MEASUREMENTS OF PLASMA DENSITY IN URAGAN-3M TORSATRON USING DUAL-POLARIZATION INTERFEROMETRY

D.L Grekov, K.K. Tretiak, V.L. Berezhnyj,V.V. Filippov

Institute of Plasma Physics NSC "Kharkov Institute of Physics and Technology", Kharkov, Ukraine

The basic idea of this work is simultaneous using of O- and X-modes for determination in torsatron not only average plasma density but density profile, too. The dual polarization interferometer was placed very close to E-E minor cross-section of U-3M torsatron. First measurements of phase shifts were made. The interpretation of obtained results is presented.

PACS: 52.70.-m

INTRODUCTION

Ordinary O-mode interferometry is well known and common used plasma diagnostic for fusion devices and plasma technology [1]. The O-mode wave number depends only on plasma density in the case of perpendicular to the confining magnetic field probing $k_o = \omega\sqrt{\varepsilon_3}/c, \varepsilon_3 = 1-\omega_p^2/\omega^2$. So, O-mode phase shift is proportional to average plasma density $\bar{n}$ along the hord of probing for wave frequency ω greater then plasma frequency ω_p. For extraordinary X-mode perpendicular probing $k_x = \omega\sqrt{\varepsilon_1^2-\varepsilon_2^2}/\left(\sqrt{\varepsilon_1}c\right)$, $\varepsilon_1 = 1-\omega_p^2/(\omega^2-\omega_c^2), \varepsilon_2 = \omega_p^2\omega_c/((\omega^2-\omega_c^2)\omega$, and X-mode phase shift depends on plasma density and confining magnetic field distributions. As magnetic field is known for torsatron-type devices, additional information as to plasma density profile may be inferкed from the X-mode phase shift measurements. For example, this may be plasma density profile peakedness $\bar{n}/n_0$, where n_0 is the plasma density in the centre of minor cross-section.

1. FORMULATION OF THE PROBLEM

Our purpose is to determine plasma density profile in U-3M via phase shifts of X-mode and O-mode measured experimentally. Experimental datasets consist of phase shifts values measured during the discharge.

To simulate propagation of X-mode and O-mode in plasma and calculate phase shifts for this waves the numerical code was developed. This code computes ray trajectories of X-mode and O-mode in plasma volume taking into account real geometry and magnetic field distribution for U-3M (Fig. 1). Density profile can varies from flat to sharp form. Finding density profile from phase shifts is reduced to solving two functional equations

$$\int_0^L \vec{k}_o(n(\xi),\omega)d\vec{l} = \varphi_o$$
$$\int_0^L \vec{k}_x(n(\xi),\omega)d\vec{l} = \varphi_x \qquad (1)$$

where ω is wave frequency, ξ - peak/flat parameter, n_0 - central density and density $n(\xi)$ defines as

$$n(\xi) = n_0\frac{e^{\xi}-e^{\xi\cdot x}}{e^{\xi}-1} \qquad (2)$$

where χ is the label of magnetic surface (0≤x≤1).

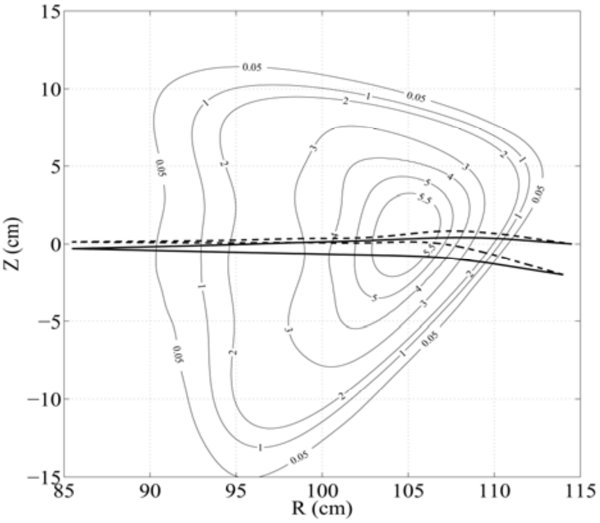

Fig. 1. Ray trajectories of X-wave (dash line) and O-wave (solid line) in poloidal cross-section of U-3M and density profile in 10^{12} cm^{-3}

So, calculated phase shifts (Fig. 2) were matched with experimental results (Fig. 3) in order to determine central density and peak/sharp parameter for U-3M plasma.

