FORMATION OF ITB IN THE VICINITY OF RATIONAL SURFACES IN THE URAGAN-3M TORSATRON

E.D. Volkov, V.L. Berezhnyj, V.N. Bondarenko, V.V. Chechkin, I.P. Fomin, L.I. Grigor'eva, V.G. Konovalov, V.D. Kotsubanov, A.E. Kulaga, V.I. Lapshin, G.G. Lesnyakov, A.P. Litvinov, A.V. Lozin, Yu.K. Mironov, V.E. Moiseenko, N.I. Nazarov, I.K. Nikol'skij, V.L. Ocheretenko, O.S. Pavlichenko, I.B. Pinos, Yu.Ya. Podoba, V.S. Romanov, A.N. Shapoval, T.E. Shcherbinina*, A.I. Skibenko, A.S. Slavnyi, E.L. Sorokovoy, I.K. Tarasov, S.A. Tsybenko, V.S. Voitsenya

Institute of Plasma Physics, National Science Center "Kharkov Institute of Physics and Technology", 61108 Kharkov, Ukraine;
****National Technical University "Kharkov Politechnical Institute", 61108 Kharkov, Ukraine***

It was shown that there is the possibility of ITB formation in the vicinity of rational surfaces in a torsatron magnetic configuration. The formation of ITB is accompanied by fast change of plasma poloidal rotation velocity, radial electric field and its shear and the decrease of plasma density fluctuations. After the ITB formation the transition to the improved plasma confinement takes place. The transition stars when electron temperature in the region of rational surfaces is sufficient to satisfy the condition $\upsilon_{Te}/\nu_{ei} >> 2\pi R_0$ (here υ_{Te} is electron thermal velocity and ν_{ei} is the frequency of ion – electron collisions, and R_0 is the major radius of the torus). Such a regime can be maintained during the whole duration of RF discharge without any disturbances.

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1. INTRODUCTION

It has been demonstrated in a variety of toroidal magnetic traps that *E×B* velocity shear is a key mechanism, which can explain the reduction of plasma turbulence and formation of transport barriers leading to the improvement of plasma confinement [1]. There are some publications [2-4] with indications that the formation of internal transport barriers *(ITB)* in toroidal devices could take place in the vicinity of low order rational surfaces *(RS)*.

In presented experiments the attempt to realize the formation of *ITB* near of island chains with $t=1/4$ and to study its influence on a *RF* discharge plasma confinement was undertaken on the Uragan-3M torsatron. The presupposition was made that the radial electric field profile, $E_r(r)$, in this case will be determined by the increase of a transversal electroconductivity due to a longitudinal motion of electrons in stochastic layers of magnetic field lines near *RS*. In accordance with this presupposition the transition will be take place when electron temperature T_e in the region of RS is sufficient to satisfy the condition $\upsilon_{Te}\cdot\tau_{ei}=\lambda>>2\pi R_0$ (here υ_{Te} is electron thermal velocity and τ_{ei} is electron – ion collisional time). In this respect the case with sufficient high heating power in the region of *RS* localization is most interesting for the study.

2. EXPERIMENTAL ARRANGEMENT

Experiments were carried out on the U-3M torsatron with an open helical divertor $(l=3,\ m=9,\ R_0=100cm,\ \bar{a}_{pl}=12,5cm)$ at the magnetic field strength $B_0=0,7T$. The measurements made by the triode and luminescent rod techniques have shown that there is the possibility to realize the magnetic configuration with two chains of islands $(t=1/4)$ located in the region of a small magnetic shear [5]. Such a configuration takes place at the ratio of vertical magnetic field to longitudinal one $B_\perp/B_0=1,25\%$. The outside shift of the magnetic axis from the geometrical axis of helical coils equals to *5,5cm* in this case (Fig.1).

