MHD PLASMA ACTIVITY IN THE U-3M TORSATRON DURING THE RF CLEANING MODE WITH THE MAGNETIC FIELD $B_\phi(0)$ = 0.02 T

V.K. Pashnev, E.L. Sorokovoy, A.A. Petrushenya, F.I. Ozherel'ev

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

In the considered mode of cleaning, plasma was created and heated by antennas at frequencies $f_{RF1} \approx 7.9$ and $f_{RF2} \approx 8.8$ MHz, the magnitude of the constant magnetic field was $B_\phi(0) \approx 0.02$ T, so that the ion cyclotron frequency was much lower than the heating frequency. The average plasma density was $\bar{n} \sim 1{\times}10^{18}$ m^{-3}, electron temperature was ~10 eV, working gas pressure was 10^{-4} Torr. Using a set of 15 magnetic sensors installed in one of the poloidal sections of the torus, fluctuations of the poloidal magnetic field were recorded. It was found that in the investigated frequency range 0...100 kHz, the spectrum of fluctuations of the poloidal magnetic field has two characteristic frequencies 6 and 49 kHz. The dynamics of the intensity of the magnetic plasma fluctuations for the investigated frequencies was also studied.

PACS: 52.55.Dy, 52.55.Hc

INTRODUCTION

Three-thread torsatron Uragan-3M (U-3M) [1] is an stellarator-type fusion device with (l = 3, m = 9, R_o = 1 m, a ≈ 0.10 m), see Fig. 1, has a characteristic feature – an open natural helical divertor [2-7] which allows to implement a rare collisional discharge mode at this facility [8-10]. Earlier, on this facility, a series of experiments was performed to study plasma MHD activity in the frequency range 0.5...70 kHz [11-13], which showed the presence of a large number of frequency peaks in the spectrum of fluctuations of the poloidal magnetic field.

The purpose of this work is to study plasma MHD activity in the frequency range 0.5…100 kHz in the cleaning mode. Knowledge on plasma MHD activity in the confinement volume in this mode will be useful for understanding the MHD processes observed in the facility in its main operational mode.

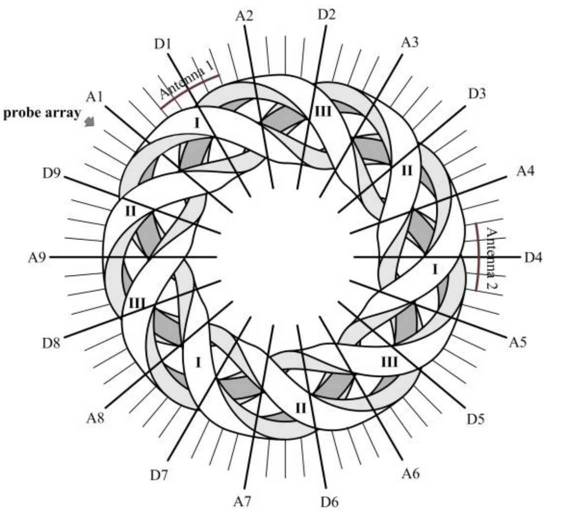

Fig. 1. Helical coils I, II, III of the U-3M torsatron. Indicated are symmetric poloidal cross-sections of the torus, A and D, in all periods 1-9 of the helical magnetic field, A1, D1, A2, D2, …, A9, D9, and position of the RF antennas. The arrow indicates the location of magnetic probes

CONDITIONS OF EXPERIMENT AND RESULTS OF STUDIES

The method of cleaning with small magnetic fields at frequencies of the order of ten megahertz is used [14] to clean the internal surfaces of the magnetic trap with plasma. In this cleaning mode plasma was generated and heated by frame antenna A1 [15] at frequency $f_{RF1} \approx 7.9$ MHz (marked A1 in the Fig. 1). Voltage at anode of RF lamp of antenna A1 was 5 kV during 50 ms. 5 ms after the start of antenna A1 the three-half-turn antenna A2 (see marked A2 in the Fig. 1) was started, which worked together with the first antenna till the end of pulse. Voltage at anode of RF lamp of antenna A2 was 6 kV, frequency was $f_{RF2} \approx 8.8$ MHz.

The magnitude of the constant toroidal magnetic field was $B_\phi(0) \approx 0.02$ T, so ion cyclotron frequency was significantly less than the plasma heating frequency. It should be noted that in the main mode of operation of U-3M for which studies of plasma MHD activity were performed in works [11-13] the RF antenna A1 was used, operating at frequency $f_{RF1} \approx 8.6$ MHz while the magnitude of toroidal magnetic field was much higher: $B_\phi(0) \approx 0.7$ T. Average plasma density in the cleaning mode was ~ 1x10^{18} m^{-3}, temperature of electrons was ~ 10 eV, hydrogen was used as working gas, working gas pressure was 10^{-4} Torr. Pulse length was 50 ms which is also close in value to the discharge length in [11-13].

