INFLUENCE OF WORKING GAS PULSE INJECTION AND FLUCTUATIONS OF THE MAGNETIC FIELD ON THE RUNAWAY ELECTRONS DYNAMICS IN URAGAN-3M

I.K. Tarasov, M.I. Tarasov, D.A. Sitnikov, V.B. Korovin, A.V. Lozin, A.N. Shapoval, M.M. Makhov, Yu.K. Mironov, V.S. Romanov, R.O. Pavlichenko, N.V. Zamanov, A.G. Kulaga, I.G. Goncharov, V.M. Listopad, N.V. Lymar, N.V. Gnidenko

National Science Center "Kharkov Institute of Physics and Technology", Institute of Plasma Physics, Kharkiv, Ukraine

E-mail: itarasov@ipp.kharkov.ua

Generation of runaway electrons in fusion experiments can drive to serious damage of plasma devices components. Injection of gas with a large mass number decreases the generation processes. Also, magnetic perturbations decrease generation of runaway electrons by increasing the loss rate. We investigated the influence of working gas pulse injection and natural fluctuations of the magnetic confining field on runaway electrons dynamics. The interaction of runaway electrons with an Alfven wave in plasma is noted.

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

INTRODUCTION

The runaway electrons (RE) phenomenon that exist in most modern thermonuclear facilities which is primary arise during plasma breakdowns pellet rapid injection and additional heating of plasma are dangerous in respect of the development of plasma instabilities. Moreover, the interaction of high energetic particles with structural elements increases the probability of their degradation and failure. One of the first attempts that controlled the generation of RE was described by A. England et al. [1]. Another example is shown by the experimental results on suppressing RE flow in the TJ-II heliac [2]. Alternatively, the resonant magnetic perturbations (RMP) can also suppress RE generation by increasing the loss rate [3, 4].

However, despite the development of several methods for the control of RE generation in the present thermonuclear fusion devices, this problem is still open from the physical and technological points of view.

1. EXPERIMENTAL SETUP AND DIAGNOSTIC ELEMENTS

Experiments were performed at U-3M device. U-3M is a l = 3, m = 9 stellarator of torsatron type with open helical divertor. The main parameters of plasma and magnetic field are R = 1 m, a = 0.13 m, B ≤ 1.2 T. In this experiment the magnetic field was B = 0.72 T. Plasma in U-3M is produced by absorption of a RF power of 200 kW in the Alfven range of frequencies (f = 8…8.6 MHz) with the use of two antennas placed inside of the helical winding near the last closed magnetic surface. Essential part of the RF power is launched as show wave, which has E- field.

During the experiments on the injected pulsed gas and the magnetic field fluctuations influence on the RE flow, we used:

– impulse valve, which allows short-term (1…60 ms) to increase the working gas pressure in the chamber ($10^{-7}…10^{-5}$ Torr);

– fluctuations in the intensity of the magnetic field, which occur when the mode at the magnetic field coils is observed (5 % of the pulse amplitude);

– fluctuations of the magnetic field intensity that occur on the field (1 % of the pulse amplitude) and at the pulse flat-top magnetic;

– fluctuations of the magnetic field caused by the Alfven wave excited in the plasma.

Uragan-3M diagnostic complex includes: optical spectroscopy, microwave reflectometry and interferometry, Langmuir probes, ECE (Radiometry), X-ray diagnostics, CX neutral energy analyzer, magnetic field diagnostics, toroidal loop, hard X-ray diagnostics and others.

At the beginning it was an attempt to produce the initial working gas breakdown before switching the main plasma production antenna-generator pair. It was done to achieve the better plasma condition inside plasma volume. For this purpose, at the low pressure ($p = 5\cdot10^{-6}$ Torr) of the working gas an additional stimulation of the plasma production at the rump-up of the magnetic field pulse, the RE was accelerated. Before the high-frequency (HF) pulse an impulse gas injection was made. The duration of the pulse varied within 5…20 ms, with a change in the working gas pressure by two orders of magnitude. However, the expected effect was not observed. There was a suppression of the ECE signal and a small increase in hard X-ray radiation (bremsstrahlung).

The injection of the working gas immediately after the end of the HF pulse produced a very interesting effect. Depending on the duration of the injection pulse, the bremsstrahlung at the rump-down phase of the magnetic field pulse was completely suppressed.

The experiments with pulse gas injection at the rump-up of the magnetic field pulse are conducted also. In this case, the first of the two bremsstrahlung pulses on the rump-down phase of the magnetic field was suppressed, and the second pulse was amplified.

2. EXPERIMENTAL RESULTS

2.1. PULSED GAS INJECTION AT THE PULSE FLAT-TOP OF THE MAGNETIC FIELD

When gas is injected in the stationary phase of the magnetic field pulse a weak interaction of the working gas with fast particles is observed. Synchrotron radiation, with is picked up by ECE system in the range of 40 GHz and signal from a hard X-ray sensor are shown on Fig. 1.

