BEHAVIOUR FEATURES OF THE RADIATIVE LOSSES OF THE TORSATRON U – 3M PLASMA

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The total bolometrically measured plasma radiation losses on the RF heating power were found. The results of measurements demonstrate a nonmonotonic dependence of radiation losses on RF power. Namely, at low RF power levels (80...170 kW) the total radiation losses raised with increasing the RF power. However, the total radiation losses decreased sharply when RF power exceeded 200 kW (down to ≈20 kW at 240 kW of RF power). Simultaneously, the intensity of impurity lines fell down significantly, whereas the average electron temperature (found from ECE measurement) did increase. The authors consider that screening properties of periphery plasma give reasons for above experimental facts.

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1. INTRODUCTION

One of the peculiarities of the U – 3M torsatron with the magnetic system disposed inside of a large vacuum volume, is the existence of a natural divertor, which is the essential part of the magnetic configuration. This circumstance creates specific conditions when measure the energy radiative losses by bolometer.

When the bolometric sensor localized in the space between helical windings at the too long distance from the confining volume (excluding the shadowing of the bolometer directional diagram), there is the possibility that it receives the charged particles from the divertor fluxes or from background plasma. In this case the sensor signal is defined not only by the radiative flux and by neutral particles, but by some part of the charged particle flux also.

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king into account mentioned above, we designed the compact bolometer sensor, having the high resistance against electromagnetic hashes and permitting to position it at the inner surface of the magnetic winding casing. The sensor measures the total radiative losses and has the reception angle near to 2π (2π – bolometer) [1,2].

In this report we present the results of measurement of the total radiative losses of the torsatron U – 3M plasma as function of the RF heating power.

2. EXPERIMENTAL DEVICE. BOLOMETERS

The U – 3M device [3] is l=3 torsatron with 9 periods of the helical magnetic field. The major tore radius is 100 cm, the inner radius of the casings of the helical windings is 19cm. Magnetic system together with the support frame are disposed inside the vacuum chamber of ~70 m^3 volume. The chamber is evacuated up to 10^{-7} Torr. Plasma is created by RF method resonance excitation of the ion cyclotron waves at the frequency 8.4 MHz. The confining magnetic field on the axis of device is B =0.7 T. The maximal power, supplied to the plasma in described experiments was of 240 kW.

One of the cross sections of magnetic configuration, defined as D-section, is presented in fig. 1, where 1 – is the plasma volume, limited by an outermost magnetic surface. The region 2 is the ergodic layer [4], where the line of force perform 1...100 turns around the major axis, before leaving the plasma volume. As follows from results of calculations [4] and from experiment [5], the thickness of ergodic layer changes from 2 to 6 cm, in dependence of azimuthal angle.

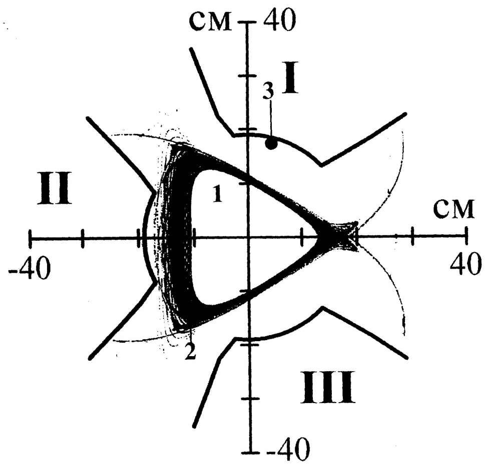

Fig. 1. Cross *section of the U – 3M magnetic configuration*

U – 3M torsatron bolometric system consists of 4 sensors, disposed on the plasma facing surfaces of the magnetic winding casings. Toroidal angles of the sensor disposition with respect to RF – antenna were from 20˚ to 180˚. The point of the sensor disposition in D – section is shown in fig 1 (3). Magnetic field in the point of sensor disposition is ~1.0 T.

The time resolution of the bolometers is ~1 ms. The lower limit of the registered power density is 20 mW/cm^2 on the surface of the sensor element. The transmission band of the bolometric channel electronics equals to ~$2 \cdot 10^3$ Hz.

3. EXPERIMENTAL RESULTS

The experimental dependence of the radiative plasma losses as a function of the RF power input is presented in fig 2. Because the radiative losses do change during the heating pulse (e.g., fig. 3), along the vertical axis of the graph in fig. 2 we put the value of the energy of radiative losses normalized to the RF power input (E).

