AUTOMATIZATION OF PLASMA DENSITY PROFILE ANALYSIS BY THE MULTICHANNEL MICROWAVE INTERFEROMETER MEASUREMENTS FOR THE TORSATRON U-2M

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The paper presents the description of the density profile computing methods by the five-channel probing on the base of the developed program code and gives the results of model investigations.
PACS: 52.55.Hc

1. INTRODUCTION

The presented complex problem was firstly developed, both on the hardware base and at the stage of data processing, for the torsatron U-3M with submillimeter probing and later on for the torsatron U-2M [1]. As a result, a program code was developed for preliminary analysis of the density profile. Subsequently, it was expanded in order to use the microwave diagnostic data for plotting and analysis of the plasma density profile.

The well-developed microwave FM-CW reflectometry is an advanced research technique permitting to obtain necessary data for density profile analysis [2, 3]. As the probing waves are very sensitive to the plasma turbulence, the reflected signals show constantly perturbations provoking the distortion in the density profiles obtained. The methods of multichannel microwave interferometry enable to reduce the turbulence effects and to simplify the density profile plotting. And having a sufficient number of probing channels one can obtain a high spatial resolution.

The probing channels are designed by the fan-like array with a maximum opening of 40° and with a central channel in the horizontal plane. The authors considered different methods of plasma profile plotting basing on the model for Abelian transformation with the use of gradient-displaced ellipses.

2. THE MODEL AND METHODS OF SIMULATION FOR PLASMA PROFILE

The development of simulation methods for determining the plasma profile is based on the calculated model of the plasma formation in the torsatron U-2M composed of 11 measured magnetic surfaces [4]. On each of these surfaces the density value is assumed to be constant (Fig.1a, for the simplicity 5 surfaces are shown). For the plasma cross-section the parabolic density distribution

$$n_e(x) = n_0\left[1 - \left(\frac{x - L}{L}\right)^2\right]^p \qquad (1)$$

was taken, where x is the number of surface in the model of plasma formation, L and p are the parameters of profile broadening-flattening.

2.1. THE PROFILE CALCULATION BY FAN-TYPE CHORDS

In accordance with the applied plasma cross-section model and five probing chords designed by the fan-like array (Fig.1a), the program was developed for calculation of plasma density profile. For every chord we determined and recorded in the program the values x_i for points of chord intersection with corresponding surfaces and, also, the point in the section center between the surfaces.

So, for chords K1, ..., K5 determined were 17, 21, 23, 21 and 17 points, respectively. For model calculations the values of measured $NL_1, ..., NL_5$ by 5 chords for the test profile were calculated using the graphic model with parabolic distribution of density values on the surfaces.

The program calculation was performed by the following procedure. The conventional profile $y(x)= n_e(x)$ for the values of $n_0 = 1\cdot10^{12}$ cm^{-3}, $L = 10$, $p = 1$ is calculated by formula (1). The x value changes within the range from 0 to 10. Thus, we obtain 11 initial values $n_1, ..., n_{11}$ for the profile model from 0 to $1\cdot10^{12}$ cm^{-3}.

Then the values $y_1(x_i), ..., y_5(x_i)$ for 5 chord probing channels in compliance with the calculated values $n_1, ..., n_{11}$ are determined. Basing on the obtained profile values in compliance with lengths x_i for every chords, the areas $S_1, ..., S_5$, proportional to the values NL of the real profile are calculated. The method for area calculation can be various, e.g. simply the method of triangles or the method with the use of smoothing splines when plotting the profile curve.

Taking the horizontal channel K3 (Fig.1a) as a basic one we determine the correspondence between the obtained value of the area S_3 and NL_3, i.e. we obtain the coefficient of density recalculation $C = NL_3 / S_3$.

2.2. AUTOMATIC CALCULATION ALGORITHM

Using the coefficient C we calculate for the rest four channels the expected values nl_1, nl_2, nl_4, nl_5, for example, $nl_1 = C \cdot S_1$ ($nl_3 = NL_3$). By comparison of the calculated values nl with measured ones, the error is determined. Basing on this error the broadening-flattening parameter profile parameters (L and p) are changed and a new calculation is performed. After several recalculations the optimum values $nl_1, ..., nl_5$ with a minimum error, relative to the measured values NL of the real profile, are chosen. The choice is carried out, for example, by the method of least squares. Finally, using the optimum values $n_1, ..., n_{11}$ the profile with $N_1, ..., N_{11}$ ($N_1 = C \cdot n_1$ etc.) is plotted.

