BEHAVIOR DYNAMICS OF LOW-FREQUENCY MHD-FLUCTUATIONS AND MAIN PLASMA PARAMETERS IN U-3M TORSATRON IN RF-HEATING MODE

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A significant decrease in the intensity of low-frequency MHD-activity is accompanied by sharp increase of plasma energy content in U-3M torsatron. Plasma is generated and heated by RF-fields with frequency of $\omega \approx 0.8\omega_{ci}$ and is in a mode of low frequency of collisions. A set of 15 magnetic sensors was installed in one of the poloidal cross-sections of torus. The poloidal component of magnetic field was registered. At some point of time there is a sharp decrease of MHD-activity of plasma with a simultaneous increase of plasma energy content.

PACS: 52.55.Dy, 52.55.Hc

INTRODUCTION

In the Uragan-3M (U-3M) torsatron ($l = 3$, $N = 9$, $R = 100$ cm, $a \approx 10$ cm, $B_\phi \approx 0.7$ T, rotational transformation angle $\iota/2\pi \le 0.4$), hydrogen plasma is created and heated by RF fields at frequency $\omega \approx 0.8\omega_{ci}$. The mode of low collision frequency is implemented in the most of confinement volume of the facility (Fig. 5 in [1]) and one can see the longitudinal plasma current of a considerable amplitude. The nature of that current can be directly related to a movement of the plasma particles in a complex geometry of the magnetic field of a stellarator type toroidal magnetic trap (bootstrap current) [1, 2]. In this mode, a spontaneous transition to an improved energy confinement state is observed [3, 4].

Earlier, it was shown in experiments at the torsatron U3-M that transition to the state of improved energy confinement is followed by significant suppression of the peripheral electrostatic turbulence [5, 6].

The aim of this work is to study the correrelation between dynamics of MHD fluctuations in the plasma confinement volume and the change of the main plasma parameters during the transition to the improved energy confinement state.

MAIN RESULTS

Fig. 1 shows temporal behavior of main plasma parameters of the discharge: (a) plasma energy content; (b) toroidal plasma current; (c) signal from diamagnetic loop; (d) ratio of toroidal current to plasma energy content; (e) ratio of average energy density in the confinement volume to the average plasma density; (f) plasma density averaged over the central chord. Plasma energy content and plasma current were obtained by means of diamagnetic loop and Rogowski coil, correspondingly; the electron density – by the use of interferometer with λ=2 mm.

Fig. 2 shows temporal behavior of plasma energy content and toroidal plasma current in larger scale, together with temporal time derivatives of these quantities. Dotted line at time 35.3 ms indicates the start of a quite sharp increase of plasma energy content, which is well illustrated by the time derivative from this graph at Fig. 2,a.

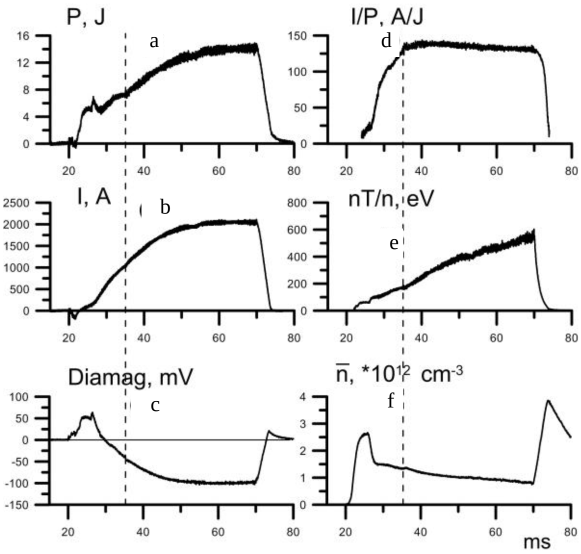

Fig. 1. The time behavior of plasma energy P, toroidal plasma current I, signal from diamagnetic loop, the ratios of I/nT and nT/n, and average plasma density

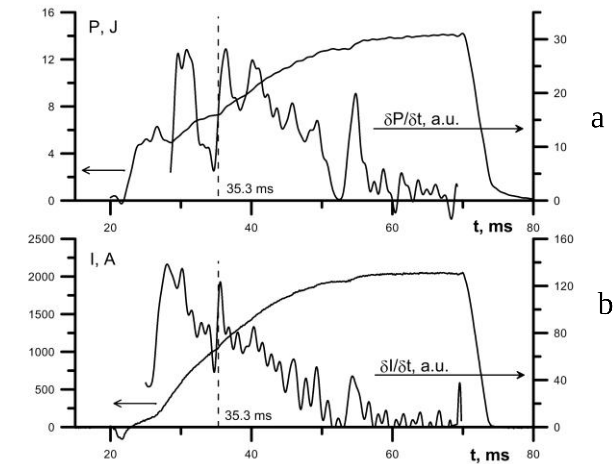

Fig. 2. The time behavior of plasma energy P, toroidal plasma current I, and their derivatives

