USAGE OF THREE-HALFTURN ANTENNA AT THE URAGAN-3M DEVICE

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Unshielded THT antenna is successfully used: (i) for heating of plasma prepared by the frame antenna pulse, (ii) for making an initial plasma with low density ~10^{10} cm^{-3} for further frame antenna operation, (iii) for independent generation and heating plasma at low magnetic fields B_0<0.7 T and (iv) for mutual operation with frame antenna. In the last scenario both antennas contribute to plasma heating.

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INTRODUCTION

A three-half-turn (THT) unshielded antenna (l_φ≈36 cm) has currents in its major straps oriented perpendicularly to the magnetic field lines near the plasma boundary surface (Fig. 1). Radio-frequency (RF) voltage is supplied to the central strap. The side straps are connected in series to the central strap and in parallel each to other. Connecting them splitter straps are recessed from the plasma to minimize their influence on wave excitation. Those antenna strap elements which intersect the divertor plasma flows have notches for minimization contact surface area. The antenna is made of stainless steel and coated with titanium nitride for decreasing impurity generation, as far as the coating improves its resistance to arcing and sputtering.

Such a THT antenna [1, 2] is aimed to excite the fast wave field and to be used for Alfvén resonance heating in the frequency range below ion cyclotron frequency.

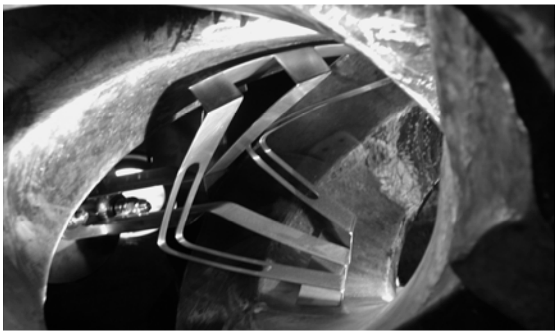

Fig. 1. THT antenna inside Uragan-3M

DESCRIPTION OF THE DEVICE

Experiments were carried out at Uragan-3M device, which is the three-turn (l=3) torsatron with nine periods (m=9) of helical magnetic field. The torus major radius is R_0=100 cm, the average plasma radius is $\bar{a}$ ≈12 cm, the rotational transform angle at the plasma edge is ι≈0.3. The typical value of the toroidal magnetic field used for cleaning discharges is B_0=0.72 T. The whole magnetic system including the helical coils, the vertical field coils and the support, is placed into a large vacuum tank, 5 meters in diameter, which volume (70 m^3) by 200 times exceeds the plasma confinement volume. An open helical divertor configuration is natural for the device.

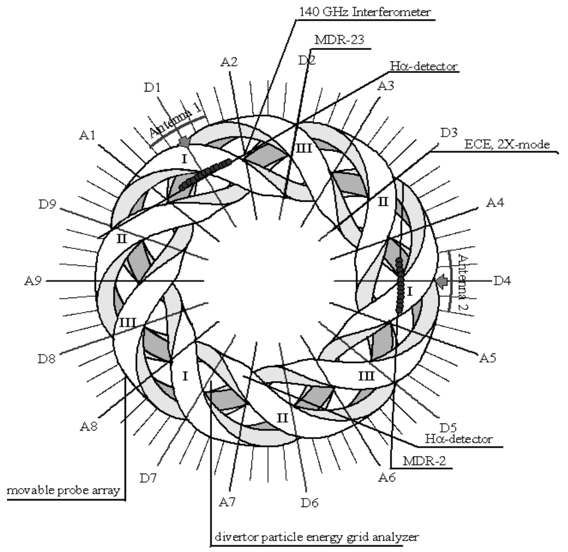

Fig. 2. Schematic allocation of torsatron Uragan-3M diagnostics

PLASMA HEATING WITH THT ANTENNA

Three-half-turn (THT) antenna is regularly used at Uragan-3M device for Alfvén plasma heating, while initial plasma is created with frame antenna which pulse precedes THT antenna impulse. An example of such a discharge is shown in Fig. 3. The parameters of the discharge are following B_0=0.72 T and P_{H2}≈10^{-5} Torr.

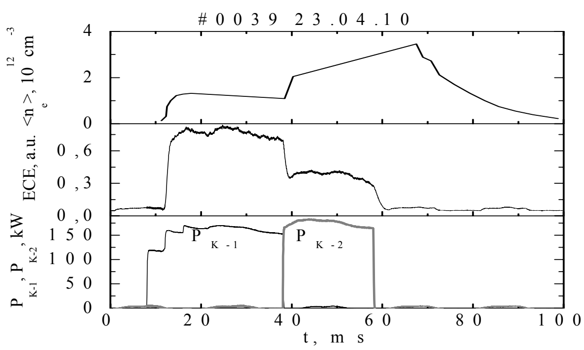

Fig. 3. Consecutive impulses of frame and THT antennas: RF powers, ECE emission and average plasma density temporal evolutions (P_{H2}=10^{-5} Torr, B=0.72 T)

The frame antenna creates and heats plasma of the density (1…2)×10^{12} cm^{-3}. After switching off the frame antenna and switching on the THT antenna plasma density sharply increases. Then it ramps up gradually during impulse and, for long pulse duration, can exceed the value of 10^{13} cm^{-3}. The electron temperature becomes lower. However, for the reason of plasma density increase, the plasma energy content remains almost the same.