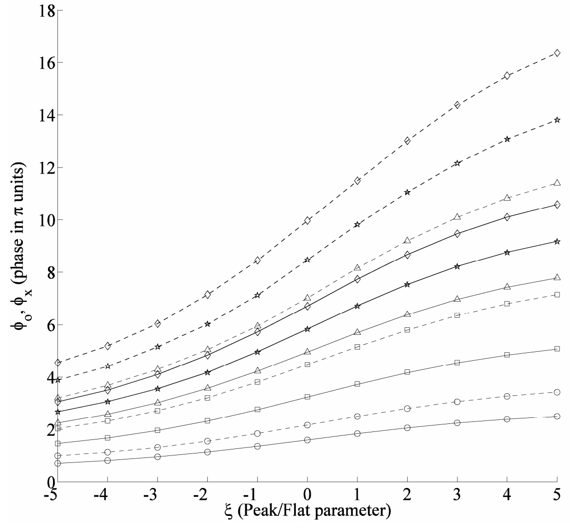

Fig .2. Calculated phases of X-wave(dash line) and O-wave(solid line) depending on density profile; circle - $n_0=1\cdot10^{12}$ cm^{-3}; square - $n_0=2\cdot10^{12}$ cm^{-3}; triangle - $n_0=3\cdot10^{12}$ cm^{-3}; star - $n_0=3.5\cdot10^{12}$ cm^{-3}; rhomb - $n_0=4\cdot10^{12}$ cm^{-3}

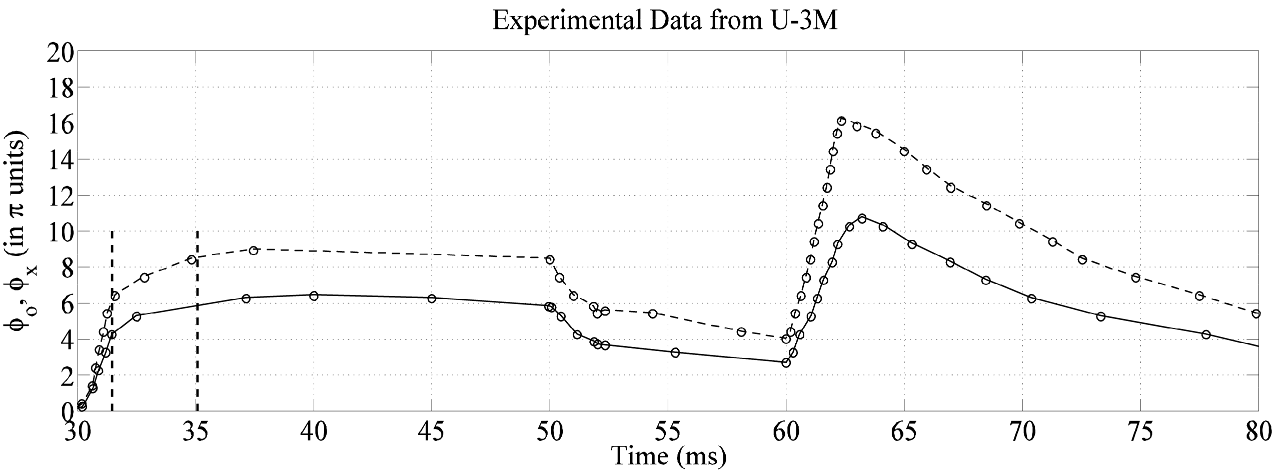

Fig. 3. Measured phase shifts for X-wave(dash line) and O-wave(solid line) depending on time of discharge in U-3M and calculated density profiles corresponding to two time points; 1st -31.44 ms, ξ =-1, n_0=$3\cdot10^{12}$ cm^{-3}; 2nd -35.06 ms, ξ =0, n_0=$3.5\cdot10^{12}$ cm^{-3}

2. EXPERIMENTAL ASPECTS

The horn antennas which were connected to the oversized waveguides were used for probing plasma in Uragan-3M. These waveguides allow propagation of E- and H-polarizations modes without their interference. For independent determination of the phase shifts of O- and X-waves we have fabricated and tested an orthomode transducer (OMT). OMT has one input for oversized waveguide and two outputs which operate in the single mode regime.