As Fig. 1,d shows, the I/P ratio, becomes constant at some point of time. We consider that current detected in plasma is the bootstrap-current, and, hence, its magnitude has to be proportional to plasma pressure P and to some shape function of the P profile [1]. It is clearly seen that started from 35.3 ms the profile shape of plasma pressure stabilizes and does not change until the end of the discharge. The nT/n ratio, Fig.1,e, can be considered as some function of electron and ion temperature in the confinement volume. It is apparent that this ratio continues to increase during the whole pulse and even during the last 10 ms of the discharge when the energy content was almost constant or showed only a weak rise. It should be noted that after transition to better confinement state (after t=35.3 ms), the energy content P was registered to be two-times increased as well as nT/n value was about tree-times increased, see Figs. 1,a,e.

In one of the poloidal cross-sections of the torsatron U-3M there is a set of 15 magnetic probes at radius b=16.8 cm, outside the plasma confinement volume, Fig. 3. Magnetic field fluctuations, registered by probes, give information on fluctuations in the whole confinement volume. This diagnostics allowed to register fluctuations of poloidal magnetic field at the same time from all sensors with discretization frequency of 150 kHz.

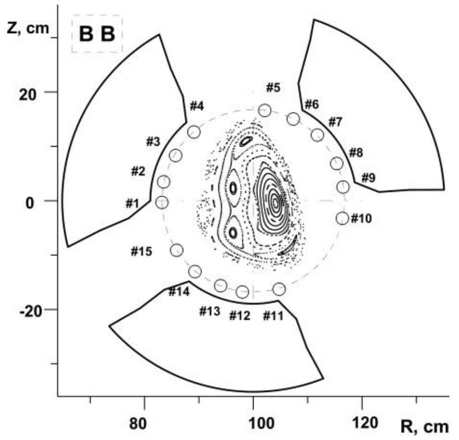

Fig. 3. The poloidal cross-section of the torus showing positions of helical coils, magnetic sensors and vacuum magnetic surfaces

Fig. 4 shows typical signal registered by the probe #10. This signal was pre-filtered to reject the frequencies below 0.1 kHz. Evidently that before the time moment t=35.3 ms the increase of fluctuation level of poloidal magnetic field is observed for the examined frequency range 0.1…70 kHz. At the same time one can see from Fig. 2 that a sharp decrease of the derivative dP/dt occurs, and the growth of plasma energy content stops.

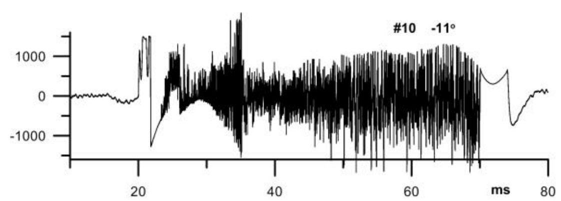

Fig. 4. The time evolution of fluctuations of the poloidal magnetic field measured by the magnetic probe #10 (see Fig. 3)

After 35.3 ms, suppression of MHD plasma activity in the test frequency range takes place simultaneously with the growth of both the function dP/dt and plasma energy content. After the interval of ~10 ms the MHD plasma activity again starts to grow, and Fig. 2 shows that this is accompanied by the termination of the growth of the energy content and some decrease of the dP/dt function.

Fig. 5 shows fluctuation amplitudes for all probes at two points of time: before transition to the improved energy state t=35.02 ms and, approximately, in 400 mks after transition t=35.44 ms. The data are presented in polar coordinates: poloidal angle is laid off according to the location of magnetic probes, and the radius corresponds to the amplitude of fluctuations at this point of time for the given probe.

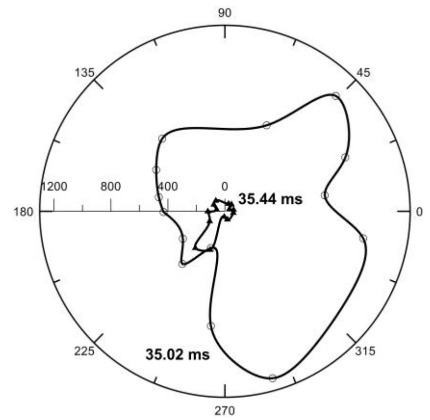

Fig. 5. The distribution of amplitude of poloidal magnetic field fluctuations at two different points of time: before and after transition to the improved confinement state

Power spectra of magnetic field fluctuations were calculated from the data of probe #10 for two time frames: before and after 35.3 ms. The results shown in Fig. 6 demonstrate an essential decrease of spectral fluctuation power for the second time frame, particularly strong suppression of high-frequency part of spectrum 25…70 kHz.