USAGE OF THT ANTENNA FOR INITIAL LOW DENSITY PLASMA GENERATION BEFORE MAIN RF DISCHARGE IMPULSE

RF power is supplied to the frame antenna in a programmable way (by three-step increase) with the aim of providing minimal start-up time of discharge and minimizing the antenna voltage. However, the programmable steps don't guarantee reproducible plasma generation (no gas breakdown occurs with probability of about 3 %). Moreover, the discharge start-up time (Δt) randomly deviates mainly within the margins of 3…7 ms, that doesn't allow maintaining stationary regime in reproducible way. An example of such a discharge with long plasma production delay is shown in Fig. 4.

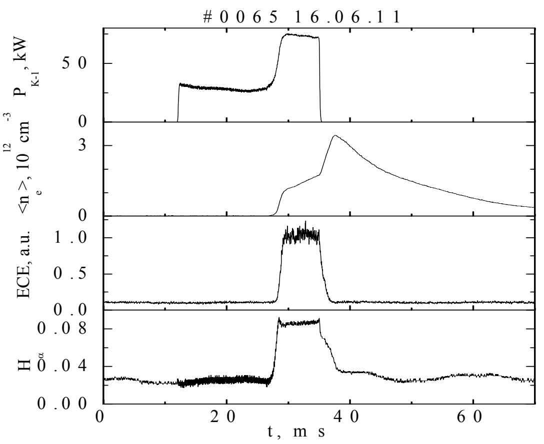

Fig. 4. Frame antenna individual pulse: RF power, ECE emission, H_α line and average plasma density temporal evolutions ($P_{H2}=10^{-5}$ Torr, $B_0=0.72$ T)

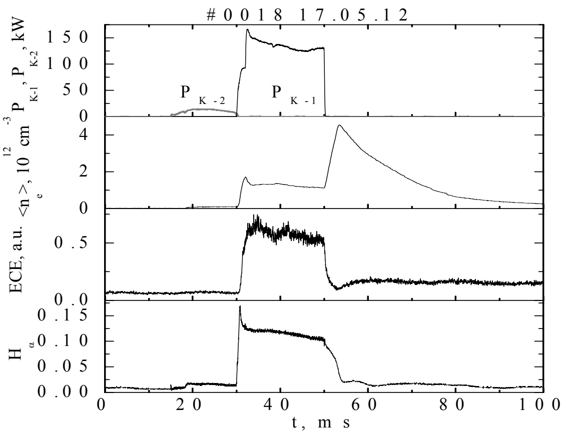

Fig. 5. Discharge with pre-ionization by THT antenna: THT antenna pulse precedes frame antenna shot; substantial plasma density is produced with frame antenna ($P_{H2}=10^{-5}$ Torr, B=0.72 T)

The frame antenna standalone discharge has a 14 ms delay according to H_α, ECE and average electron density signals.

THT antenna doesn't create dense plasma in standard regime for Uragam-3M (B_0=0.72 T, RF heating frequency f=8.6 MHz), but low density plasma (≈10^{10} cm^{-3}) is created sufficiently stably. This phenomenon can be explained by slow wave generation that is excited by THT antenna via electrostatic mechanism. Experiments show that such a plasma is quite suitable as initial one for further stable production of dense plasma using the frame antenna.

As displayed in Fig. 5, RF discharge (start at 15 ms and switch-off at 30 ms) induced by the THT antenna starts before impulse of the frame antenna (30 ...50 ms). For pre-ionisation regime, 20 kW of input power to antenna is sufficient for plasma generation with two orders of magnitude less plasma density than in the regular regime. Although the initial density is small, its influence on further gas breakdown development is strong: the plasma production delay is shortened substantially and the reproducibility of the discharges increases.

PLASMA PRODUCTION AND HEATING WITH THT ANTENNA

Decrease of magnetic field decreases a critical density value starting from which Alfvén resonances appear in plasma column. As soon as this value gets less than the plasma density created with the slow wave, plasma production becomes possible in the relay-race mode regime. It's experimentally shown that a THT antenna impulse creates dense plasma at magnetic field less than 0.7 T without pre-ionization, and plasma creation delay time decreases with magnetic field. The THT antenna is able to create high density plasma (Fig. 6), emit high power and implement acceptable delays of the start-up.

