DYNAMICS OF THE MAIN PLASMA PARAMETERS DURING SPONTANEOUS TRANSITION INTO THE MODE OF IMPROVED CONFINEMENT IN TORSATRON U-3M

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The work [1] contains discussion about the changes in plasma energy content and energy lifetime during the transition into the mode of improved confinement at RF-heating in torsatron U-3M in range of rare collision frequencies of plasma particles. It was proved, that both energy content of plasma volume and energy lifetime increase as a result of transition into the mode of improved confinement. This increase is almost in 2 times. Temporal behavior of such plasma parameters as ion and electron temperature, plasma density and average charge state of plasma ions in the modes with improved confinement are discussed and reviewed in this work.
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1. MAIN RESULTS

Experimental conditions and temporal behavior of plasma parameters are presented in [1]. Fig. 1 shows temporal behavior: average plasma density n_e, plasma pressure ρ, calculated using diamagnetic measurements [2], intensity of soft X-Ray radiation I_{XR}, that has gone through thin aluminum foil with thickness of 1 μm, and average over the cross-section ion temperature measured by charge exchange neutral energy analyzer. Besides, Fig. 1 shows temporal behavior of calculated average electron temperature T_e and average charge number of ions Z.

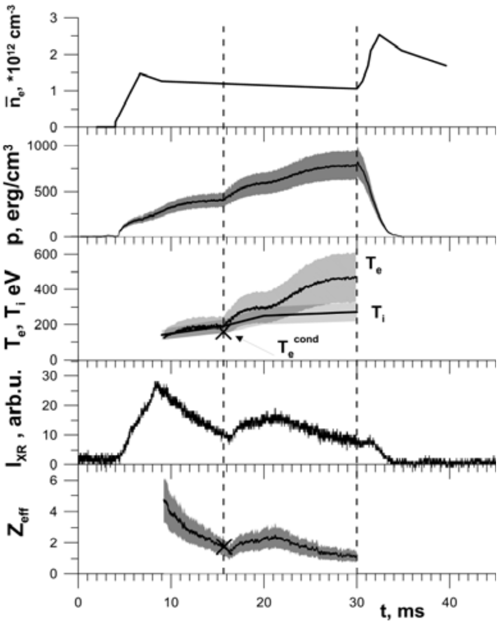

Fig. 1. The time behavior of the measured main plasma parameters n_e, T_i, I_{XR} and calculated p, T_e, Z. Symbol cross denotes the value of T_e and Z, obtained from the conductivity of plasma at the time of transition in the regime of improved confinement. The hatching denotes the range of reliable results

Temporal behavior T_e and Z is calculated according to data of diamagnetic measurements $p = n_e T_e + \sum_i n_i T_i$, and ion temperature T_i, and radiation intensity of soft X-Ray I_{XR}. As it was shown in [2], temperature of impurity ions is essentially lower than temperature of protons, and their concentration is small, therefore, it can be written as:

$$p=n_e(T_e+\alpha_H T_i). \quad (1)$$

Here, $\alpha_H = n_H / n_e < 1$ – fraction of ions in discharge. For simplicity, consider the case with only one category of impurities with concentration $\alpha_{Fe} = n_{Fe} / n_e$, i.e. plasma contains only ions of hydrogen with $Z_P=1$ and iron=Z_{Fe}>>1. Assuming that

$$Z = \frac{\sum_i n_i Z_i^2}{n_e}, \quad (2)$$

it is easy to obtain

$$\alpha_H \cong 1 - \frac{Z-1}{Z_{Fe}-1}. \quad (3)$$

Temporal behavior of intensity of soft X-Ray radiation shows that essential decrease (more than in 3 times) of radiation is observed in the mode of improved confinement. And besides, insignificant increase of radiation intensity is observed after transition, however, further decline of X-Ray remains. According to [3], expression for radiation intensity of soft X-Ray has the form:

$$I_{XR} \propto n_e T_e^{1/2} \exp^{-E_x/T_e} \sum_i n_i Z_i^2, \quad (4)$$

or considering (2)

$$I_{XR} \propto n_e^2 Z T_e^{1/2} \exp^{-E_x/T_e}. \quad (5)$$

Here, E_x – minimal energy of X-Ray radiation passing through the foil. In our experiments $E_x << T_e$ and $\exp(-E_x/T_e) \approx 1$. Then, expression (5) can be rewritten as follows

$$I_{XR} \propto n_e^2 Z T_e^{1/2}. \quad (6)$$

Joint solution of expressions (1), (3) and (6) allows to obtain temporal behavior T_e(t) and Z(t). It was assumed that our main impurity is iron with Z_{Fe} – linearly changing

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during discharge from Z_{Fe}=8 to Z_{Fe}=11. The results of calculations are given in the Fig. 2 and show that in discharges with $n_e \approx 10^{12}$ cm^3 at T_e=100…300 eV the time of achieving of the charge of iron ion state Z_{Fe}=8…11 is less than 2 ms.