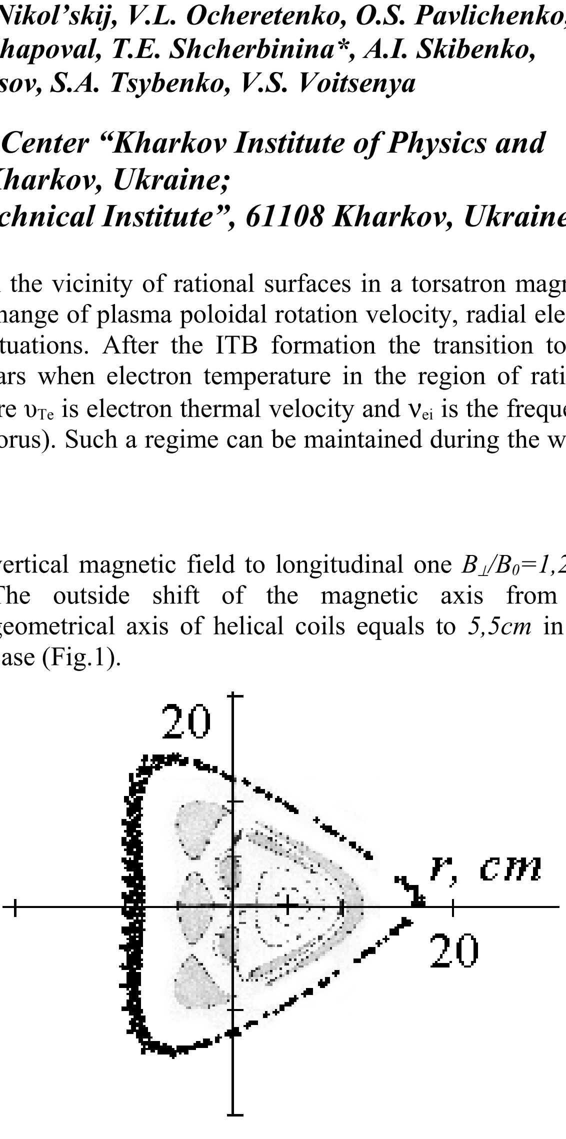

Fig.1 The magnetic configuration of the U-3M torsatron in the cross-section symmetric relative to the middle plane of the torus. The cross indicates the position of the magnetic configuration axis

The frame type antenna was used for *RF* plasma production and heating in the ion cyclotron range of frequencies $(f=8,8MHz,\ P_{RF}\leq 200kW)$ to provide a sufficient heating power in the region of localization of island chains. Numerical simulations have shown that Alfven waves excited by this antenna absorb at the external part of a plasma column $\bar{r}/a_{pl}>0,5$ where *RS* are located at the plasma density $\overline{n_e} \cong 2\cdot 10^{12} cm^{-3}$ [6].

The multichannel microwave interferometry $(\lambda=2\div 8mm)$ and reflectometry $(\lambda=8\div 17mm)$ were used for the radial density profile $n_e(r)$ reconstruction. The density fluctuation $(f=10\div 40kHz)$ level, $\delta n/n$, was estimated from reflected signal phase fluctuations measured by the cross-detection technique. Radial distributions of radial wave numbers, *$k_r(r)$*, and the poloidal rotation velocity of plasma, *$V_\theta(r)$*, were measured by means of the dual-polarization radial correlation reflectometry and the poloidal correlation reflectometry. The radial distribution of electron temperature, *$T_e(r)$*, was obtained from the data of *ECE* measurements. The diamagnetic and saddle type coils were used for the plasma energy content, $\overline{nT}$, measurements. The bootstrap current, *I_{bs}*, measured by Rogovski coil.

3. EXPERIMENTAL RESULTS

The transition to the improved plasma confinement regime was observed in the U-3M torsatron with the island magnetic configuration at *RF* power *$P_{RF}>140kW$*. It was shown that the transition moves to the beginning of the discharge with the increase of *P_{RF}* (Fig.2). The time evolution of plasma parameters in the presence of such a transition is shown in Fig.3.