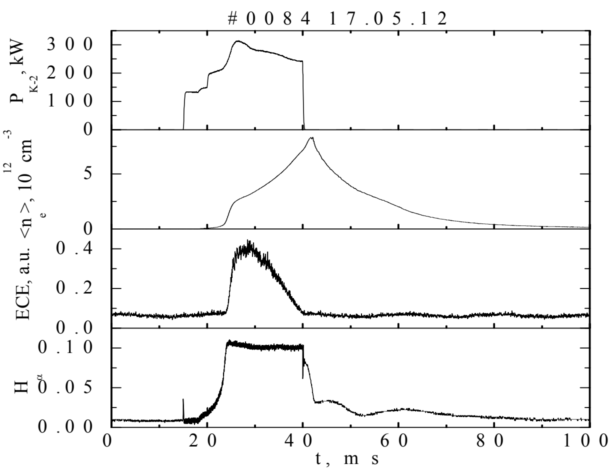

Fig. 6. THT antenna individual pulse: RF power, ECE emission, H_α line and average plasma density temporal evolutions ($P_{H2}=2\cdot10^{-5}$ Torr, B=0.68 T)

PLASMA PRODUCTION AND HEATING WITH THT AND FRAME ANTENNAS

Simultaneous work of frame and THT antennas provided high temperature plasma during whole impulse at magnetic field 6.8 T. At this magnetic field value for heating frequency f=8.9 MHz, the optimum plasma density is low for THT antenna. However, the gas break-down occurs only at neutral gas pressures higher than $P_{H2}>10^{-6}$ Torr, and the resulting plasma density is higher than $(2…3)·10^{12}$ cm^{-3}. This turns the THT antenna pulse away of optimum condition. The pulse of the frame antenna causes decrease of plasma density (see Fig. 7), and the THT antenna heating efficiency increases.

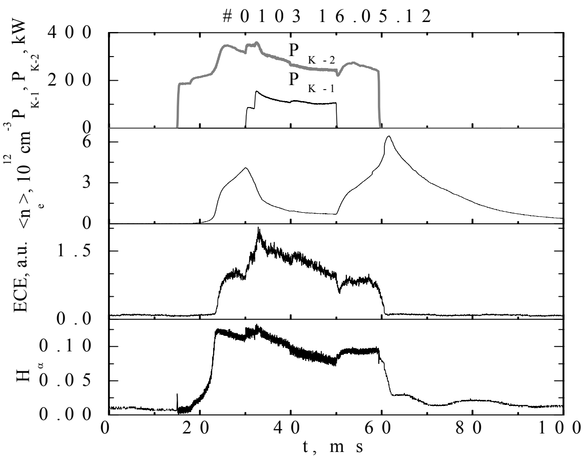

Fig. 7. «Frame antenna in the middle» scheme of the discharge, according to power lines; High density is created by THT antenna and high temperature by frame antenna; H_α changes much like ECE ($P_{H2}=10^{-5}$ Torr, B=0.68 T)

As indicated by ECE signal, the electron temperature has a peak at optimum plasma density. This plasma density value is also reached after the frame antenna switch-off, but without the frame antenna input the heating effect is less pronounced.

CONCLUSIONS

Unshielded THT antenna is successfully used:

a) For heating of plasma prepared by the frame antenna pulse. The heating is more efficient when the gas puff is used [3].

b) For making an initial plasma with lower density ~10^{10} cm^{-3} for further frame antenna operation. This plasma minimizes the start-up delay and increases reproducibility of the frame antenna discharges.

c) For independent generation and heating plasma at low magnetic fields B_0<0.7 T.

d) For mutual operation with frame antenna. In this scenario both antennas contribute to plasma heating.

Three last scenarios of the THT antenna operation are developed recently and will be studied in detail in near future.

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ИСПОЛЬЗОВАНИЕ ТРЕХПОЛУВИТКОВОЙ АНТЕННЫ НА УСТАНОВКЕ УРАГАН-3М

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Неэкранированная трехполувитковая антенна успешно используется: (i) для нагрева плазмы, подготовленной импульсом рамочной антенны; (ii) для создания начальной плазмы низкой плотности ~ 10^{10} см$^{-3}$ для дальнейшей работы рамочной антенны; (iii) для независимого создания и нагрева плазмы в магнитных полях B_0 <0,7 Тл; (iv) для совместной роботы с рамочной антенной (в этом случае обе антенны дают вклад в нагрев плазмы).

ВИКОРИСТАННЯ ТРЬОХНАПІВВИТКОВОЇ АНТЕНИ НА УСТАНОВЦІ УРАГАН-3М

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Неекранована трьохнапіввиткова антена успішно використовується: (i) для нагріву плазми, підготовленої імпульсом рамкової антени; (ii) для створення початкової плазми з низькою густиною ~ 10^{10} см$^{-3}$ для подальшої роботи рамкової антени; (iii) для незалежного створення та нагріву плазми в магнітних полях B_0 <0,7 Тл; (iv) для взаємної роботи з рамковою антеною (у цьому випадку обидві антени роблять внесок до нагріву плазми).