DYNAMICS OF PLASMA POLOIDAL ROTATION IN THE U-3M TORSATRON

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Results of experimental study of plasma rotation dynamics in the U-3M torsatron during transition to the improved confinement mode are presented. The rotation velocity is measured using the Doppler reflectometry methods.
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1. INTRODUCTION

The E×B poloidal rotation of the plasma in tokamaks and stellarators is accompanied with appearance of transport barriers that influence on the transport of energy and particles. By studying the rotation of plasma, we can understand such key moments as the suppression of turbulence and the transport barrier formation in the regime of improved confinement.

One of the main diagnostics in the study of these processes is the microwave reflectometry. It is used to determine the position of plasma layer in space, the restoration of profiles of density and its fluctuations and also to study the rotation speed of the plasma layers. Plasma probing by O- and X-waves expands the possibilities of reflectometry. This is due to the fact that the refractive index of X-waves depends on the magnetic field. It is perspective in stellarators where the spatial distribution of the magnetic field is known.

The experimental study of the plasma rotation can be carried out not only by the correlational microwave diagnostic [1]. The using of Doppler reflectometry can also give a comprehensive information about the plasma rotation velocity [2]. By changing the angle of entry of the microwave beam in plasma one can determine the speed of rotation of plasma in different layers by measuring the shift of the frequency. Thus, the radial profile of the plasma rotation velocity can be obtained. To determine the radial plasma layers where the transport barriers (ITB, ETB) are localized one should outline the points in the measured profile where the velocity sign changes [3].

In this work the dynamics of the Doppler frequency shift and the velocity of poloidal rotation are investigated, taking into account the specific character of the asymmetric geometry of the closed magnetic surfaces in the U-3M torsatron at average density $n_{cp} \approx 10^{12}$ cm^{-3}.

2. EXPERIMENT

The experiments were carried out on the U-3M device with the magnetic field strength B_0 = 7.2 kOe, at the anode voltage of the Cascade-1 RF generator U_1= 7.5 kV, and the hydrogen pressure $p = 4{\cdot}10^{-6}$ Torr. The average density (by the 2mm interferometer), the local density (by the 20…25 GHz X-wave reflection), and the Doppler shift of the 10 GHz frequency recorded by the UHF analyzer were measured in the experiment. The disposition of diagnostics is presented in Fig. 1.

The X-waves reflectometry was carried out on the low field side (external probe). Fig. 2 shows the signals of sensors – the average density, the phase shift of the reflectometer, the signal from the microwave analyzer.

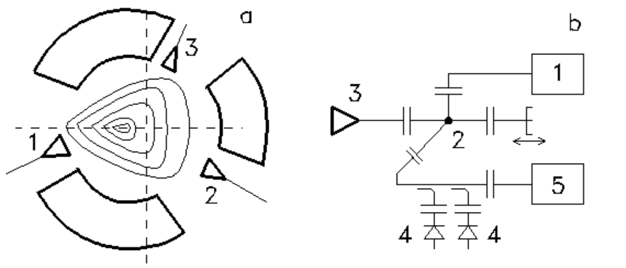


Fig. 1. a) 1,2 - X-waves f=20-25GHz, 3 – O-wave f=10GHz; b) the scheme of the measurement of the frequency shift using the analyzer and the spectral analysis

The reflection radius was determined from the calculated dependence:

$$\frac{\varphi}{2\pi} = \frac{2}{\lambda}\int_0^{r_{ref}} \mu_x dr, \tag{1}$$

$$\mu_x = \left[\frac{u^2 - (1-v)^{\frac{1}{2}}}{u^2 - (1-v)}\right]^{\frac{1}{2}}, \tag{2}$$

where $u = \frac{f_{ce}}{f}$, $v = \frac{n}{n_{cr}}$, $n(r) = n_0\left[1 - (\frac{r}{r_0})^p\right]$, $n_0 = \frac{p+1}{p}\bar{n}$.

Eq. (1) was calculated for p = 1 and p = 2. To find the reflecting layer position by the phase of X-wave reflection and the mean density, the methods proposed in [4] were also used. To identify the rotation speed of the plasma from the Doppler shift of the backscattered signal frequency, we used the formula

$$v = \frac{\Delta f}{2f}\frac{c}{\mu(r_{ref})}. \tag{3}$$

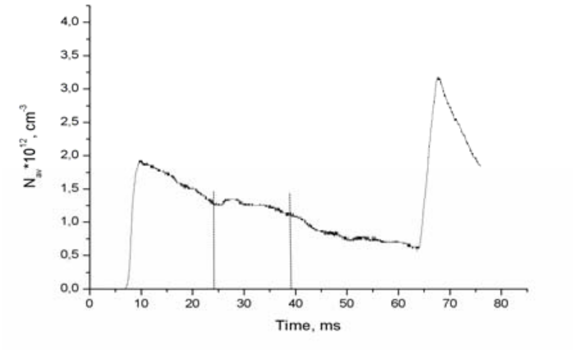
Thus, for the moment of the observed pulse of frequency offset, the level and localization of the density (refractive index) of the reflecting layer are necessary to be known. For a known radial density distribution, the value of $\mu(r_{ref})$ was determined from

$$\mu(r_{ref}) = \left[1 - \frac{n(r_{ref})}{n_{cr}}\right]^{\frac{1}{2}} \tag{4}$$

(at the point of backward Bragg scattering) and r_{ref}, which can be found, considering that

$$r_0 \sin\varphi_0 = r_i \mu_i \sin\varphi_i = r_{ref}\mu_{ref}, \tag{5}$$

and taking into account that the point of reflection $\sin\varphi_i = \sin\frac{\pi}{2} = 1$ (where φ_0 is the angle of incidence at the plasma boundary).