Set of 15 magnetic probes made in the form of Mironov coils was used to register the fluctuations of poloidal magnetic field. Preliminary, frequency characteristic of probes was taken and it showed that frequency in the range 0.5….100 kHz are registered by magnetic probes without distortion, after 100 kHz, the signal is lowered. Signals from probes were sent to 16-channel analog-to-digital converter (ADC) with total digitization rate 2400 MHz (150 kHz per channel). When reading the information from all 15 probes the maximum frequency in the spectrum, the Nyquist frequency, could be 75 kHz. Signal from only 5 probes digitalized to increase it, which allowed to increase the Nyquist frequency up to 240 kHz. Fig. 2 shows the

ISSN 1562-6016. ВАНТ. 2019. №1(119)

poloidal cross-section where a set of magnetic probes was installed.

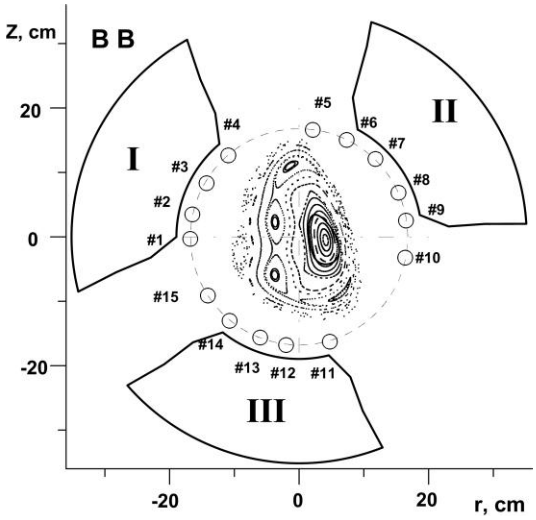

Fig. 2. Relative lay-out of helical coils I, II, III and calculated structure of the magnetic surfaces in the poloidal cross-section where measurements are made. The spatial arrangement of the magnetic sensors. Probes were installed at a radius b_{pr}=16.8 cm

Fig. 3 shows a signal from magnetic probe № 6, while the signal to ADC was sent only from 5 probes (№ 6-10), so maximum detection frequency was 240 kHz. Antenna A1 worked over time 0…50 ms and antenna A2 – 5...50 ms.

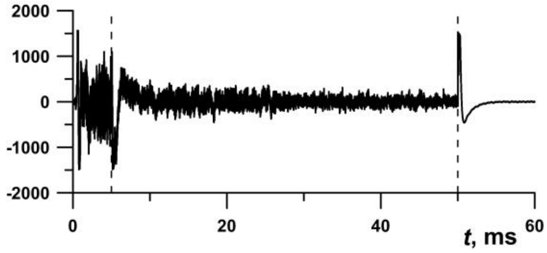

Fig. 3. The signal recorded by one of the sensors (probe № 6). The dotted line indicates the time on and off the second antenna A_2

Fig. 4 shows power spectrum calculated for the signal shown in the Fig. 3 within the range 20….30 ms. This spectrum shows the presence of two highly peak frequencies 6 and 49 kHz and low frequency band-pass 0.5…2 kHz. At frequencies of 100...240 kHz, the power spectrum was almost zero, therefore, for convenience, in Fig. 4 the axis X is limited to 100 kHz.

Signal in Fig. 3 was processed by numerical band-pass filters 4.5…6.5 and 48.5…50.5 kHz to trace the temporal behavior of frequencies 6 and 49 kHz throughout the pulse. Fig. 5 shows the results. In Fig. 5, the color bar highlights the temporal range for which the power spectrum was calculated (see shown in the Fig. 4). From Fig. 5 it is clear that fluctuation intensity of poloidal magnetic field at frequencies close to 6 and 49 Hz are not constant in time. Possible instabilities that cause in the power spectrum the frequencies 0.5… 2.0, 6 and 49 kHz require their identification and further studies.

