CREATION OF LOW DENSITY STARTING PLASMA WITH SMALL FRAME ANTENNA AT URAGAN-3M DEVICE

M.M. Kozulya, E.D. Kramskoy, V.B. Korovin, A.V. Yevsyukov, A.V. Lozin, A.A. Kasilov, L.I. Grigor'eva, A.E. Kulaga, S.M. Maznichenko, Yu.K. Mironov, V.S. Romanov, V.V. Chechkin, and Uragan-3M team

Institute of Plasma Physics of the NSC KIPT, Kharkov, Ukraine

Deficient shot-to-shot stability of Uragan-3M discharges makes difficult to reproduce experimental results over the period of experimental session. An efficient way of reducing difference between shots is creation of initial low density plasma before the main discharge to start up. A RF pre-ionization in the same frequency range as that of the main discharge is used in the Uragan-3M torsatron. The pre-ionization provides stable discharges during the whole experimental campaign. The main parameters of the pre-ionization plasma are measured and discussed.

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INTRODUCTION

In the Uragan-3M (U-3M) torsatron a hydrogen plasma with the average density $\bar{n}_e$ of units 10^{12} cm^{-3} is produced and heated by RF waves in the $\omega \lesssim \omega_{ci}$ range of frequencies. To ignite the main RF discharge, an initial amount of free electrons is necessary. There is a random amount of such electrons in the vacuum chamber before each discharge pulse, thus resulting in a random delay of the main discharge start. Thus, with the use of RF antennas (frame antenna [0] and three half-turn antennas [0, 0]) for plasma production and heating in Uragan-3M torsatron, in some operational regimes the problem arises with the reproducibility of the discharge start. The situation was significantly improved after an additional small RF antenna became to be used as a part of the pre-ionization system. This so-called small frame antenna (SFA) was shown is able to provide plasma of similar shot-to-shot density before start-up of the main discharge pulse. The objective of this work is elucidation of abilities of this pre-ionization system.

DESCRIPTION OF EXPERIMENTAL SETUP

The U-3M device (Fig. 1) is an l=3/m=9 torsatron with the torus major radius R_0=100 cm, the average plasma radius $\bar{a}\approx$12 cm, the rotational transform at the plasma boundary $\iota(a)/2\pi\approx0.3$. The toroidal magnetic field of regular discharges is B_0=0.72 T. The whole magnetic system, including the helical coils, vertical field coils and supports, is enclosed into a large 5 m diameter vacuum tank, its free volume (≈70 m^3) being ~200 times as large as the plasma confinement volume.

The pre-ionization system (Fig. 2) consists of the RF oscillator (named as Kaskad-0), cable feeder line, matching device and small frame antenna (SFA). The plasma will be effectively created by SFA provided the Landau damping condition $\omega\approx kv_{Te}$ is fulfilled, where k is the parallel (with respect to the confining magnetic field) wave number generated by the antenna, v_{Te} is the thermal velocity of electrons. To fulfil this condition, the parallel length of the antenna L_a should be approximately half wavelength, i.e., $L_a\approx\pi v_{Te}/\omega$.