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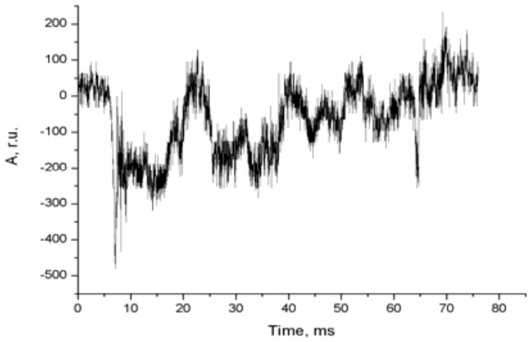

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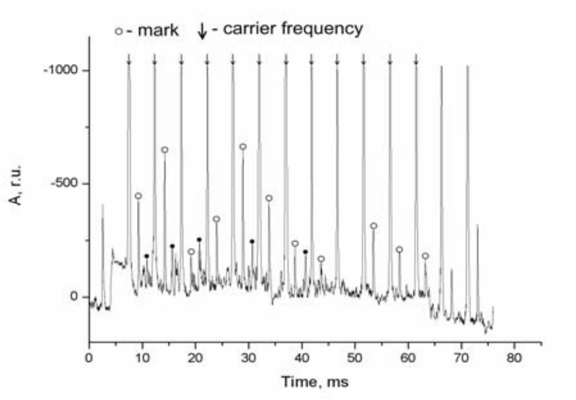


c

Fig. 2. Recorded signals:
a) average density; b) the phase shift of the reflectometer; c) microwave analyzer

The radial density profile in the vertical direction can be calculated from the density profile measured on the outer side of the torus and the dependence shown on Fig. 3.

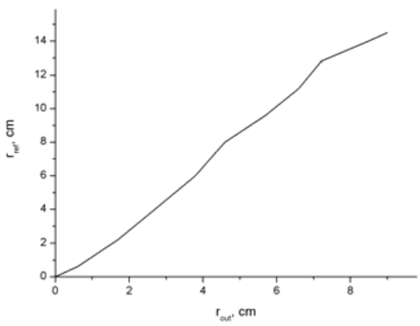
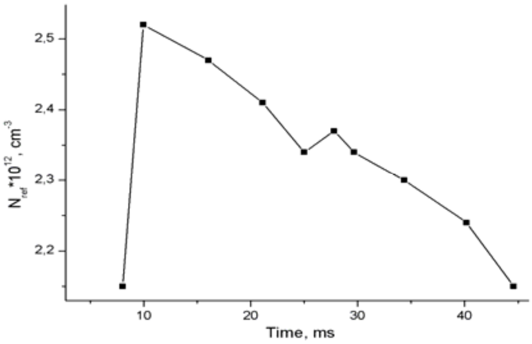
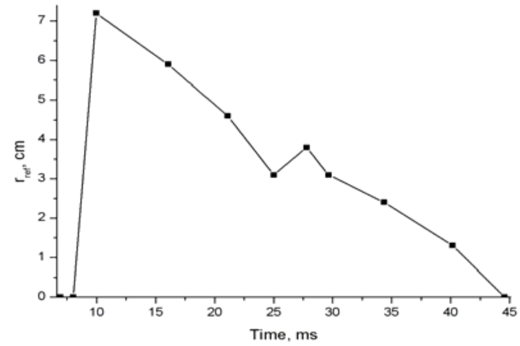


Fig. 3. Dependence of the O-wave reflection radius from the radius of the X-wave reflection



a



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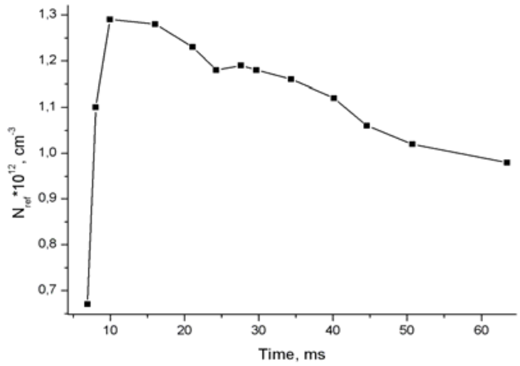

