

# THE DYNAMICS OF INDUCTIVELY ACCELERATED ELECTRONS IN THE U-3M TORSATRON

*M.I. Tarasov, I.K. Tarasov, D.A. Sitnikov, V.K. Pashnev, I.G. Goncharov, V.M. Listopad, N.V. Lymar, A.F. Shtan', S.I. Solodovchenko*  
*Institute of Plasma Physics NSC "Kharkov Institute of Physics and Technology",  
Kharkov, Ukraine*  
*E-mail: itarasov@jpp.kharkov.ua*

Additional experimental data for the runaway electrons flow in the Uragan-3M torsatron were obtained. In particular the synchrotron and ultrahigh frequency radiation were measured. Also the flow current dynamics was studied by Rogovski coil and toroidal loop. Finally the experiments with the runaway flow stimulation were carried out.

PACS: 52.59.Rz, 52.70.Nc, 52.70 La

## INTRODUCTION

The effect of runaway electrons generation was intensively studied in tokamak devices [1-2]. Unfortunately in stellarators the consequences of formation of runaway particles flow was not considered in a proper way. In this work we continue our previous studies of runaway electron flow parameters [3] in the Uragan-3M torsatron together with the particles ejection to the system edge. We investigate the conditions of the flow formation and propagation using a number of traditional diagnostic methods. In particular the results of the flow current measurements are presented together with the flow radiation which was studied at different frequency ranges. The clearest evidences of the flow presence are the generation of hard X-Ray radiation, synchrotron radiation output and the generation of strong signal in the infrared spectrum range. To study the conditions of runaway electrons generation in the U-3M torsatron the experiments with additional ionization were carried out. The amount of charged particles in the U-3M torsatron during the magnetic field rise was increased by introducing additional UHF-power into the confinement volume at the magnetic field pulse front.

## 1. EXPERIMENTAL SETUP

The experiments were carried out at the "Uragan-3M" torsatron. The major and minor device radii are  $R = 1$  m,  $r_0 = 0.12$  m. Magnetic field strength  $B_0 \leq 1$  T. The parameters of helical coils were  $l = 3$  and  $m = 9$ .

The experimental measurements were carried out by a number of diagnostic methods which includes optical spectroscopy, microwave reflectometry and interferometry, Langmuir probes, ECE (Radiometry), X-ray diagnostics, CX neutral energy analyzer, magnetic field diagnostics, bolometry, pyrometric detector, toroidal loop.

## 2. EXPERIMENTAL RESULTS

A synchrotron radiation output was observed during the RF – power introduction into the main confinement volume. The amplitude of the signal increased with the radiation frequency (Fig. 1).

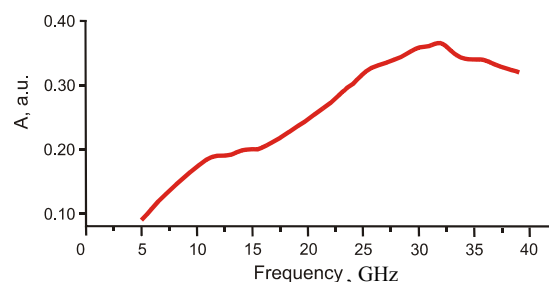


Fig. 1. The dynamics of level of synchrotron radiation observed during the RF-heating pulse

The measurements of radiation output in the submillimeter and infrared spectral ranges were carried out by the  $\text{LiNbO}_3$  pyrometric detectors placed at the plasma edge.

The results have shown a strong noise level during the whole magnetic field pulse (Fig. 2). On this 'noisy' background a number of spikes corresponded to the RF-heating pulse and the magnetic field pulse fronts were observed.

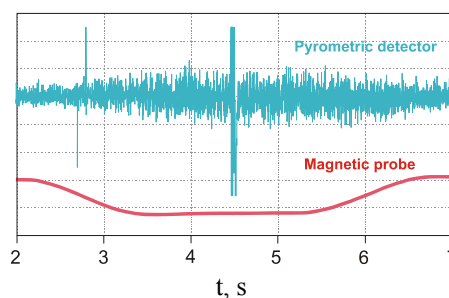


Fig. 2. Submillimeter and infrared radiation ( $f = 10 \dots 1000$  GHz) during the whole magnetic field pulse

The energy of accelerated particles was approximately evaluated from the spectrum of the X-Ray radiation output which occurs after the flow particles interaction with metallic elements of the U-3M torsatron confining magnetic field coils.

Usually the inductively accelerated particles leave U-3M confinement volume after passing deceleration stage at the back front of the magnetic field pulse. So the energies of the particles become significantly lower.

But if the studied cross-section contains a limiter the particles interact with the metal surface much earlier. Thus the X-Ray output energies in this cross-section are much higher (Fig. 3).