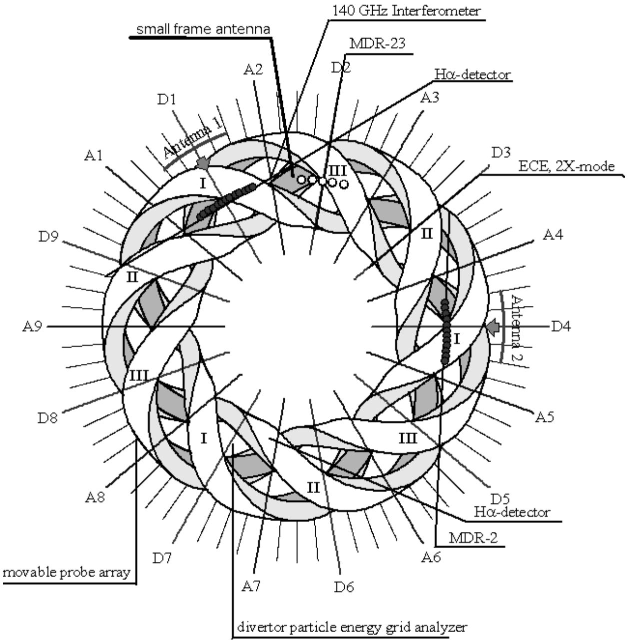

Fig. 1. Helical coils I, II, III of the U-3M torsatron. Symmetric poloidal cross sections A1, D1, A2, D2, …, A9, and D9 in helical field periods 1, 2, …, and 9, respectively, and positions of main diagnostics are indicated. Also, positions of the small frame antenna, frame antenna (Antenna 1) and three-half-turn antenna (Antenna 2) over the torus are indicated

Assuming v_{Te}~10^8 cm/s and the frequency of the Kaskad-0 oscillator $\omega/2\pi$=5 GHz, the length of SFA should be $L_a\approx$10 cm.

SFA is plane and made of a 2 cm width stripe and has the shape of an 11 cm side square. It is inserted in the symmetric poloidal cross-section D2 of the U-3M torus (see Fig. 1) and can be connected to the oscillator in two ways, as a conductor and as a potential electrode. In the current experimental series the second variant is used. The Kaskad-0 oscillator driving SFA operates in the range of frequencies 3...9 MHz, whereas the RF oscillators Kaskad-1 and Kaskad-2. which drive the frame and three half-turn antennae producing the main plasma, operate at frequencies $\omega_1/2\pi$=8.8 MHz and $\omega_2/2\pi$=8.9 MHz, accordingly.

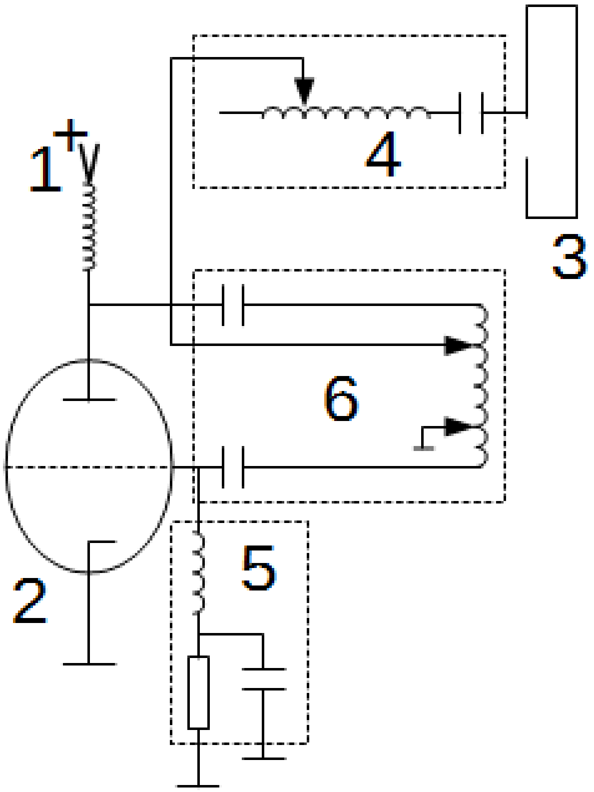

Fig. 2. Electrical scheme of pre-ionization system: 1 – power supply; 2 – electron tube; 3 – antenna; 4 − matching device; 5 – HF ground connection; 6 − oscillating circuit with feedback

The measurements of local plasma parameters with SFA in operation were performed using a single movable Langmuir probe (Fig. 3).