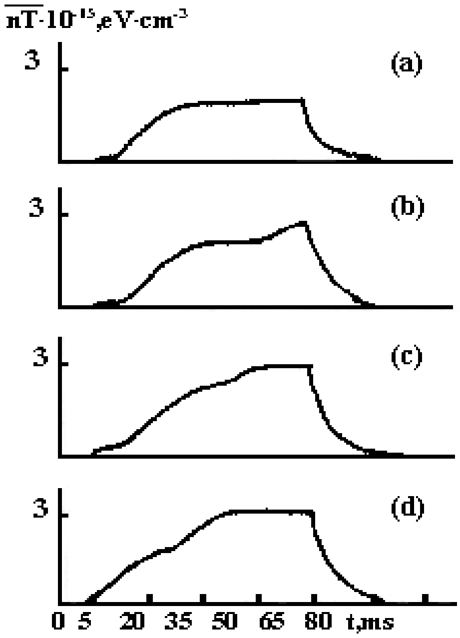

Fig.2 Time evolution of $\overline{nT}$ for discharges with the different P_{RF}: (a) – 120 kW, (b) – 140 kW, (c) – 170 kW, (d) – 220 kW

The transition accompanied by the increase of $\overline{n_e}$, *T_e*, *I_{bs}*, $\overline{nT}$, and *CV* intensity. The decrease of *δ_n/n*, fast change of $|V_\theta|$ and $|E_r|$ (Fig.4) and the widening of *$n_e(r)$* (Fig.5) were observed in the process of transition. High plasma poloidal rotation velocity shear was detected in the vicinity of *RS* after the transition (Fig.6).

It is interesting to note that the relative increase of *T_e* (*T_e* after transition/*T_e* before transition) is most large in the region of *RS* (Fig.7). The radial electric field distribution, *E(r)*, after the transition was calculated from measured *$T_e(r)$*, *$n_e(r)$* and *$V_\theta(r)$* using the force balance equation

$$E_r = \left(Z_i e n_i\right)^{-1}\nabla P_i - V_\theta B_0 + V_T B_\theta$$

in the presupposition *$V_T B_0=0$* (Fig.8). It is seen that the sharp change of *E_r* takes place in the vicinity of island