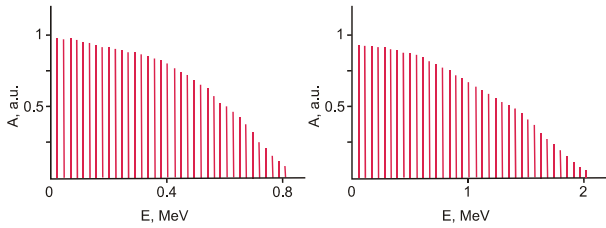


Fig. 3. Hard X-Ray radiation spectrum from the U-3M cross-section with (right) and without (left) limiter

To study the process of the accelerated particles flow creation we monitored signals in the Rogovski coil circuit. The experimental measurements have shown that the flow is formed on the magnetic field pulse fronts (Fig. 4). The flow direction changed depending on sign of temporal derivative of the magnetic field strength and the current of runaway electrons varied in the range of 100 to 200 A.

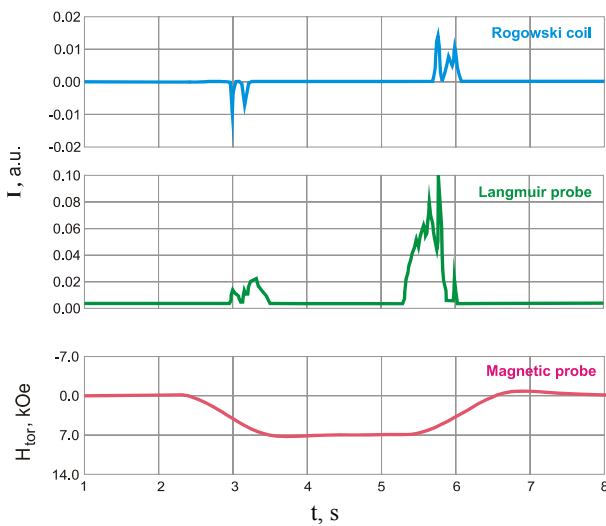


Fig. 4. Langmuir probe and Rogovski coil current signals during the magnetic field pulse

The measurements carried out by a peripheral Langmuir probe demonstrate that the flow formation correlates in time with ejection of electrons to the confinement volume edge.

The mechanism of particle acceleration is based on variation of magnetic field amplitude at the magnetic field pulse fronts. The intensity of toroidal magnetic field component varies together with the intensity of poloidal and vertical components. Time variation of the vertical component of magnetic field creates a loop voltage which accelerates charged particles in the U-3M confinement volume. The particles velocity increment is proportional to the loop voltage magnitude.

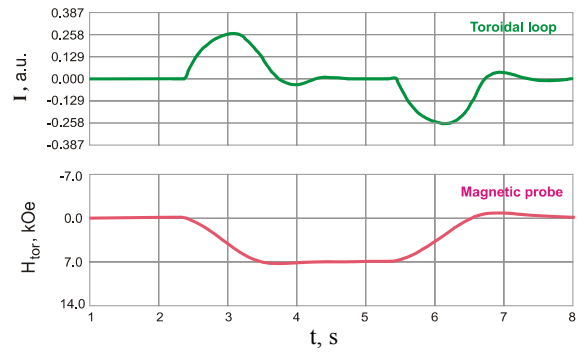


Fig. 5. The signal from toroidal loop during the magnetic field pulse

Therefore the loop voltage measurements are of great interest. In our case to provide such measurements a toroidal loop was used. The experimental results showed that the average loop voltage for the magnetic field pulse equals to 7.2 kOe is  $\sim 0.25$  V (Fig. 5).

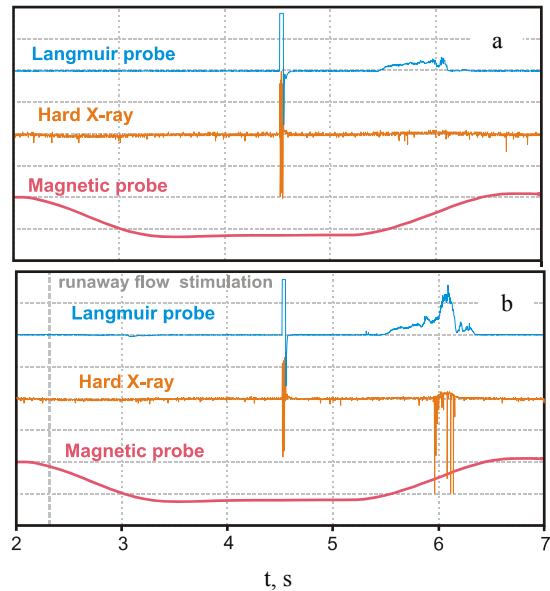


Fig. 6. The signals from Langmuir probe, magnetic probe and X-Ray detector with (b) and without (a) the runaway flow stimulation by the additional ionization

The flow of runaway electrons was stimulated by the additional UHF-ionization which occurred at the magnetic field pulse front. The UHF-generator introduced  $\sim 0.5$  kW at frequency 2.45 GHz to create plasma when the magnetic field passes the resonance value (0.86 kOe). Noticeable changes in the flow characteristics were observed through the measurements of current to the peripheral Langmuir probe together with the X-Ray output at the back front of the magnetic field pulse (Fig. 6).