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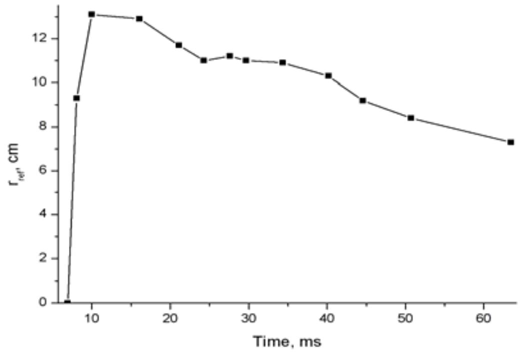

d

Fig. 4. Density of the reflection and the radius of reflection for the two frequencies of the reflectometer: a), b) – f=25.1 GHz; c), d) – f = 20.8 GHz

In this calculations the plasma asymmetry along the chord defining the reflected wave phase and along the Doppler scattering chord and the constancy of the density at a given magnetic surface as well are taken into account.

The dependences of density of the reflection and the radius of reflection for two frequencies on the chord of scattering are shown in Fig. 4.

In some discharges the frequency shift in the red and in the blue regions were simultaneously observed (in one period) (Fig. 5).

DISCUSSION

In RF discharges in the U-3M torsatron the transition to the improved confinement regime in the range 25…40 ms is observed. This mode differs by a slight increase in the density and a significant slowing down of the rate of density decrease (see Fig. 2, a).

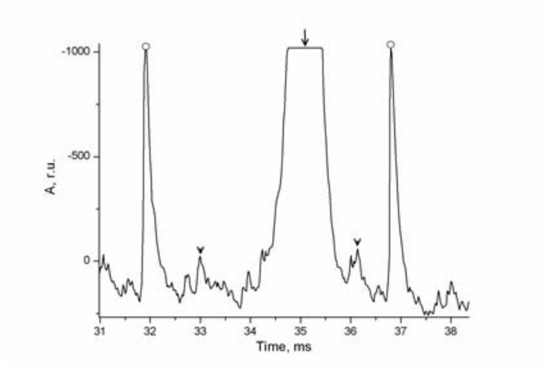

Fig. 5. Frequency shift in the red and in the blue region

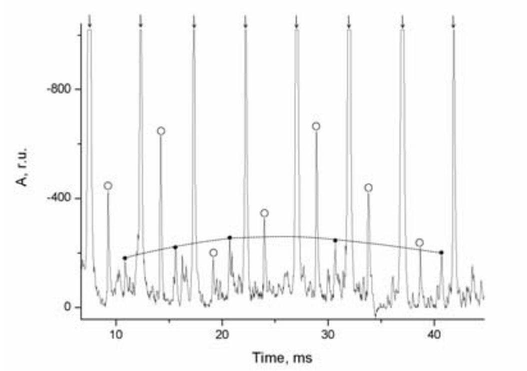

Fig. 6. Change of the amplitude of the scattered signal during the pulse

The scattered signal with the Doppler frequency shift appears before the transition to the regime of improved plasma confinement. The signal intensity increases smoothly before the time of improved confinement and gradually decreases afterwards (Fig. 6).

The observation of several peaks with different frequency shifts is possible as a result of a split of the probe beam and the occurrence of scattering from different layers corresponding to different μ and *r*.

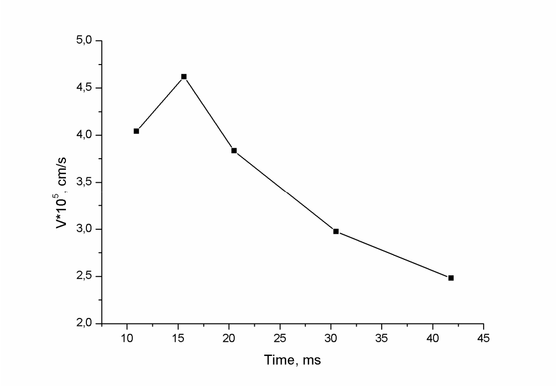

Fig. 7. Velocity of rotation during the pulse

The frequency shift in the red and blue sides may indicate the presence of a poloidal velocity shear and, consequently, an electric field shear. Considering that scattering occurs at $\rho \approx (r / a) \approx 0.75…0.9$, one can speak of the appearance of an edge transport barrier prior to the appearance of the regime of improved confinement.

The velocity of rotation decreases sharply after the end of the improved confinement time (Fig. 7). At the time before the transition several pulses of scattered frequency are observed (Fig. 6).

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ДИНАМИКА ПОЛОИДАЛЬНОГО ВРАЩЕНИЯ ПЛАЗМЫ В ТОРСАТРОНЕ У-3М

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Представлены результаты экспериментального изучения динамики вращения плазмы в торсатроне У-3М во время перехода разряда в режим улучшенного удержания. Скорость вращения определялась методом допплеровской рефлектометрии.

ДИНАМІКА ПОЛОЇДАЛЬНОГО ОБЕРТАННЯ ПЛАЗМИ В ТОРСАТРОНІ У-3М

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Представлено результати експериментального вивчення динаміки обертання плазми в торсатроні У-3М під час переходу розряду в режим покращеного утримання. Швидкість обертання визначалася методом допплеровської рефлектометрії.