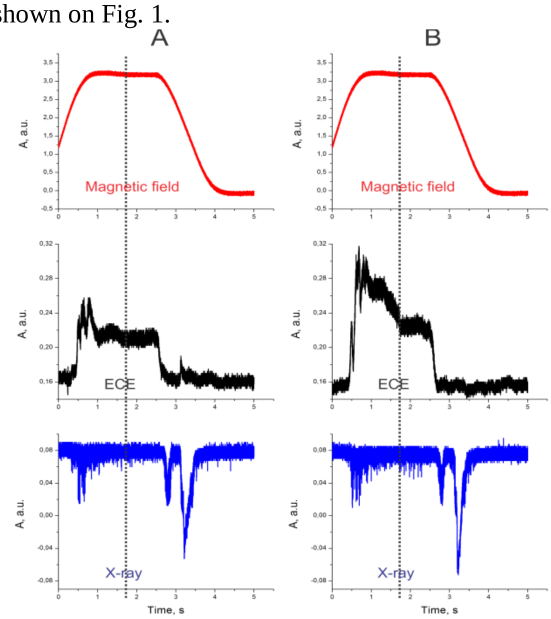

Fig. 1. The duration of the gas injection pulse are 2 ms (A) and 20 ms (B) Dash line is a start of the injection pulse. B = 0.65 T, p =1·10^{-5} Torr

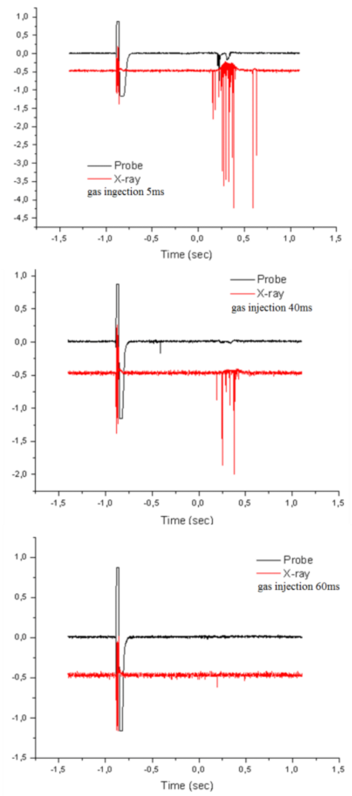

Fig. 2. Suppression of RE by pulsed gas injection after the high-frequency pulse. B = 0.65 T, p = 2·10^{-5} Torr

To investigate the possibility of interaction between the RE and the working gas, an experiment was performed with a pulsed gas injection after the end of the HF heating pulse. Within the experiment, the duration of the injection pulse was varied. It is shown that an increase in the duration of the injection pulse leads to the suppression of bremsstrahlung at the rump-down of the magnetic field pulse (Fig. 2).

2.2. PULSED GAS INJECTION AT THE RUMP-UP PHASE OF THE MAGNETIC FIELD PULSE

Bremsstrahlung at the rump-down phase of the magnetic field pulse at a low pressure of the working gas has the form of a pulse with two maxima. The pulse injection of the working gas at the rump up phase of the magnetic field pulse increase suppressed the first bremsstrahlung pulse at the rump-down phase of the magnetic field pulse (Fig. 3).

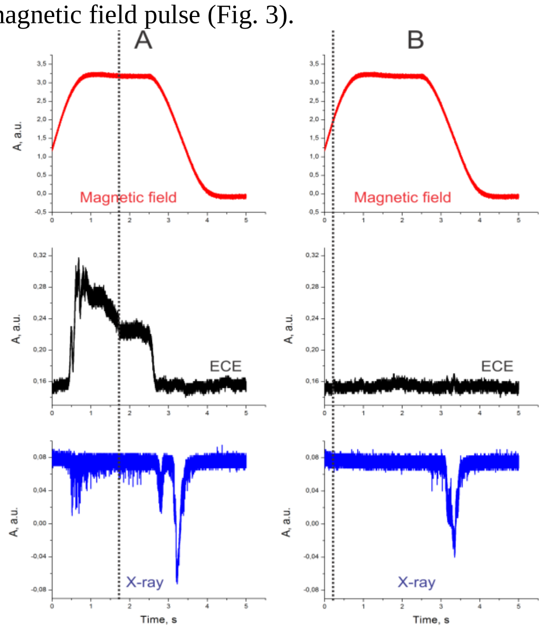

Fig. 3. Compare the working gas pulse injection at the flat-top (A) and at the rump up (B) phase of the magnetic field. Dash line is a start of the injection pulse. B = 0.65 T, p = 9·10^{-6} Torr

2.3. MAGNETIC FIELD FLUCTUATIONS

Magnetic field fluctuations at the Uragan-3M torsatron have both an artificial origin (connected with the deviation from the operating mode of the generator of the feeding magnetic field coil), and the natural one (connected with the constant mode of operation of the generator).