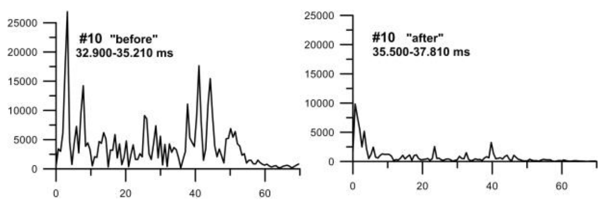

Fig. 6. The power spectra of the poloidal magnetic field fluctuations measured by probe #10 before and after the transition to the state of improved energy confinement

In Fig. 7 are presented the dynamics of changing of magnetic field fluctuations with frequency range 25…50 kHz for all probes at the time frame of 34…36 ms. In this 3D diagram: time is laid on x-axis, poloidal angle, from -180 to +180 degrees, – y-axis and closed lines indicate levels of fluctuation amplitude square. Higher levels are indicated by darker colors. Rapid decrease of fluctuation level after 35.3 ms is clearly seen.

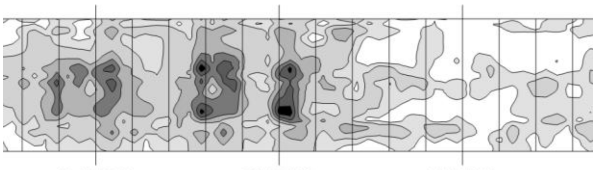

Fig. 7. Distribution of fluctuation power, in the range of 25…50 kHz, of poloidal magnetic field obtained from magnetic probes on the measured surface point in time in the vicinity of transition to the state of improved energy confinement

CONCLUSIONS

1. 15 magnetic probes were installed in torsatron U-3M to measure the poloidal component of magnetic field produced by toroidal plasma current. The frequency range of their operation is from 0.1…70 kHz.
2. MHD plasma activity was measured in a low collisional mode of plasma confinement, in the presence of longitudinal plasma current.
3. Temporal behavior of MHD plasma activity does correlate with the time behavior of the plasma energy content and longitudinal current.
4. A sharp rise of growth of plasma current and plasma energy content is accompanied by significant decrease of the amplitude of magnetic field fluctuations.
5. The time behavior of plasma density is not directly connected to MHD plasma activity.
6. Since the MHD plasma activity decay the I/P ratio is stabilized what may correspond to stabilization of the profile of plasma energy content.
7. The observed azimuthal dependence of magnetic field fluctuation intensity denotes the complex spatial structure of plasma instabilities.

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Article received 16.10.2016

ДИНАМИКА ПОВЕДЕНИЯ НИЗКОЧАСТОТНЫХ МГД-ФЛУКТУАЦИЙ И ОСНОВНЫХ ПАРАМЕТРОВ ПЛАЗМЫ В ТОРСАТРОНЕ У-3М В РЕЖИМЕ ВЧ-НАГРЕВА

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Существенное уменьшение интенсивности низкочастотной МГД-активности сопровождается резким повышением энергосодержания плазмы в торсатроне У-3М. Плазма создаётся и нагревается ВЧ-полями с частотой $\omega \approx 0,8\omega_{ci}$ и находится в режиме редких частот соударений. В одном из полоидальных сечений тора был установлен набор из 15 магнитных датчиков. Регистрировалась полоидальная компонента магнитного поля. В некоторый момент времени наблюдается резкое уменьшение МГД-активности плазмы при одновременном росте энергосодержания плазмы.

ДИНАМІКА ПОВЕДІНКИ НИЗЬКОЧАСТОТНИХ МГД-ФЛУКТУАЦІЙ І ОСНОВНИХ ПАРАМЕТРІВ ПЛАЗМИ В ТОРСАТРОНІ У-3М У РЕЖИМІ ВЧ-НАГРІВУ

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Суттєве зменшення інтенсивності низькочастотної МГД-активності супроводжується різким підвищенням енергозмісту плазми в торсатроні У-3М. Плазма створюється і нагрівається ВЧ-полями з частотою $\omega \approx 0,8\omega_{ci}$ і знаходиться в режимі рідкісних частот зіткнень. В одному з полоідальних перетинів тора був встановлений набір з 15 магнітних датчиків. Реєструвалася полоідальна компонента магнітного поля. В деякий момент часу спостерігається різке зменшення МГД-активності плазми при одночасному зростанні енергозмісту плазми.