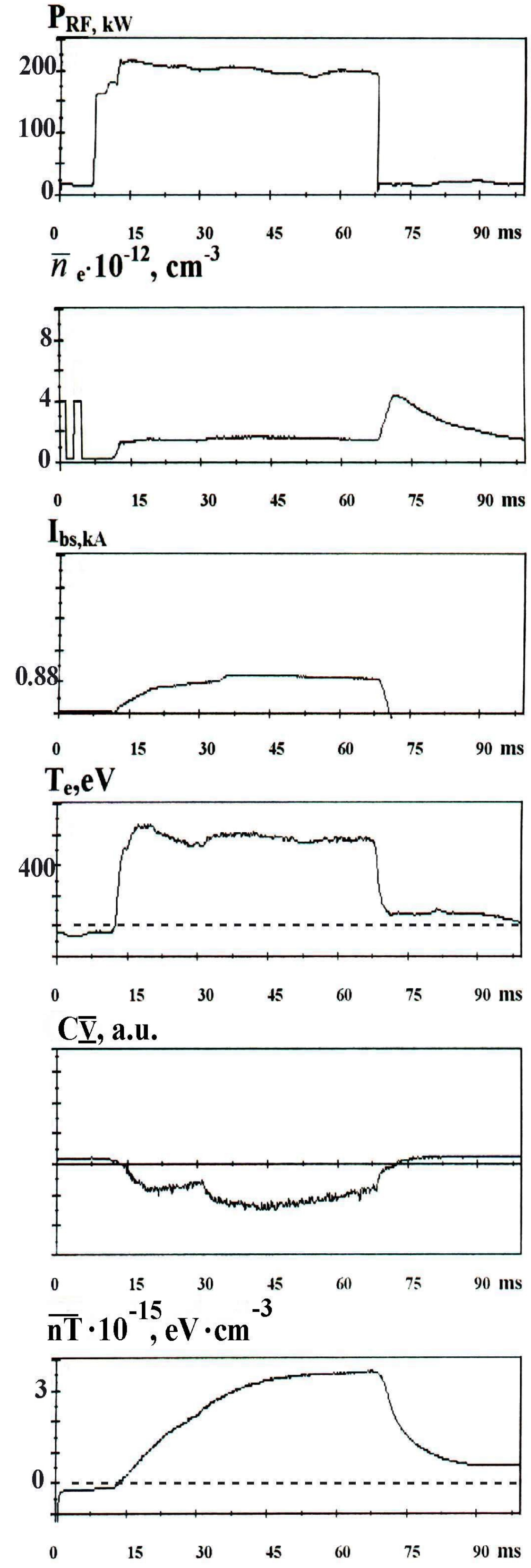

Fig.3. Time evolution of P_{RF}, $\overline{n_e}$, I_{bs}, T_e, CV, and $\overline{nT}$ in the presence of transition to the improved confinement regime

chains. The value of $|E_r|$ decreases up to $E_r=0$ in the region of the outer *RS*. The smaller change of $|E_r|$ was observed near the internal *RS*. The formation of high radial electric field shear regions takes place in the vicinity of both island chains. The observed maxima of radial wave numbers are located in the same regions (Fig.9).

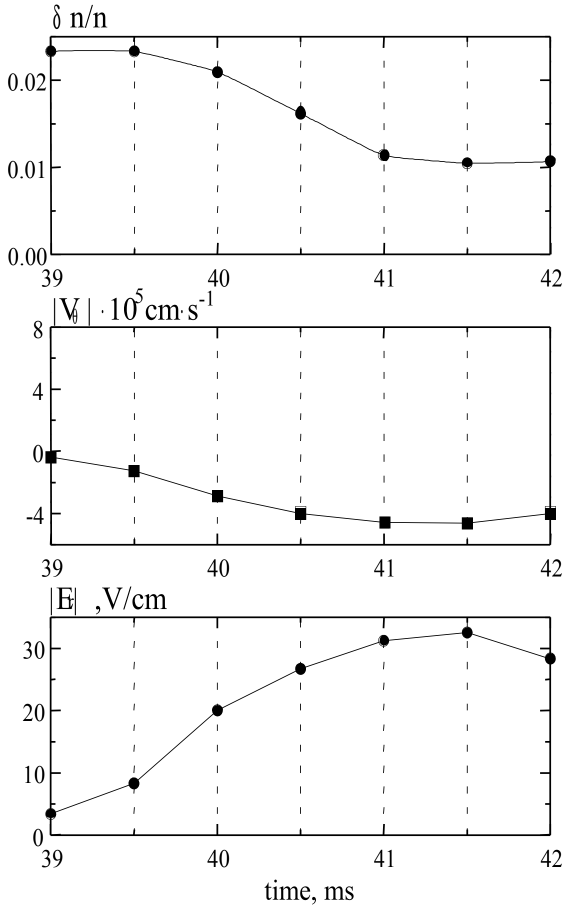

Fig.4. The behaviour of the density fluctuation level, δ n/n, poloidal rotation velocity $|V_{\theta}|$ and radial electric field $|E_r|$ during the transition to the improved

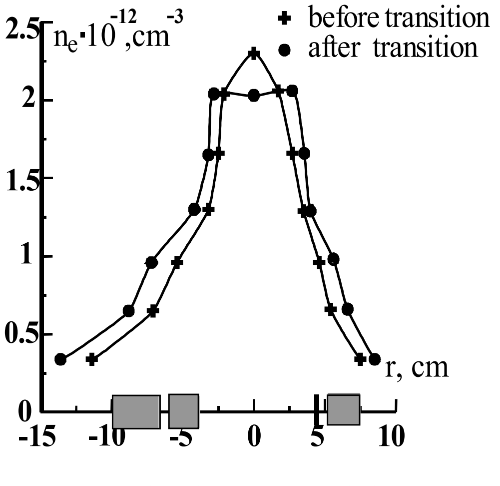

Fig.5. The radial distributions of plasma density relative to the magnetic axis before and after transition to the regime of improved confinement