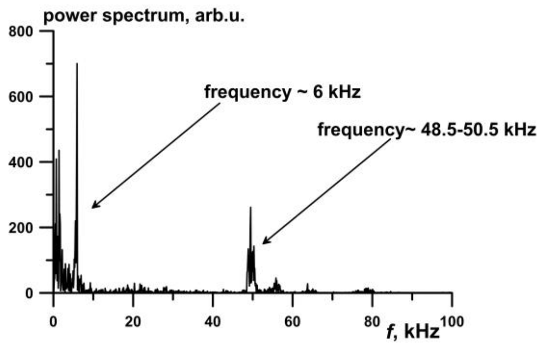

Fig. 4. The power spectrum of the signal from the magnetic probe № 06 is constructed for a time interval of 20…30 ms

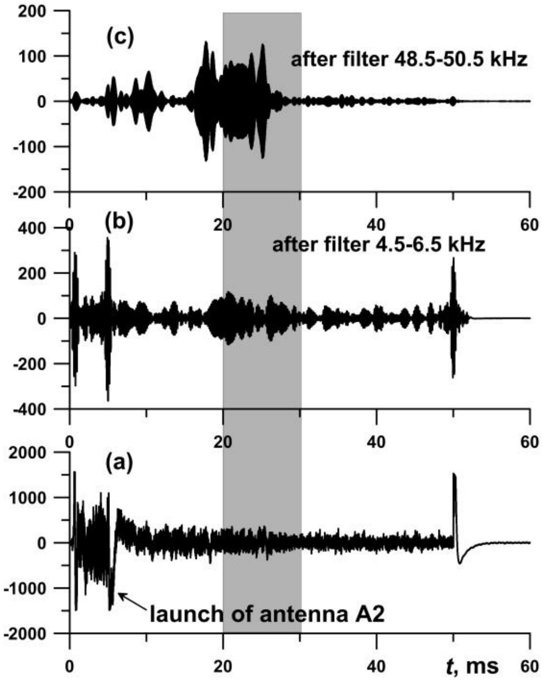

Fig. 5. The signal from one of the magnetic sensors (probe № 06) (a); the same signal after processing by a bandpass filter 4.5…6.5 kHz (b);
c – the same signal after processing by a bandpass filter 48.5…50.5 kHz (c). Antenna 1 operates 0…50 ms; Antenna 2 operates 5…50 ms

CONCLUSIONS

1. Plasma MHD activity was studied on Torsatron U-3M in cleaning mode at low magnetic field so ion cyclotron frequency was much less than the heating frequency.

2. Power spectrum of poloidal magnetic field fluctuations was obtained in the frequency range 0.5…240 kHz. Two frequencies are particularly noticeable in the spectrum: 6 and 49 kHz.

3. Poloidal magnetic field fluctuations at frequencies 6 and 49 kHz are not constant in time.

REFERENCES

1. V.S. Voitsenya, A.I. Lyssoivan, V.E. Moiseenko, et al. The present state of investigations on stellarators in

Kharkov // *Plasma and Fusion Research*. 2011, v. 6, p. 2402024.
2. G.G. Lesnyakov, E.D. Volkov, A.V. Georgievskij, et al. Study of the magnetic configuration of an l=3 torsatron by the triode and the luminescent rod methods // *Nucl. Fusion*. 1992, v. 32(12), p. 2157.
3. V.Y. Bykov, V.V. Chechkin, I.P. Fomin, et al. Divertor studies in the l = 3 Uragan-3m torsatron // *Plasma Physics and Controlled Fusion*. 1995, v. 37(3), p. 271.
4. V.V. Chechkin, L.I. Grigor'eva, M.S. Smirnova, et al. Plasma flow asymmetries in the natural helical divertor of an l = 3 torsatron and their relation to particle losses // *Nucl. Fusion*. 2002, v. 42(2), p. 192.
5. V.V. Chechkin, L.I. Grigor'eva, E.L. Sorokovoy, et al. Plasma heating effects on divertor flow vertical asymmetries in the Uragan-3M torsatron // *Nucl. Fusion*. 2003, v. 43(10), p. 1175.
6. V.V. Chechkin, L.I. Grigor'eva, Ye.L. Sorokovoy, et al. Studies of fast ion outflow to the helical divertor of the U-3M torsatron // *Plasma Devices and Operations*. 2008, v. 16(4), p. 299.
7. V.V. Chechkin, I.P. Fomin, L.I. Grigor'eva, et al. Density behaviour and particle losses in RF discharge plasmas of the Uragan-3m torsatron // *Nucl. Fusion*. 1996, v. 36(2), p. 133.
8. V.K. Pashnev, E.L. Sorokovoy. Appearance of neoclassical effects in plasma behavior in torsatron Uragan-3M // *Problems of Atomic Science and Technology.* 2008, № 6, p. 31.
9. V.V. Chechkin, L.I. Grigor'eva, Ye.L. Sorokovoy, et al. Processes arising in the edge and diverted plasmas during ITB formation in the U-3M torsatron // *Plasma Physics and Controlled Fusion*. 2006, v. 48, p. A241.
10. V.V. Chechkin, L.I. Grigor'eva, Ye.L. Sorokovoy, et al. Fast ion loss-driven H-mode transition in RF discharge plasmas of the Uragan-3M torsatron // *Plasma Physics Reports*. 2009, v. 35(10), p. 852.
11. V.K. Pashnev, E.L. Sorokovoy, A.A. Petrushenya, et al. Structure of intensive MHD fluctuations in U-3M torsatron in the mode of low frequency collisions // *Problems of Atomic Science and Technology.* 2017, v. 1, p. 49.
12. V.K. Pashnev, E.L. Sorokovoy, A.A. Petrushenya, et al. Behavior dynamics of low-frequency MHD-fluctuations and main plasma parameters in U-3M torsatron in RF-heating mode // *Problems of Atomic Science and Technology.* 2016, v. 6, p. 33.
13. V.K. Pashnev, E.L. Sorokovoy, A.A. Petrushenya, et al. Structure of MHD fluctuations in the torsatron U-3M in steady-state stage of discharge // *Problems of Atomic Science and Technology.* 2018, v. 6, p. 35.
14. A.V. Lozin, V.E. Moiseenko, L.I. Grigor'eva, et al. Cleaning of inner vacuum surfaces in the Uragan-3M facility by radio-frequency discharges // *Plasma Physics Reports.* 2013, v. 39, № 8, p. 624.
15. V.V. Chechkin, L.I. Grigor'eva, R.O. Pavlichenko, et al. Characteristic properties of the frame-antenna-produced RF discharge evolution in the Uragan-3M torsatron // *Plasma Physics Reports*. 2014, v. 40(8), p. 601.