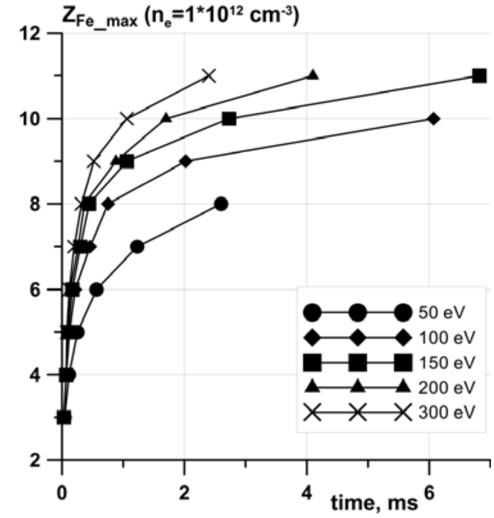

Fig. 2. Dynamics of the appearance of maximum ion charge F_e when plasma density $n_e = 10^{12}$ cm^{-3}

Since absolute calibration of intensity I_{XR} was not done, we used the possibility to determine the value $T_e^{3/2}/Z$ according to plasma conductivity at the time of transition into the mode of improved confinement. The work [1] shows that longitudinal plasma current increases drastically at the time of transition. Typical change of current occurs with time τ = L/Ω. Therefore, value $T_e^{3/2}/Z$ =1100±300 (eV)$^{3/2}$ was determined at the time of transition. Due to this, the following values were normalized: T_e(t) and Z(t). The results are given in the Fig. 1.

Fig. 1 shows that temporal behavior T_e and T_i do not differ very much from each other. With such low plasma density, the energy exchange between electrons and ions is insignificant during the time of discharge. Thus, we can conclude that heating of electrons and ions is occurred simultaneously. The main power at the same time is absorbed by electrons as energy confinement in them is significantly worse [2], and temperature is comparable with ion temperature. Z(t) behavior shows that process of self cleaning plasma from impurities take place just after gas ionization. Z value increases slightly after transition into the mode of improved confinement, but further on Z value continues to decrease. The parameters of the plasma seem to enable us to see the glow through CVI. However, during experiments such radiation didn't detect. A possible explanation is the rapid withdrawal of impurities from the confinement volume.

Mechanism of plasma self cleaning requires further investigation. This issue is also discussed in the work [2].

2. CONCLUSIONS

1. Temporal behavior and electron temperature value were obtained. Transition into the mode of improved confinement leads to increase of both ion and electron temperatures. T_e changes from 190 before the transition to 470 eV at the end of RF-pulse, Ti, correspondingly, change from 190 to 270 eV. RF-heating of both electron and ion plasma component takes place in the studied mode.
2. Improvement of plasma energy confinement occurs, mainly, due to decrease of losses of energy in electron channel.
3. Temporal behavior of average charge plasma composition was calculated. It is clear that process of plasma self cleaning is observed. Mechanism of this phenomenon requires further investigations.

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ПОВЕДЕНИЕ ОСНОВНЫХ ПАРАМЕТРОВ ПЛАЗМЫ ПРИ СПОНТАННОМ ПЕРЕХОДЕ В РЕЖИМ УЛУЧШЕННОГО УДЕРЖАНИЯ В ТОРСАТРОНЕ У-3М

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В торсатроне У-3М в режиме редких частот соударений проведены измерения энергосодержания плазмы и энергетического времени жизни. Показано, что при переходе в режим улучшенного удержания наблюдается почти двухкратное увеличение энергосодержания и энергетического времени жизни плазмы.

ПОВЕДІНКА ОСНОВНИХ ПАРАМЕТРІВ ПЛАЗМИ ПРИ СПОНТАННОМУ ПЕРЕХОДІ НА РЕЖИМ ПОЛІПШЕНОГО УТРИМАННЯ В ТОРСАТРОНІ У-3М

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У торсатроні У-3М в режимі рідкісних частот зіткнень проведені вимірювання енерговмісту плазми та енергетичного часу життя. Показано, що при переході в режим поліпшеного утримання спостерігається майже двократне збільшення енерговмісту та енергетичного часу життя.