ON THE IMPROVED PLASMA CONFINEMENT IN TOROIDAL SYSTEMS. MEASURING OF THE PLASMA DENSITY INHOMOGENETIES NEAR THE GAS VALVE

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Comparison of plasma density increase was carried out in outer and inner channels of the interferometer in T-11M tokamak. There were two cases of gas puffing: by outer valve or upper one. Amplitude of difference of the plasma density increase consisted of 9% near the outer valve. Perturbation of the electric potential $e\Phi_1/T_e$ can have similar value. This perturbation can lead to appearance of the additional losses.
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1. INTRODUCTION

A requirement of self-closure of drift particles trajectories after m turns around the torus looks like:

$$t = t_B + t_E = n/m, \quad (1)$$

where t is the total rotational transform number of the drift trajectories, connected with rotational transform angle i by the formula $t = i / (2\pi)$, t_B – magnetic rotation number, t_E – electric rotation number of the drift trajectories:

$$t_E = E_r R / (rBv_{||}) \quad (2)$$

in crossed electric E_r and magnetic fields B , n and m – integers, $v_{||}$ - is component of velocity along the magnetic field, R - radius of the torus, r – radius of the magnetic surface. At the Maxwellian's velocity distribution there are always particles with such $v_{||}$, for which the resonant condition (1) will be fulfilled for some integer m and n. Existence of such resonant particles has been noted in [1]. Also a possibility of the diffusion coefficient independence on the particles collision frequency ("plateau") has been indicated in this paper. The conditions of such independence were calculated, too. It was clarified in [2] that the island-like structure of drift surfaces at resonance (1) arises when equipotent and magnetic surfaces are not coinciding. They will coincide in magneto-hydrodynamic equilibrium conditions only, and no islands will exist in this case. Nevertheless, the existence of some potential difference Φ_1 on a magnetic surface has been postulated in [2]. It is possible to find that small perturbations $e\Phi_1/T_e < 1\%$ can lead to noticeable additional transport processes and reduce a confinement time.

The reasons of potential Φ_1 perturbations occurrence were found in [3]. In particular, the cold plasma appears in discharge as the result of ionization of the gas injected from a local valve. It spreads from area of injection along a magnetic field. As the thermal velocity of electrons is higher, than the ion's one, an area of injection will have a positive potential, which is just a perturbation. Calculations of the potential were executed in [3] for one-dimensional spread of high density plasma. When cold plasma fluxes are weak, the potential is determined by retraction of bulk plasma electrons in area of injection (according to Boltzmann distribution law):

$$e\Phi_1/T_e = n_c/n, \quad (3)$$

where T_e, n – the temperature and density of electrons of the bulk plasma, correspondingly, n_c – density of cold plasma. Theoretical solution of three-dimensional problem is very complicate, so experimental measuring of plasma density inhomogenety on a magnetic surface is rather essential. First approach to such measurements was conducted on the T-11M tokamak (B = 1.2 T, a =0.23 m, R = 0.7 m, I_p = 100 kA, n_e = 2-3×10^{19} m^{-3}, T_e = 300 eV, T_i = 100 eV).

2. SCHEME OF EXPERIMENT

The gas valve No 4 was located in the same cross section of vacuum chamber, where the multi-channel microwave interferometer with a vertical direction of probing radiation (Fig. 1) is placed. Additional gas was injected from the low field side of the plasma cross section, as the interferometer measures plasma density distribution in a horizontal plane. Gas from the valve moved through a tube near the equatorial plane of vacuum vessel (Fig. 1). For more symmetric gas injection another valve No 2 placed in the top of vacuum chamber was used. These valves were used in different discharges.

The position of a plasma column in the T-11M tokamak is now determined insufficiently precisely. So a comparison of steep increase of additional plasma density was made at the moment of the discharge about 60-th ms from plasma current beginning.