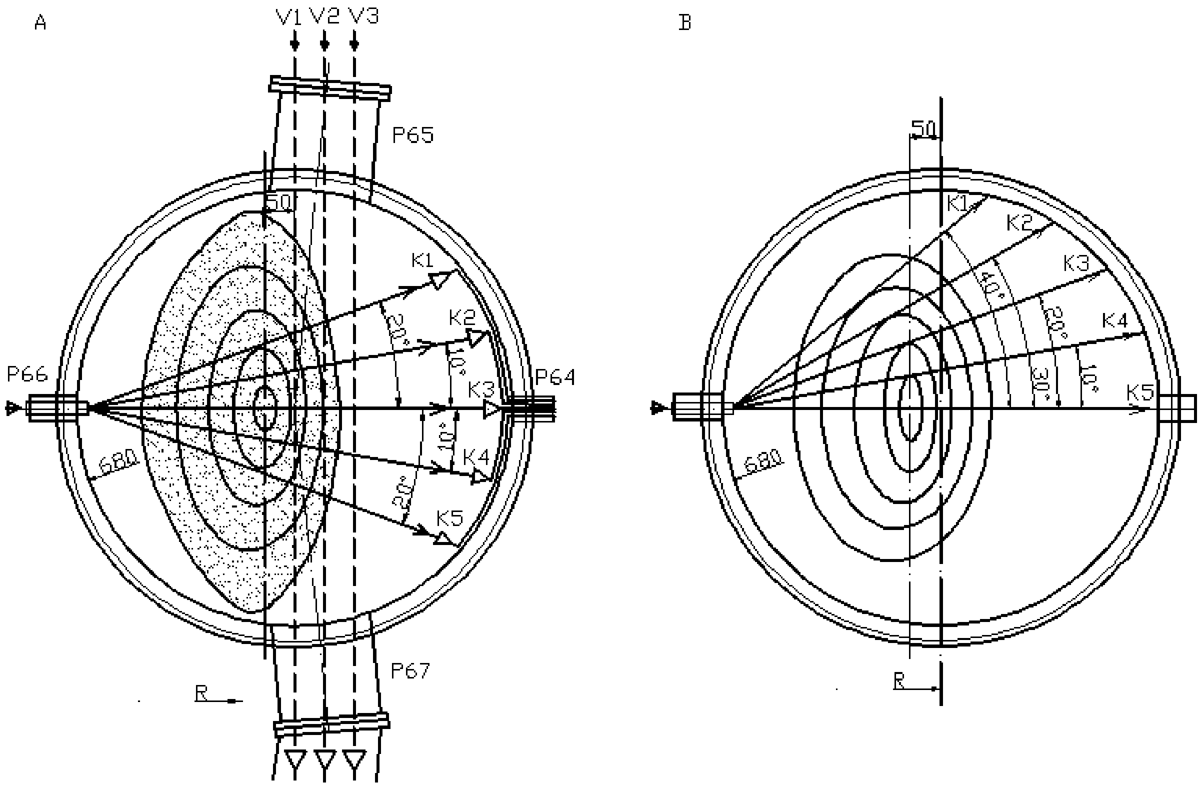

Fig.1. Arrangement of the model probing chords for microwave interferometers in the torsatron U-2M

The simulation results are presented in Fig.2. For the test parabolic profile the error in determining the values $NL_1, ..., NL_5$ is ~ 1%.

In the real experiment for every probing channel it is intended to use a quadrature interferometer with the two separate output signals $S_1 = A \cdot \cos\varphi$ and $S_2 = A \cdot \sin\varphi$. The processing and conversion program allow us to obtain the phase values for every chord. These data are used for determination of the current measured values $NL_1, ..., NL_5$. With the data reception frequency of 3 MHz for the discharge time interval of ~10 ms it is possible to obtain near 3000 profiles.