Article received 16.10.2018

МГД АКТИВНОСТЬ ПЛАЗМЫ В ТОРСАТРОНЕ У-3М В РЕЖИМЕ ВЧ-ЧИСТКИ ПРИ МАГНИТНОМ ПОЛЕ $B_\phi(0)$=0,02 Тл

В.К. Пашнев, Э.Л. Сороковой, А.А. Петрушеня, Ф.И. Ожерельев

В рассматриваемом режиме чистки плазма создавалась и нагревалась антеннами на частотах $f_{RF1} \approx 7{,}9$ и $f_{RF2} \approx 8{,}8$ МГц, величина постоянного магнитного поля $B_\phi(0) \approx 0{,}02$ Тл, так что ионная циклотронная частота была много меньшей частоты нагрева. Средняя плотность плазмы была $\bar{n}$ ~1x10^{18} м$^{-3}$, электронная температура ~ 10 эВ, давление рабочего газа 10^{-4} Торр. С помощью набора из 15 магнитных датчиков, установленных в одном из полоидальных сечений тора, регистрировались флуктуации полоидального магнитного поля. Было обнаружено, что в исследуемом диапазоне частот 0…100 кГц спектр флуктуаций полоидального магнитного поля имеет две характерные частоты – 6 и 49 кГц. Также была прослежена динамика интенсивности магнитных флуктуаций плазмы для исследуемых частот.

МГД АКТИВНІСТЬ ПЛАЗМИ В ТОРСАТРОНІ У-3М У РЕЖИМІ ВЧ-ЧИСТКИ ПРИ МАГНІТНОМУ ПОЛІ $B_\phi(0)$= 0,02 Тл

В.К. Пашнєв, Е.Л. Сороковий, А.А. Петрушеня, Ф.І. Ожерел'єв

У розглянутому режимі чищення плазма створювалася і нагрівалася антенами на частотах $f_{RF1} \approx 7{,}9$ та $f_{RF2} \approx 8{,}8$ МГц, величина постійного магнітного поля $B_\phi(0) \approx 0{,}02$ Тл, так що іонна циклотронна частота була набагато меншою частоти нагріву. Середня густина плазми була $\bar{n}$ ~1x10^{18} м$^{-3}$, електронна температура ~ 10 еВ, тиск робочого газу 10^{-4} Торр. За допомогою набору з 15 магнітних датчиків, встановлених в одному з полоїдальних перетинів тора, реєструвалися флуктуації полоїдального магнітного поля. Було виявлено, що в досліджуваному діапазоні частот 0…100 кГц спектр флуктуацій полоїдального магнітного поля має дві характерні частоти – 6 та 49 кГц. Також вивчена динаміка інтенсивності магнітних флуктуацій плазми для досліджуваних частот.