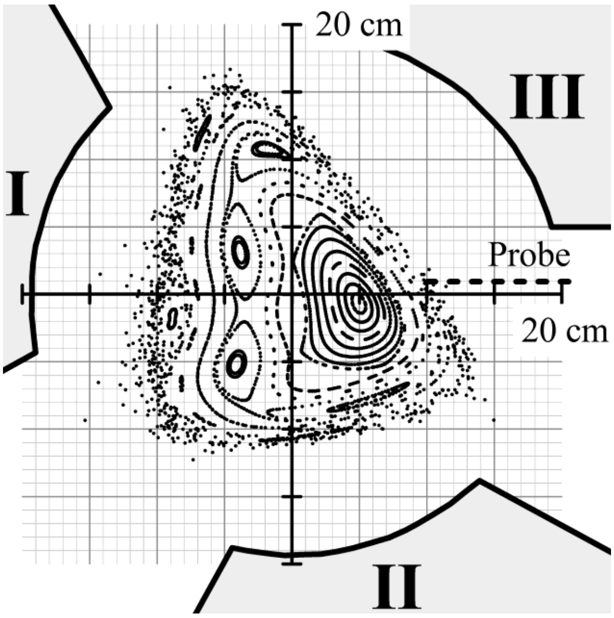

Fig. 3. Probe position in the poloidal cross-section of the U-3M torus and its movement (dashed line) with respect to the helical coils I, II, III

EXPERIMENTAL RESULTS

The time evolution of the line-averaged electron density $\bar{n}_e$ produced by SFA only is shown in Fig. 4. The maximum value of $\bar{n}_e$ ~ 10^{10} cm^{-3} is attained by ~ 20 ms after RF pulse start. In the operating regime the oscillator K1 used for initial plasma production was switched on at 10 ms where the average pre-ionization density $\bar{n}_e$ was ~ $4\cdot10^9$ cm^{-3}.

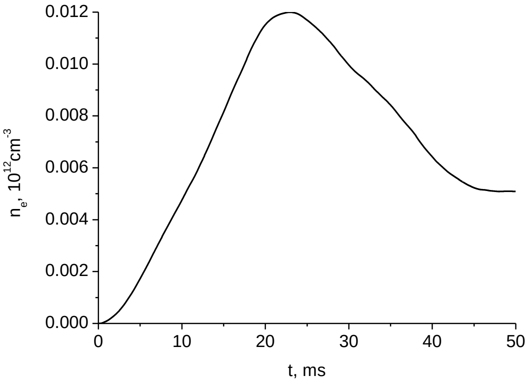

Fig. 4. Time behavior of average electron density $\bar{n}_e$ produced by the small frame antenna

The measured profiles of the electron density $n_e(h)$ and temperature $T_e(h)$ are shown in Fig. 5.

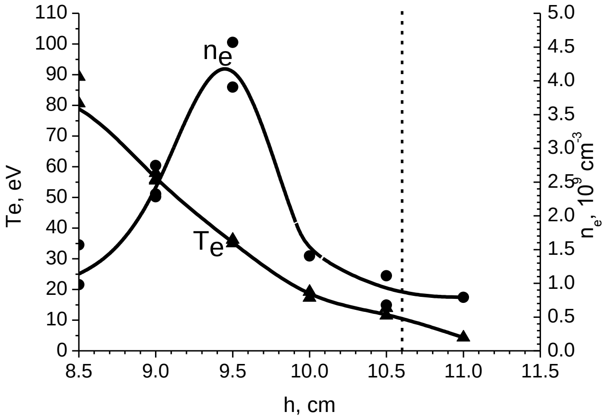

Fig. 5. Local electron density n_e and temperature T_e versus distance h between the probe and the vertical axis of the poloidal cross-section. The calculated plasma boundary is indicated by vertical dashed line

As is seen in Fig. 5, the maximum values of n_e (h = 8.5 cm) and T_e (h = 9.5 cm) derived from probe measurements attain ~$4\cdot10^9$ cm^{-3} (being in accord with $\bar{n}_e$ measurements) and ~ 100 eV, respectively. As a probable reason for the observed local electron temperature fall at $h < 9.5$ cm, the cooling of electrons resulting from deep penetration of the probe into the confinement volume could be.

A stabilizing effect of the RF discharge driven by SFA is demonstrated in Fig. 6 where time evolutions of discharges driven by the frame and three-half-turn antennae are compared under conditions without and with SFA in operation.