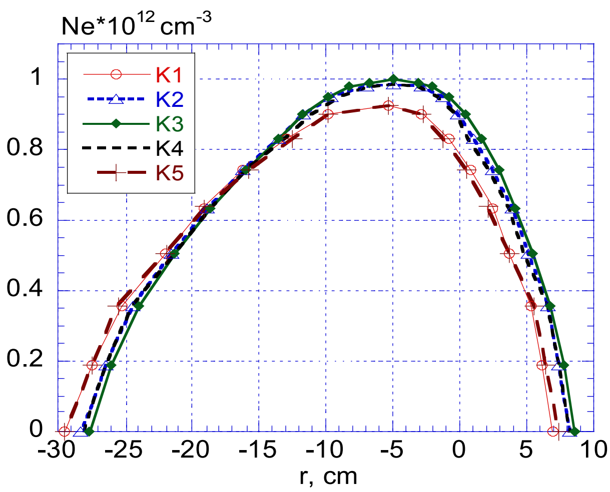

Fig.2. Result of the calculation of the test parabolic profile model for five probing chords K1 – K5 (Fig.1a)

2.3. USE OF THE MODEL FOR ABELIAN TRANSFORMATION

Plasma profile plotting basing on the Abelian transformation is often applied to the layered onion-like structures [5]. The external chord K1 determines the density value in the external layer (Fig.1b). The next chord K2 intersects the external and second layers and so on.

The above-described method was considered as a base for plasma profile plotting in the case of five probing chords located in the upper part of the chamber (Fig.1b). Here the cross-section of plasma surfaces is simulated by the five gradient-displaced ellipses. In this model for the first channel K1 we have three intersection points – on the left with the last surface, in the contact with the second one and on the right. For the second chord K2 there are 5 points, for K3 -7 points and for K4 – 9 points. And, at last, for K5 there are 11 points (with taking into account the central point).

The simulation procedure was as follows. First we calculated the initial test profile for 11 plasma surfaces (similar to that in Section 2.1), named $P_{1\text{-}11}$ (the analogous profile is shown in Fig.2, curve K3). Then the calculation results were used to determine the expected values $nl_1, ..., nl_5$ for probing chords K1 – K5 (Fig.1b). They were used as the initial data to calculate the profile basing on the model for Abelian transformation which we named $PA_{1\text{-}5}$.

At the first stage, the profile $P_{1\text{-}11}$ by formula (1) with the parameters $L = 10$, $p = 1$ was calculated. Unfortunately, for this profile we did not succeed in plotting the maximally corresponding profile $PA_{1\text{-}5}$ (with changing the parameters $L = 4 - 5$, $p = 0.4 - 3$) because of a great error, from 20% to 70% over the channels.