The classic homodyne interferometers which have double balanced detection were connected to the output waveguides of OMT. Measurement scheme is shown in Fig. 4. The output signals of interferometer are:

$$\begin{aligned} S1(t) &= AgAs_{o.w}(t)\sin\ _{o.w.}(t) \\ S2(t) &= AgAs_{x.w}(t)\sin\ _{x.w.}(t), \end{aligned} \qquad (3)$$

where: Ag is amplitude of the reference signal, $As_{o.w}$ and $As_{x.w}$ are amplitudes of signals passing through the plasma.

Double balanced mixer additionally contains signals proportional to the sum of the amplitudes of the reference signal and passing through the plasma signal. But for the high quality determination of the phase shifts the accurate calibration must be performed. It was not made at this time.

During the determination of the value of phase shifts we had some difficulties which were caused by fast changes in the amplitude of signals passing through the plasma during plasma discharge. Also, the small differential sensitivity of sin (φ) when $\varphi \approx 0.5\pi+m\pi$, $m=0,1\ldots$ made difficult determination the dynamics of change of the phase shift in these areas. In part the latter problem was solved by not-in-phase signal of phase shift for the ordinary and extraordinary waves. Therefore, the exact values of the phase shifts determined where its equal to $m\pi$, $m=0,1\ldots$

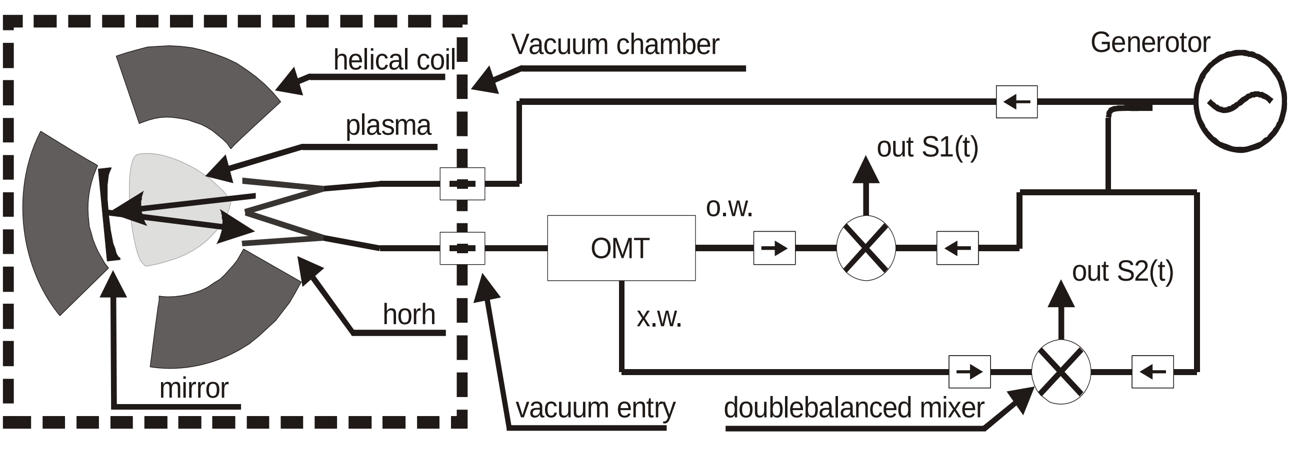

Fig. 4 Principal scheme of dual polarization interferometry at Uragan-3M torsatron

DISCUSSION

Measurements of plasma density by dual-polarization interferometry give us information not only about average plasma density and about density profile form too. Plasma density profiles were established for two time periods of U-3M discharge. But, we need in simultaneous (in the same time points) and more precise data to make conclusion about plasma profile behavior from the beginning to the end of U-3M discharge.

We have to start the work at modification of the interferometer in order to obtain signals proportional to cos(φ) and sin(φ) for each polarization. This modification will solves the problem with the change of the signal amplitude and the exact definition of the dynamics of the phase shift during plasma discharge. Supposed accuracy of the phase shift will be about 2 degrees.

