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HIGH-FREQUENCY PLASMA HEATING IN A STELLARATOR

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The development of methods of supplying energy for plasma heating in closed magnetic traps is presently one of the serious problems for controlled thermonuclear reactions (CTR). One of the possible solutions of this problem is high-frequency heating. Attempts to use this method in closed magnetic systems entail a number of difficulties connected with the technique of introducing large powers and exciting waves in a dense plasma located in a metallic chamber and in a strong magnetic field [1 - 3].

We report here preliminary results of experiments of high-frequency plasma heating in a closed magnetic trap, namely the "Sirius" stellarator [4]. The main purpose of the investigation was to ascertain the possibility of supplying high-frequency energy to the plasma with the aid of an exciting system that produces a spatially-periodic longitudinal electric field on the periphery of the plasma column. We use such an exciting system in the form of a metallic vacuum chamber of the stellarator, to the dielectric separator of which we connected a high-frequency generator through a system of feeders (Fig. 1).

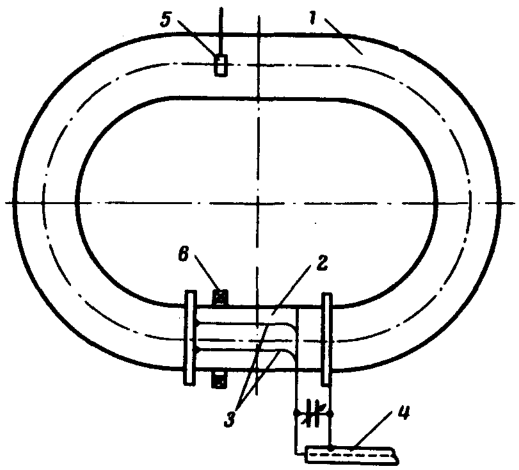

Fig. 1. Diagram of exciting system: 1) metallic vacuum chamber, 2) ceramic section, 3) high-frequency voltage buses; 4) high-frequency supply feeder, 5) high-frequency magnetic probe, 6) diamagnetic probe.

As shown by a theoretical analysis, such systems produce on the periphery of the plasma column a longitudinal electric field E_z with a broad wavenumber spectrum

$$E_z = \sum_{n=0}^{\infty} E_{zn} \cos k_{\parallel n} z , \qquad (1)$$

where $k_{\parallel n} = 2\pi n/L$ and ℓ is the length of the vacuum chamber. They can excite in the plasma "slow" electromagnetic waves in which the longitudinal field component E_z exceeds considerably the azimuthal field E_ϕ [5]. For a weakly-inhomogeneous bounded plasma filament, the condition for effective excitation of the slow wave with longitudinal wave number $k_{\parallel n}$ can be written in the form

$$\epsilon_1 k_{\perp n} d \lesssim 1, \quad \frac{c^2}{\omega^2} k_{\parallel n}^2 \gtrsim \epsilon_1 \,, \tag{2}$$

where $\varepsilon_1 = 1 + \sum_\alpha [\omega_{p\alpha}^2/(\omega_{H\alpha}^2 - \omega^2)]$, $k_{\perp n}$ is the transverse wave number for the slow wave, and d is the distance between the plasma filament and the wall of the vacuum chamber. The condition (2) can be particularly easily satisfied when slow waves are excited at frequencies close to the electron-ion or ion-ion hybrid resonances, where $\varepsilon_1 \sim 1$ and $k_{\perp n} \sim (\omega_{pe}/\omega)k_{\parallel n}$. The experiment was therefore performed on a plasma consisting of a mixture of ions of two sorts (50% helium and 50% hydrogen).

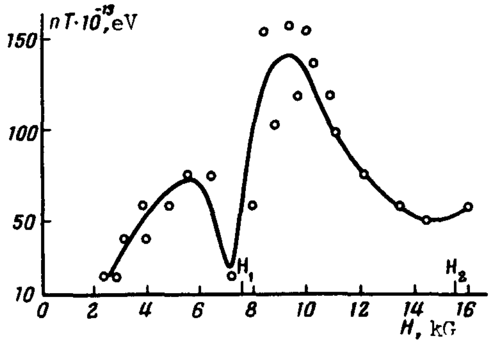

Fig. 2. Dependence of gaskinetic plasma pressure on the magnetic field.