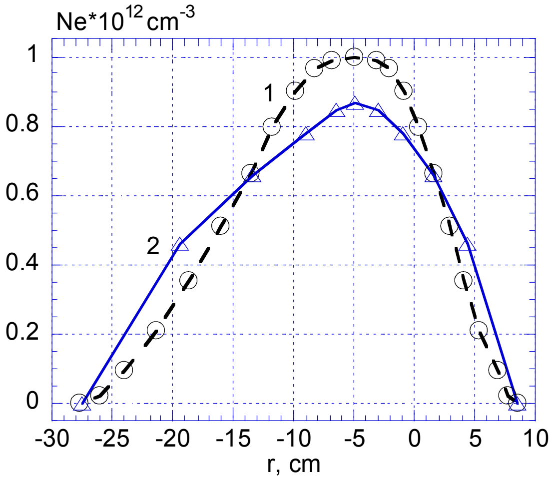

Fig.3

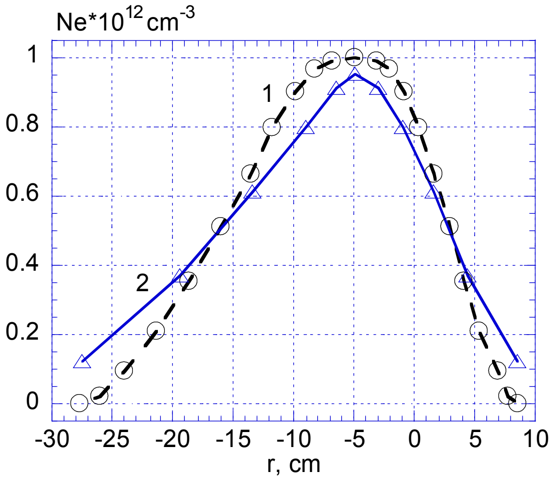

Fig.4

At the second stage of calculations it has been established that the best correspondence between the initial profile $P_{1\text{-}11}$ and the calculated profile $PA_{1\text{-}5}$ can be obtained by plotting $P_{1\text{-}11}$ with the parameter $p = 2.3$ (Fig.3, curve 1). In this case for the profile $PA_{1\text{-}5}$ (with the parameters $L = 5$, $p = 0.62$, Fig.3, curve 2) the maximum error in determination of the values nl_1, ..., nl_5 was near 9%. In the profile center the density decrease by ~14% is obtained.

At the third stage we introduced into formula (1) the additional coefficient of profile correction n_p:

$$n_e(x) = n_p + n_0\left[1 - \left(\frac{x - L}{L}\right)^2\right]^p, \qquad (2)$$

that permitted to decrease the error in the calculation of the values nl_1, ..., nl_5. So, for the profile $PA_{1\text{-}5}$ (with the parameters $n_p = 0.15\cdot n_0$, $L = 5$, $p = 1.18$, Fig.4, curve 2) the maximum error in the calculated values nl_1, ..., nl_5 was 2%. Thus, in the central profile part the density values became lower (by 5 – 15 %) due to the additional density increase at the extremity.

3. CONCLUSION

Reasoning from the calculation results, the following is deduced. Using the model with a sufficient number of surfaces (11 and more), the plasma profile can be reconstructed with a high accuracy (to several percents). For the case of simulation with the use of 5 gradient-displaced ellipses the value of error depends on the calculation method and can be within 5 – 20 %.

REFERENCES

1. V.L. Berezhniy, V.I. Kononenko, V.L.Ocheretenko, V.A. Maslov, V.A. Svich, A.N. Topkov // *Fizika Plazmy (20)*. 1994, №1, p. 12-14 (in Russian).
2. L. Zeng, G. Wang, E.J. Doyle, T.L. Rhodes, W.A. Peebles and Q. Peng // *Nucl. Fusion.* 2006, v. 46, p. 677-684.
3. P. Varela, M.E. Manso, A. Silva, the CFN Team and the ASDEX Upgrade Team // *Nucl. Fusion.* 2006, v. 46, p. 693-707.
4. G.G. Lesnyakov, D.P. Pogozhev, Yu.K. Kuznetsov, N.T. Besedin, E.D. Volkov, O.S. Pavlichenko *// 23rd European Physical Society Conference on Controlled Fusion and Plasma Physics. Kiev, Ukraine, 24-28 June 1996. Contributed Papers*. Part II, p. 547.
5. A.T. Ramsey and M. Diesso // *Rev. Sci. Instrum.* 1999, v. 70, №1, Part II, p. 380-383.

Article received2 22.09.08.

АВТОМАТИЗАЦИЯ АНАЛИЗА ПРОФИЛЯ ПЛОТНОСТИ ПЛАЗМЫ ПО ИЗМЕРЕНИЯМ МНОГОКАНАЛЬНЫМ СВЧ ИНТЕРФЕРОМЕТРОМ ДЛЯ ТОРСАТРОНА У-2М

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Описаны методы расчета профиля плотности при пятиканальном зондировании на основании разработанного программного кода и приведены результаты модельных исследований.

АВТОМАТИЗАЦІЯ АНАЛІЗУ ПРОФІЛЮ ГУСТИНИ ПЛАЗМИ ПО ВИМІРЮВАННЯХ БАГАТОКАНАЛЬНИМ НВЧ ІНТЕРФЕРОМЕТРОМ ДЛЯ ТОРСАТРОНА У-2М

В.Л. Очеретенко, В.Л. Бережний, А.В. Прокопенко, І.Б. Пінос

Описані методи розрахунку профілю густини при п'яти канальному зондуванні на підставі розробленого програмного коду і приведені результати модельних досліджень.