REFERENCES

1. V.E. Golant. *Microwave methods of plasma investigation.* Moskow: "Soviet Radio", 1968.

Article received 16.10.12

ИЗМЕРЕНИЕ ПЛОТНОСТИ ПЛАЗМЫ В ТОРСАТРОНЕ У-3М С ИСПОЛЬЗОВАНИЕМ ДВУПОЛЯРИЗАЦИОННОЙ ИНТЕРФЕРОМЕТРИИ

Д.Л. Греков, К.К. Третьяк, В.Л. Бережный, В.В. Филипов

Интерферометрия с использованием обыкновенной волны хорошо известна и часто применяется в диагностике плазмы. В случае перпендикулярного распространения относительно удерживающего магнитного поля волновое число обыкновенной волны зависит только от плотности плазмы $k_o = \omega\sqrt{\varepsilon_3} / c$, $\varepsilon_3 = 1 - \omega_p^2 / \omega^2$. Для обыкновенной волны набег фазы пропорционален средней плотности вдоль зондирующего луча для частот ω больших, чем плазменная частота ω_p. Для необыкновенной волны при перпендикулярном зондировании набег фазы зависит от плотности плазмы и распределения удерживающего магнитного поля $k_x = \omega\sqrt{\varepsilon_1^2 - \varepsilon_2^2} / \sqrt{\varepsilon_1} c$, $\varepsilon_1 = 1 - \omega_p^2 /(\omega^2 - \omega_c^2$, $\varepsilon_2 = \omega_p^2 \omega_c /((\omega^2 - \omega_c^2)\omega$. При известном магнитном поле для установок типа торсатрон, измерение набега фазы необыкновенной волны дает дополнительную информацию о профиле плотности плазмы. Величина $\bar{n} / n_0$ может характеризовать пикированность профиля, где n_0 – центральная плотность плазмы в малом сечении шнура. Мы предполагаем, что профиль плазмы монотонный. Двуполяризационный интерферометр был установлен очень близко к малому сечению Е-Е-торсатрона У-3М. Представлены первые результаты измерения и их интерпретация.

ВИМІРЮВАННЯ ГУСТИНИ ПЛАЗМИ В ТОРСАТРОНІ У-3М З ВИКОРИСТАННЯМ ДВОПОЛЯРИЗАЦІЙНОЇ ІНТЕРФЕРОМЕТРІЇ

Д.Л. Греков, К.К. Третяк, В.Л. Бережний, В.В. Філіпов

Інтерферометрія з використанням звичайної хвилі добре відома і часто використовується для діагностики плазми. Для випадку перпендикулярного поширення відносно утримуючого магнітного поля хвильове число звичайної хвилі залежить тільки від густни плазми $k_o = \omega\sqrt{\varepsilon_3} / c$, $\varepsilon_3 = 1 - \omega_p^2 / \omega^2$. Для звичайної хвиі для частот ω, що значно більші за плазмову частоту ω_p, набіг фази є пропорційним до середньої густини плазми вздовж променя, що зондує. Для незвичайної хвилі при перпендикулярному поширенні набіг фази залежить від густини плазми і розподілу магнітного поля, що утримує плазму, $k_x = \omega\sqrt{\varepsilon_1^2 - \varepsilon_2^2} / \sqrt{\varepsilon_1} c$, $\varepsilon_1 = 1 - \omega_p^2 /(\omega^2 - \omega_c^2$, $\varepsilon_2 = \omega_p^2 \omega_c /((\omega^2 - \omega_c^2)\omega$. Для установок типу торсатрон розподіл магнітного поля є відомим. Тому вимірювання набігу фази незвичайної хвилі дає додаткову інформацію що до профілю густини плазми. Величина $\bar{n} / n_0$ може характеризувати пікированість профілю. Тут n_0 – центральна густина плазми в малому перерізі. Ми припускаємо, що профіль плазми є монотонним. Двополяризаційний інтерферометр було встановлено дуже близько до малого перерізу Е-Е-торсатрону У-3М. Наведено перші результати вимірювань та їх інтерпретацію.