The plasma was produced by an ohmic discharge. A pulse from an 11.6-MHz generator was applied to the decaying plasma at the instant when its density fell to $n = 1 \times 10^{13}$ cm^{-3}.

During the course of the experiments we measured the high-frequency voltage and the current, the wave field on the periphery of the plasma filament, the plasma density, and the magnetic-flux change due to the diamagnetism of the plasma.

At a low power input level (less than 10 W), we investigated the radiotechnical characteristics of the excitation system. It turned out that once the plasma is produced the system input impedance at the feeder connection has an inductive character and is determined mainly by the stray inductance of the supply buses. The inductive component of the input impedance was neutralized with a variable capacitor whose value was set to produce resonance in the exciting system in the presence of the plasma. Its Q at that time had an approximate value of 10, and the frequency deviation during the pulse was negligible.

Diamagnetic measurements were used to study the dependence of the gaskinetic pressure of the plasma on the magnetic field intensity H at a high level of the total power supply ($P \lesssim 60$ kW; the maximum high-frequency input current measured in the supply buses reached 150 A). The results of the diamagnetic measurements are shown in Fig. 2. The dependence of nT on H has a resonant character. The maximum of nT is reached in the interval between the magnetic-field values H_1 and H_2 corresponding to the cyclotron frequencies for the hydrogen and doubly-ionized helium ions. The position of the diamagnetic-signal maximum agrees well with the region of the ion-ion hybrid resonance, where slow waves with relatively small longitudinal wave numbers, $k_\parallel \gtrsim 2\pi/L$, can exist. This region corresponds to $H \simeq 9.6$ kOe at the investivated plasma parameters. It is interesting that an appreciable drop in the diamagnetic-signal level is observed in the region of existence of the ion cyclotron wave ($H_1 < H < 8.8$ kOe and $H > H_2$), where according to [2] the excitation of slow waves is ineffective. In the ion-ion hybrid resonance region, the plasma temperature reaches T = 100 - 150 eV.

When high-frequency power is fed at magnetic fields $H_1 < H < H_2$, an azimuthal component H_ϕ of the high-frequency field was observed in the plasma (with the aid of a magnetic probe).

Thus, the experiments demonstrate the feasibility of using the proposed excitation system to heat a plasma in a closed magnetic trap. The system has significant design advantages over those used in [1 - 3]. The measurements of nT show that high-frequency power absorption is resonant in a region close to the ion-ion hybrid frequency.

In conclusion, the authors consider it their pleasant duty to thank Professor K.N. Stepanov and Professor V.T. Tolok for interest in the work and for useful discussions.

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MAGNETOSENSITIVE INJECTION-FIELD EFFECT IN SEMICONDUCTORS

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It is known that the magnetodiode effect [1, 2], wherein the nonequilibrium conductivity produced in a semiconductor by carrier injection in a magnetic field B, is due to the dependence of the ratio of the effective distance d_{eff} between the injection contacts to the effective length L_{eff} of the fusion displacement on B. L_{eff} can vary as a result of a change of carrier mobility in the magnetic field or a change of their effective lifetime τ_{eff}, which is determined by the volume and surface recombination. In the latter case the magnetodiode effect depends on the state of the semiconductor surface, particularly on the rate of surface recombination S [3 - 5].

Since S is a function of the surface potential ψ_s, the surface-recombination rate can be controlled with the aid of an external electric field E_s perpendicular to the semiconductor surface, which leads to a change of ψ_s. Therefore in semiconductor samples of thickness $\ell \lesssim L_{eff}$ the value of τ_{eff} and consequently L_{eff} should be determined also by the value of E_s. In this case one can expect variation of E_s to change the ratio d_{eff}/L_{eff} (even if $B \neq 0$), and accordingly the injection conductivity of the semiconductor. It is known that for differently processed semiconductor surfaces the $S(\psi_s)$ dependence can be either "monotonic" or "nonmonotonic" (in the simplest case, "bell-shaped") [6]. The magnitude of the effect under consideration will vary accordingly. It is also necessary to take into account the dependence of S on the injection level.