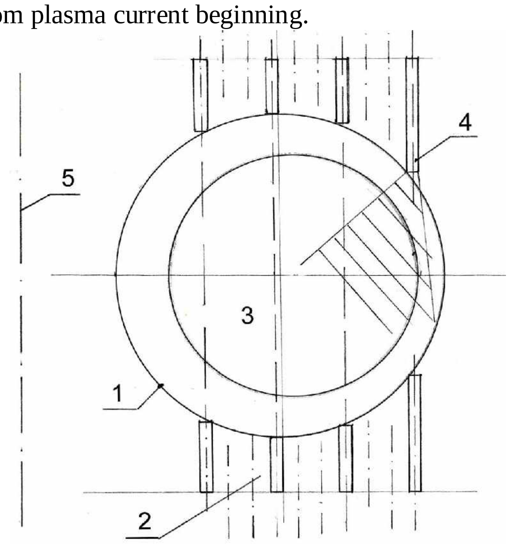

Fig. 1. 1-vacuum chamber; 2- multi-channel microwave interferometer; 3-plasma; 4- area of gas injection; 5- main axis

3. EXPERIMENTAL RESULTS

Time dependences of mean plasma density are shown for two discharges with gas injection from the upper valve (Fig. 2) and the outer one (Fig. 3).

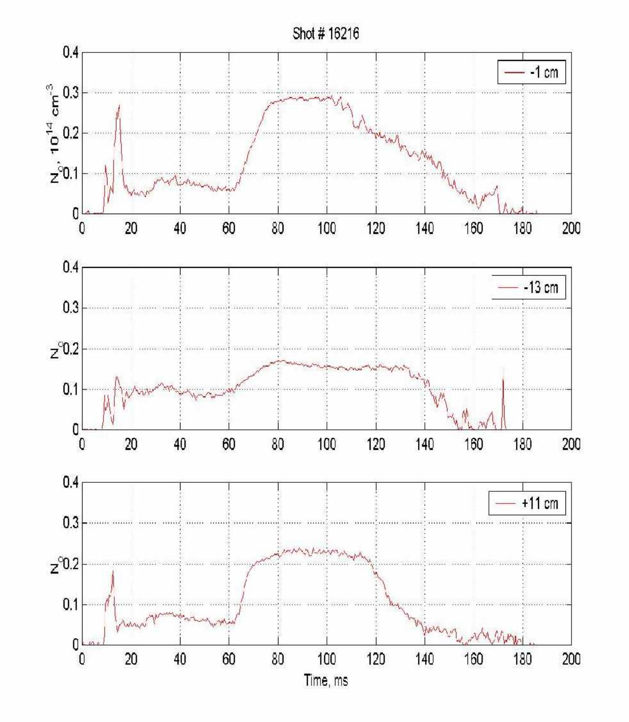

Fig. 2. Plasma density evolution in shot #16250 (chords -1 cm, -13 cm, +11 cm),valve No 2 is symmetric with respect to the centre of vacuum chamber

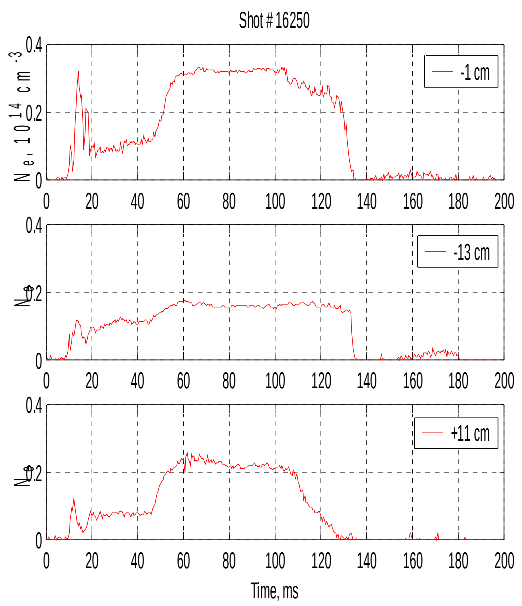

Fig. 3. Plasma density evolution in shot #16250 (chords -1 cm, -13 cm, +11 cm). Outer valve No 4

In each case there are curves for three channels of the interferometer. First channel was located in -1 cm position near the vacuum vessel center (inner valve), second one in -13 cm and third in +11 cm (outer valve). Increase of density in each curve is shown in the Table.