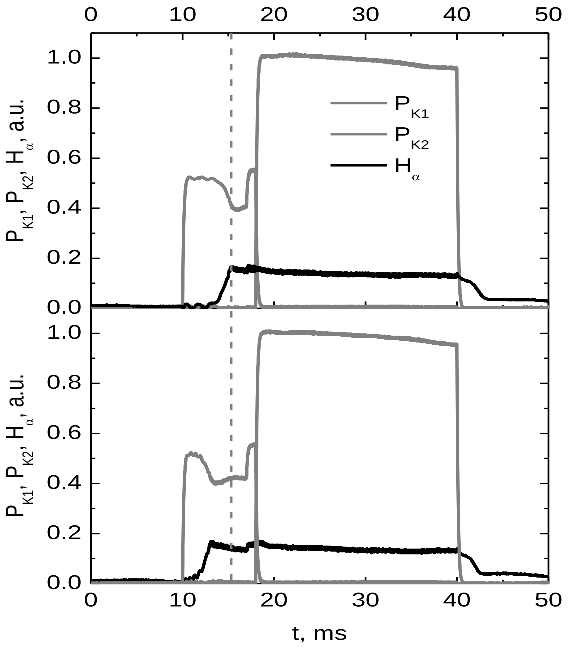

Fig. 6. Time behaviour of H_α emission and Kaskads' power without (upper) and with (lower) Kaskad-0 small frame antenna used. The dashed line marks the end of plasma production for discharge without pre-ionization by SFA

Without SFA pulse the time delay of the end of the plasma production stage of the discharge from the beginning of K1 pulse is 3...6 ms. It varies from shot to shot. With the SFA the time delay is stable and is equal to 3 ms. With usage of the SFA, repeatability discharges becomes acceptable for pulse-to-pulse measurements of radial distributions of the plasma parameters.

SUMMARY

To stabilize ignition and parameters of RF-discharges driven by the frame and three-half-turn antennae, a pre-ionization with the use of a low density RF-discharge plasma produced by the small frame antenna is realized.

Increased discharge repeatability allowed to perform pulse-to-pulse plasma parameters measurements. Small frame antenna does not influence significantly the plasma parameters of the main discharge.

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СОЗДАНИЕ НИЗКОПЛОТНОЙ ПЛАЗМЫ МАЛОЙ РАМОЧНОЙ АНТЕННОЙ НА УСТАНОВКЕ УРАГАН-3М

М.М. Козуля, Е.Д. Крамской, В.Б. Коровин, А.В. Евсюков, А.В. Лозин, А.А. Касилов, Л.И. Григорьева, А.Е. Кулага, С.М. Мазниченко, Ю.К. Миронов, В.С. Романов, В.В. Чечкин, и команда Ураган-3М

Нестабильность разрядов Урагана-3М затрудняет воспроизведение экспериментальных результатов в течение одной экспериментальной кампании. Эффективным способом устранения различия между параметрами плазмы в разных импульсах является предионизация ВЧ-разрядной низкоплотной плазмой, которая создается малой рамочной антенной. Предионизация обеспечивает стабильность разрядов в течение всей экспериментальной кампании. Были измерены и оценены основные параметры предионизационной плазмы.

СТВОРЕННЯ НИЗЬКОЩІЛЬНОЇ ПЛАЗМИ МАЛОЮ РАМКОВОЮ АНТЕНОЮ НА УСТАНОВЦІ УРАГАН-3М

М.М. Козуля, Є.Д. Крамской, В.Б. Коровін, А.В. Євсюков, А.В. Лозін, А.А. Касілов, Л.І. Григор'єва, А.Є. Кулага, С.М. Мазніченко, Ю.К. Миронов, В.С. Романов, В.В. Чечкін, і команда Ураган-3М

Нестабільність розрядів Урагана-3М утрудняє відтворення експериментальних результатів на протязі однієї експериментальної кампанії. Ефективним способом усунення різниці між параметрами плазми в різних імпульсах є передіонізація ВЧ-розрядною низькощільною плазмою, яка створюється малою рамковою антеною. Передіонізація забезпечує стабільність розрядів на протязі всієї експериментальної кампанії. Були виміряні й оцінені основні параметри передіонізаційної плазми.