The flow of inductively accelerated particles interacts with the RF-plasma and affects the dynamics of such parameters as plasma electrons density, plasma temperature and plasma current (Fig. 7).

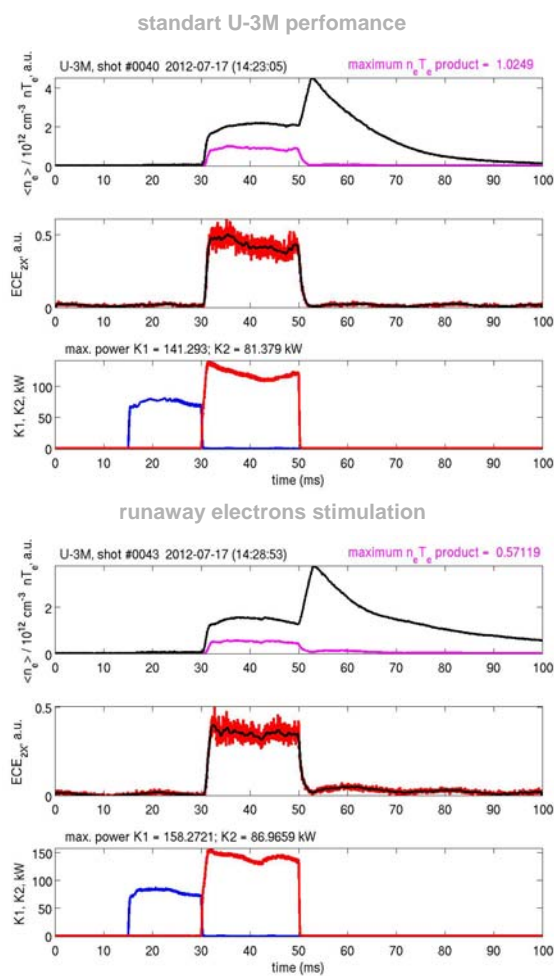


Fig. 7. The results of interaction of the flow particles with plasma of the U-3M torsatron with and without the runaway particles stimulation

## CONCLUSIONS

The presence of hyperthermal particles flow in the U-3M torsatron confinement volume was proved by a number of experimental measurements. A synchrotron radiation (5...44 GHz) output was observed during the RF-heating pulse. Microwave and infrared frequency range (10...1000 GHz) radiation was registered during the whole magnetic field pulse. The X-Ray radiation energy reaches  $\sim 2$  MeV what proves the suggestion about formation of a high energetic particles flow due to pulse character of the confining magnetic field.

The Rogovski coil measurements registered the flow current  $I_{FLOW} = 100...200$  A. The accelerating mechanism was revealed after obtaining the results of measurements via toroidal loop which detected a loop voltage of 0.25 V at the magnetic field pulse fronts.

## REFERENCES

1. V.V. Alikaev, Yu.I. Arseniev, G.A. Bobrovskiy, A.A. Kondratiev, K.A. Razumova // *Jornal of Technical Physics*. 1975, v. XLV, №3, p. 515-522.
2. H. Dreicer. Electron and ion runaway in a fully ionized gas // *Phys. Rev.* 1960, v. 117, №2, p. 329-342.
3. M.I. Tarasov, I.K. Tarasov, V.K. Pashnev, D.A. Sitnikov, V.V. Olshansky, K.N. Stepanov, E.D. Volkov // *International Conference and School on Plasma Physics and Controlled Fusion and 4-th Alushta International Workshop on the Role of Electric Fields in Plasma Confinement in Stellarators and Tokamaks*, Alushta (Crimea), Ukraine, September 13-18, 2010: Book of Abstracts, p. 53.

Article received 10.10.12

## ДИНАМИКА ИНДУКЦИОННО-УСКОРЕННЫХ ЭЛЕКТРОНОВ В ТОРСАТРОНЕ У-3М

**М.И. Тарасов, И.К. Тарасов, Д.А. Ситников, В.К. Паинев, И.Г. Гончаров, В.М. Листопад, Н.В. Лымарь, А.Ф. Штань, С.И. Солодовченко**

Получены дополнительные экспериментальные данные о динамике потока убегающих электронов в торсатроне Ураган-3М. Произведены измерения синхротронного и СВЧ-излучения потока, получены результаты измерений тока потока и напряжения на обходе стелларатора. Кроме того, проведены эксперименты по стимуляции потока убегающих электронов.

## ДИНАМІКА ІНДУКЦІЙНО-ПРИСКОРЕНИХ ЕЛЕКТРОНІВ У ТОРСАТРОНІ У-3М

**М.І. Тарасов, І.К. Тарасов, Д.А. Ситников, В.К. Паинев, І.Г. Гончаров, В.М. Листопад, М.В. Лимар, А.Ф. Штань, С.І. Солодовченко**

Отримано додаткові експериментальні дані щодо динаміки потоку утікаючих електронів у торсатроні Ураган-3М. Проведено вимірювання синхротронного та НВЧ-випромінювання потоку, отримано дані вимірювань струму потоку та напруги на обході стелларатора. Проведено експерименти зі стимуляції потоку утікаючих електронів.