Shot/valve	Chord	Density increment $[10^{13}\ cm^{-3}]$	Normalized density increment
#16216 valve 2	-1	2.26	1
	-13	0.87	0.39
	+11	1.50	0.67
#16250 valve 4	-1	2.12	1
	-13	0.62	0.29
	+11	1.54	0.73

To minimize the errors connected with dispersion of gas quantity from these valves in different discharges, increase of mean plasma density in inner and outer channels was normalized by the central channel increase (see Table), when statistical data development was provided. It is well seen that plasma density increase in outer interferometer channel is remarkably greater when the outer valve worked then in case of gas injection from the upper valve. The initial density value could differ significantly. This difference doesn't affect the obtained asymmetry of the plasma density increases.

The rise of a density on interior area of plasma did not depend on which valve worked. The statistical handling of results was conducted under the following scheme: normalized amplitude of density perturbation has been assumed as:

$$n_c = ½ (\Delta n_{e4} - \Delta n_{i4} – (\Delta n_{e2} - \Delta n_{i2})) , \qquad (4)$$

where indexes *e* and *i* describe external and internal channels of the interferometer, 4 and 2 – numbers of valves used.

Mean density n has been calculated as a sum of mean normalized Δn and mean normalized initial density.

For shots # 16216 and # 16250 the value $n_c/n = 0.11$ was obtained. Statistical processing of many discharges gave the value $n_c/n = 0.09 \pm 0.03$

4. CONCLUSIONS

The measured amplitude of plasma density and electric potential perturbations (see (2)) is rather large: approximately 10% near the gas valve. At such perturbations the resonances relevant to different modes m/n are overlapped [2]. Trapping of electrons by the electric field takes place in these conditions [3]. It results perhaps in forming of electrical "super bananas". This effect can be responsible for poor confinement of electrons.

Thus symmetrization of the gas injection could reduce particles losses. However, it is indispensable but is not sufficient in a tokamak without a divertor, as the limiter also gives asymmetrical gas fluxes due to recycling.

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ОБ УЛУЧШЕННОМ УДЕРЖАНИИ ПЛАЗМЫ В ТОРОИДАЛЬНЫХ СИСТЕМАХ. ИЗМЕРЕНИЕ НЕОДНОРОДНОСТИ ПЛОТНОСТИ ПЛАЗМЫ ВБЛИЗИ ГАЗОВОГО КЛАПАНА

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Производилось сравнение импульсного увеличения плотности плазмы на внутреннем и внешнем каналах многоканального интерферометра при импульсном включении клапанов, подающих газ либо во внешней либо в верхней части плазменного шнура токамака Т-11М. Обнаруженное повышение плотности плазмы вблизи бокового клапана составило 9% по амплитуде. Такую же величину может составить возмущение потенциала $e\Phi_1/T_e$. Это возмущение может приводить к появлению дополнительных каналов потерь тепла и частиц плазмы.

ПРО ПОЛІПШЕНЕ УТРИМАННЯ ПЛАЗМИ В ТОРОІДАЛЬНИХ СИСТЕМАХ. ВИМІР НЕОДНОРІДНОСТІ ГУСТИНИ ПЛАЗМИ ПОБЛИЗУ ГАЗОВОГО КЛАПАНА

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Проведено порівняння імпульсного збільшення густини плазми на внутрішньому і зовнішньому каналах багатоканального інтерферометра при імпульсному включенні клапанів, що подають газ або в зовнішній або у верхній частині плазмового шнура токамака Т-11М. Виявлене підвищення густини плазми поблизу бічного клапана склало 9% по амплітуді. Таку ж величину може скласти збурювання потенціалу $e\Phi_1/T_e$. Це збурювання може призводити до появи додаткових каналів втрат тепла і часток плазми.