In addition, fluctuations of natural origin are divided into two categories. The first can be attributed a rather slow fluctuation along the rump-up phase of the magnetic field pulse, the duration of which is about of hundreds of milliseconds. The second type of fluctuations during the pulse periodically repeats with a frequency of the order of 6…10 Hz. The amplitude of the fluctuations of the first category is 5 % of the amplitude of the magnetic field pulse, and the second 1 % of the amplitude of the magnetic field pulse.

We should separately consider periodic fluctuations of the magnetic field in the confinement region of the plasma caused by an Alfven wave. It is not entirely correct to treat the wave process as a certain fluctuation, but the RF wave action interaction with the RE flow occurs during the formation, confinement and heating of the plasma in the Uragan-3M torsatron.

Fluctuations in the flat-top of the magnetic field have frequency of the order of 1 Hz and Light radiation is observed H_α and hard X-ray radiation at the stationary phase of the magnetic field pulse (Fig. 4).

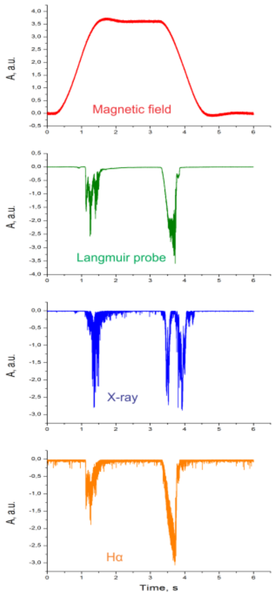

Fig. 4. The influence of fluctuations at the flat-top on the magnetic field. B = 0.72 T, p =9·10^{-6} Torr

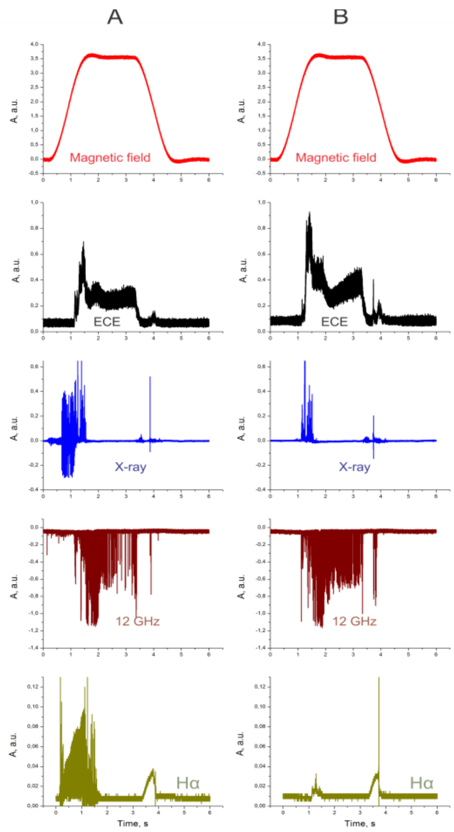

Fig. 5. The influence of slow fluctuations of the magnetic field. A – stimulation by the microwave generator, B – without stimulation by the microwave generator. B = 0.72 T, p = 9·10^{-6} Torr

The signal from the Langmuir probe located at a distance of 8 cm from the center of the plasma column.

The influence of slow fluctuations following of the rump-up phase magnetic field pulse is also investigated. The amplitude can reach the value corresponding to 5 % of the absolute amplitude of the magnetic field pulse (Fig. 5).

2.4. FLUCTUATIONS DUE TO THE INTERACTION OF THE RE WITH THE ALFVEN WAVE

The signals from electrostatic probes correspond the different frequencies. These frequencies are different harmonics of the RF-pumping which appear on the probes with different offset relative to the appearance of hard X-ray (Fig. 6). Usually, the offsets for higher harmonics were smaller [5].

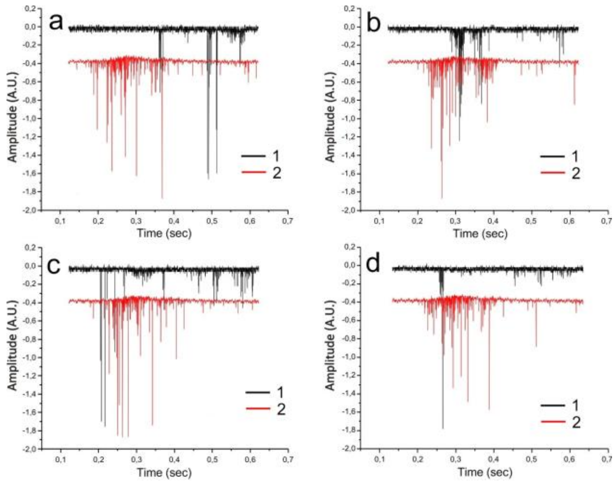

Fig. 6. The signals from electrostatic probe (1) for different harmonics of RF-pumping (a – first harmonic, b – second harmonic, c – third harmonic, d – fourth harmonic) and hard X-ray (2).
B = 0.72 T, p =1·10^{-5} Torr

CONCLUSIONS

The working gas injection at the flat-top of the magnetic field pulse before the RF pulse did not indicate any noticeable effect on the flow of RE.