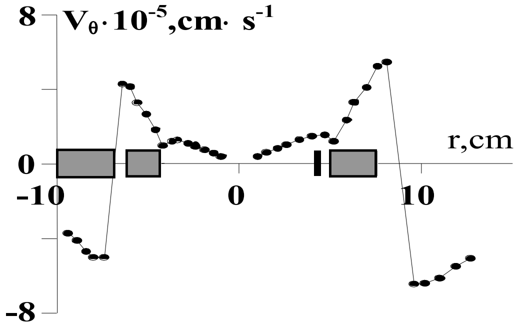

Fig.6. The radial distribution of E_r relative to the magnetic axis after the ITB formation

The *RF* discharge plasma with $\overline{n_e} \cong 2 \cdot 10^{12} cm^{-3}$, $T_e \cong (400 \div 600) eV$, $T_i(0) \cong (300 \div 350) eV$ maintained after the transition in the

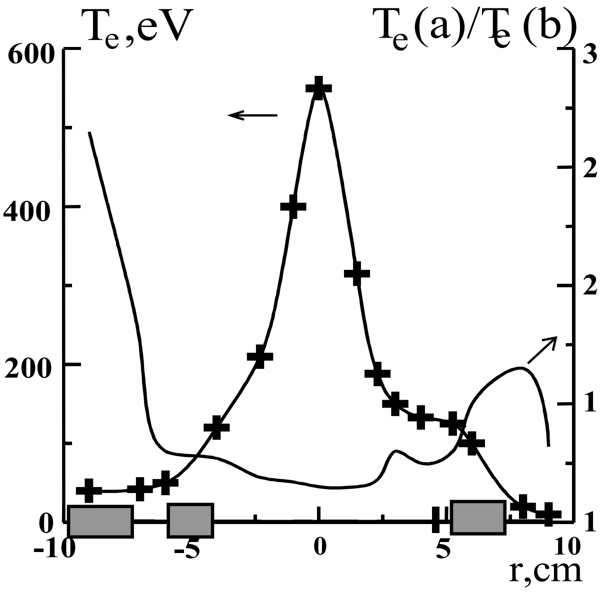

Fig.7. The radial distributions of T_e and the relative increase of T_e after the transition (T_e after transition/ T_e before transition)

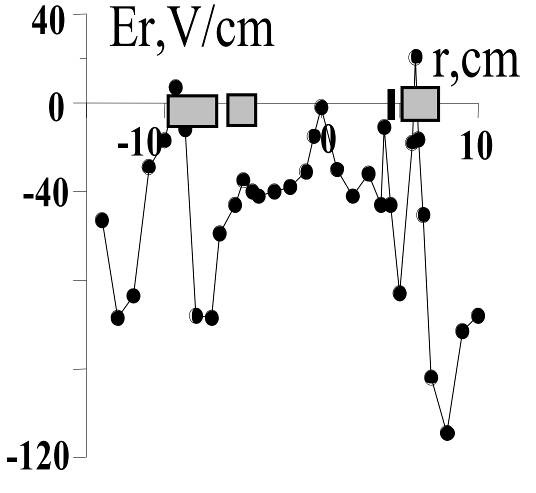

Fig.8. The radial distribution of E_r after ITB formation

improved confinement regime during the whole duration of discharge ($\Delta t=50ms$) without any disturbances.

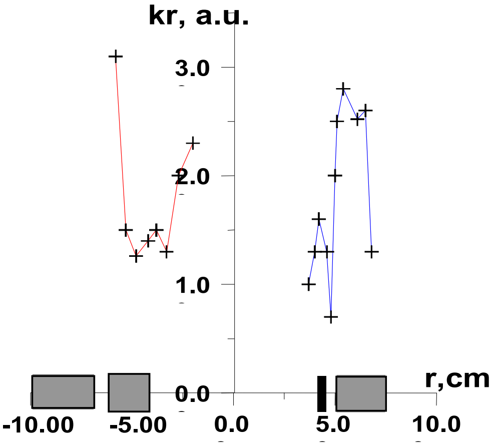

Fig.9. The radial distribution of k after ITB formation

4. CONCLUSION

It is shown that there is the possibility of *ITB* formation in the vicinity of *RS* in a torsatron magnetic configuration. The formation of such a barrier takes place if the condition $\upsilon_{Te}\cdot\tau_{ei}=\lambda>>2\pi R_0$ is satisfied in the region of *RS*. This condition was fulfilled in the presented experiment at $\overline{n_e}\cong 2\cdot 10^{12} cm^{-3}$ and $P_{RF}>140kW$. In the process of the *ITB* formation were observed the next phenomena:

- the widening of $n_e(r)$ and the decrease of δ_n/n in the region of *RS*,
- the increase of bootstrap current,
- fast changes of $|V_\theta|$ and $|E_r|$,
- the formation of regions with high radial electric field shear in the vicinity of *RS*.

After the *ITB* formation the transition moves to the beginning of the discharge with the increase of P_{RF}. After the *ITB* formation the regime of improved plasma confinement can be maintained during the whole duration of *RF* discharge without any disturbances.

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ФОРМУВАННЯ ВТБ В ОКОЛИЦІ РАЦІОНАЛЬНИХ ПОВЕРХОНЬ В ТОРСАТРОНІ УРАГАН-3М

Є.Д.Волков, В.Л.Бережний, В.М.Бондаренко, В.В.Чечкін, І.П.Фомін, Л.І.Григорьєва, В.Г.Коновалов, В.Д.Коцубанов, А.Є.Кулага, В.І.Лапшин, Г.Г.Лесняков, А.П.Литвинов, О.В.Лозин, Ю.К.Миронов, В.Є.Моісеєнко, М.І.Назаров, І.К.Никольський, В.Л.Очеретенко, О.С.Павличенко, І.Б.Пінос, Ю.Я.Подоба, В.С.Романов, А.М.Шаповал, Т.Є.Щербиніна, А.І.Скибенко, О.С.Славний, Е.Л.Сороковой, І.К.Тарасов, С.А.Цибенко, В.С.Войценя

Показано, що існує можливість формування внутрішнього теплового бар'єру (ВТБ) в плазмі ВЧ розряду в околиці раціональних поверхонь в торсатронній магнітній конфігурації. Формування ВТБ супроводжується бистрими змінами швидкості полоідального обертання плазми, радіального електричного поля и його шира і зменшенням флуктуацій густини плазми поблизу раціональних поверхонь. Після формування ВТБ спостерігається перехід в режим поліпшеного утримання плазми. Час переходу зменшується із збільшенням ВЧ потужності нагріву.

ФОРМИРОВАНИЕ ВТБ В ОКРЕСТНОСТИ РАЦИОНАЛЬНЫХ ПОВЕРХНОСТЕЙ В ТОРСАТРОНЕ УРАГАН-3М

Е.Д.Волков, В.Л.Бережный, М.Н.Бондаренко, В.В.Чечкин, И.П.Фомин, Л.И.Григорьева, В.Г.Коновалов, В.Д.Коцубанов, А.Е.Кулага, В.И.Лапшин, Г.Г.Лесняков, А.П.Литвинов, А.В.Лозин, Ю.К.Миронов, В.Е.Моисеенко, Н.И.Назаров, И.К.Никольский, В.Л.Очеретенко, О.С.Павличенко, И.Б.Пинос, Ю.Я.Подоба, В.С.Романов, А.Н.Шаповал, Т.Е.Щербинина, А.И.Скибенко, А.С.Славный, Э.Л.Сороковой, И.К.Тарасов, С.А.Цыбенко, В.С.Войценя

Показано, что имеется возможность формирования внутреннего теплового барьера (ВТБ) в плазме ВЧ разряда в окрестности рациональных поверхностей в торсатронной магнитной конфигурации. Формирование ВТБ сопровождается быстрыми изменениями скорости полоидального вращения плазмы, радиального электрического поля и его шира и уменьшением флуктуаций плотности плазмы вблизи рациональных

поверхностей. После формирования ВТБ наблюдается переход в режим улучшенного удержания плазмы. Время перехода сокращается с увеличением ВЧ мощности нагрева.