absence of RF heating. The analyzer is located in the same section as the exciter.

Thus, the present study has experimentally confirmed the feasibility in principle of obtaining a two-component tokamak regime by cyclotron heating of the ions of a small admixture by fields of a magnetosonic wave.

[1]I. M. Dawson, H. P. Furth, and F. H. Tenny, Phys. Rev. Lett. **26**, 1156 (1971).

[2]R. A. Demirhanov, Yu. V. Kursanov, and L. P. Skrinal', At. Energ. **34**, 490 (1973).

[3]V. I. Pistunovich, At. Énerg. **35**, 11 (1973).

[4]I. N. Golovin, V. I. Pistunovich, and G. E. Shatalov, Preprint Inst. At. Énerg., Moscow, 1973.

[5]H. P. Furth and D. L. Jassby, Phys. Rev. Lett. **32**, 1176 (1974).

[6]T. H. Stix, Nuclear Fusion **15**, 737 (1975).

[7]R. Klima, A. V. Longivinov, and K. N. Stepanov, Zh. Tekh. Fiz. **46**, 704 (1976) [Sov. Phys. Tech. Phys. **21**, 409 (1976)].

[8]N. V. Ivanov, I. A. Kovan, V. V. Siluyanov, and N. N. Shvindt, At. Énerg. **36**, 374 (1974).

[9]N. V. Ivanov and I. A. Kovan, At. Énerg. **38**, 229 (1975).