The working gas injection at the flat-top of the magnetic field pulse after the high-frequency pulse showed a strong influence on the flow of RE, down to their total suppression.

The working gas injection at the rump-up phase of the magnetic field pulse indicate a strong influence on the flow of RE that appear at the rump-up phase.

The suppression level of RE flow depends on the length of the working gas pulse.

The perturbation of the magnetic field causes the appearance of the radiation in the microwave ranges of 12 and 40 GHz. The hard X-ray radiation near the rump-up phase of the magnetic field is detected also.

Fluctuations of the magnetic field at the magnetic field flat-top cause the appearance of the radiation in the range of 12, 40 GHz, Hα and in the hard X-ray range.

It was noticed the resonance interaction of RE flow with Alfven wave.

REFERENCES

1. A.C. England, G.L. Bell, R.H. Fowler, et al. // *Physics of Fluids B: Plasma Physics*. 1991, v. 3, № 7, p. 1671-1686.
2. L. Rodriguez-Rodrigo, A. Lopez-Fraguas, A. Gabriel // *Rev. Sci. Instrum.* 1999, v. 70, № 1, p. 645.
3. P. Helander, L-G. Eriksson, F. Andersson. Suppression of runaway electron avalanches by radial diffusion // *Physics of Plasmas*. 2000, v. 7, № 10, p. 4106-4111.
4. N. Commaux, L.R. Baylor, S.K. Combs, et al. Novel rapid shutdown strategies for runaway electron suppression in DIII-D // *Nuclear Fusion*. 2011, v. 51, № 10.
5. M. Lehnen, S.A. Bozhenkov, S.S. Abdulaev // *Phys. Rev. Lett.* 2008, v. 100, p. 255003.

Article received 16.10.2018

ВЛИЯНИЕ ИМПУЛЬСНОГО НАПУСКА РАБОЧЕГО ГАЗА И ФЛУКТУАЦИЙ МАГНИТНОГО ПОЛЯ НА ДИНАМИКУ УБЕГАЮЩИХ ЭЛЕКТРОНОВ В ТОРСАТРОНЕ УРАГАН-3М

И.К. Тарасов, М.И. Тарасов, Д.А. Ситников, В.Б. Коровин, А.В. Лозин, А.Н. Шаповал, М.М. Махов, Ю.К. Миронов, В.С. Романов, Р.О. Павличенко, Н.В. Заманов, А.Г. Кулага, И.Г. Гончаров, В.М. Листопад, Н.В. Лымарь, Н.В. Гниденко

Генерация убегающих электронов в экспериментах синтеза может привести к серьезному повреждению компонентов плазменных устройств. Инжекция тяжелого газа уменьшает процессы генерации. Магнитные возмущения также подавляют генерацию убегающих электронов за счет увеличения скорости потерь. Исследовалось влияние импульсного напускающего газа и естественных флуктуаций удерживающего магнитного поля на динамику убегающих электронов. Отмечено взаимодействие убегающих электронов с альфвеновской волной в плазме.

ВПЛИВ ІМПУЛЬСНОГО НАПУСКУ РОБОЧОГО ГАЗУ І ФЛУКТУАЦІЙ МАГНІТНОГО ПОЛЯ НА ДИНАМІКУ УТІКАЮЧИХ ЕЛЕКТРОНІВ У ТОРСАТРОНІ УРАГАН-3М

І.К. Тарасов, М.І. Тарасов, Д.А. Ситников, В.Б. Коровін, О.В. Лозін, А.М. Шаповал, М.М. Махов, Ю.К. Миронов, В.С. Романов, Р.О. Павліченко, М.В. Заманов, А.Г. Кулага, І.Г. Гончаров, В.М. Листопад, М.В. Лимарь, М.В. Гниденко

Генерація утікаючих електронів в експериментах синтезу може привести до серйозного пошкодження компонентів плазмових пристроїв. Інжекція важкого газу зменшує процеси генерації. Магнітні збурення також пригнічують генерацію утікаючих електронів за рахунок збільшення швидкості втрат. Досліджено вплив імпульсного напуску газу і природних флуктуацій утримуючого магнітного поля на динаміку утікаючих електронів. Відзначено взаємодія утікаючих електронів з альфвеновською хвилею в плазмі.