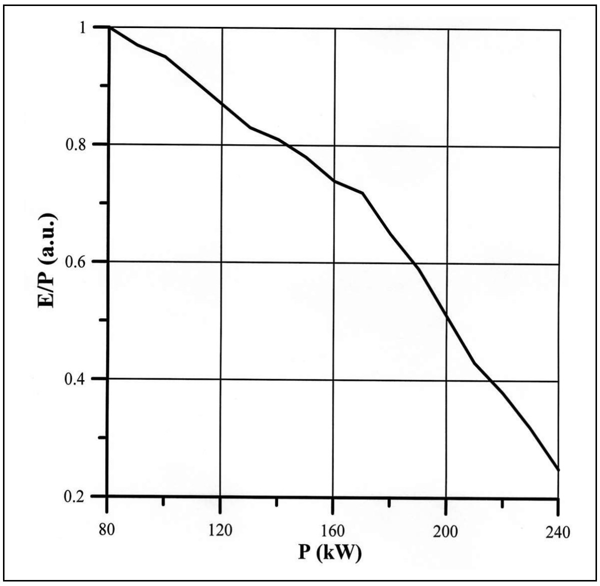

Fig 2. Normalize dependences radiative losses per pulse on the applied RF power

Fig 3. shows the temporal dependences of the radiative loss power (P) for three levels of RF power: 1 – 80 kW, 2 – 170 kW, and 3 – 240 kW.

As it is seen from the pictures, for the relative low levels of the applied power (80...170 kW) the total radiative losses increase significantly with the RF power. In this power interval the total radiative losses were about 40...50% of the RF power input.

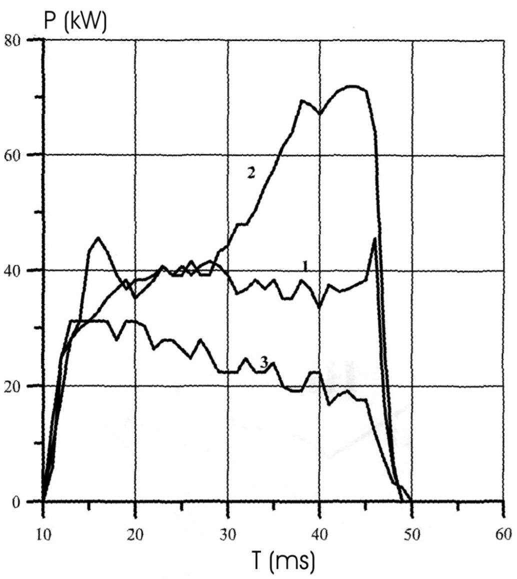

Fig 3. Temporal behaviour of radiative losses at three levels of RF power

The radiative losses decreased sharply when applied RF power exceeds ≈ 200kW. In this case the part of radiative losses dropped to ~10% of the RF power. Simultaneously the following effects are observed:

1. Decreasing (more than factor ten) the intensity of the light impurity (C^{+2}, O^{+2}) spectral lines.
2. Decreasing the average electron density from $3.6 \cdot 10^{12}$ cm^{-3} by $1.6 \cdot 10^{12}$ cm^{-3}.
3. Increasing up to 80 eV of the electron temperature in the ergodic layer region. At that T_e in the central part of confining volume increased up to 600 eV (measured by ECR radiometer).

4. DISCUSSIONS

The abovementioned experimental results may be explained by decreasing n_e in the confining volume, when the RF power is increased [6]. Fig. 4 shows the dependences of the average electron density (<n_e>) and radiative losses (at 30 ms after discharge start) as a function of the RF power. It is seen from fig. 4 that there is no simple proportionality between the time behavior of radiative losses and electron density. Electron density remains almost constant, when RF power changed from 80 to 170 kW. In this case the maximal level of the radiative losses increased from 40 to 76 kW.

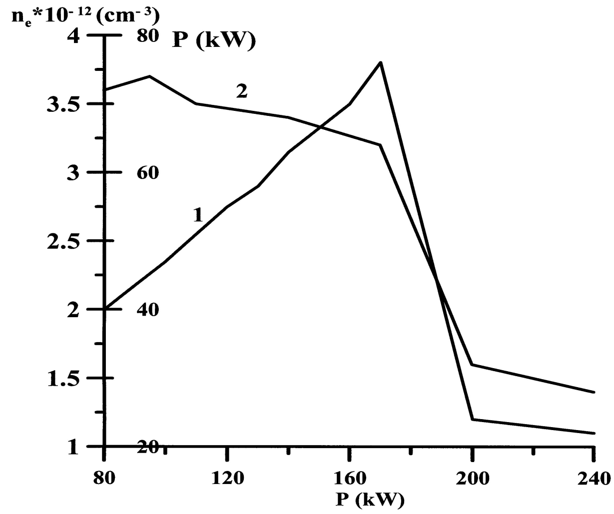

Fig 4. Dependences of the average electron density and radiative losses level from RF power:

1 – radiative losses level, 2- electron density

More adequately the majority of the experimental data may be explained by the divertor properties of the ergodic layer of the magnetic configuration U – 3M device (fig. 1). When the levels of RF power are lower, the periphery of plasma column remains cold, and the degree of ionization is low enough. In this case the impurities desorbed from the inner surfaces of the magnetic winding casings, can practically freely penetrate through the ergodic layer, undergoing ionization in the plasma confinement volume.

When the level of the RF power is increased, T_e of the plasma periphery begins to increase too, reaching 80 eV in ergodic layer, when the RF power level increases up to 240 kW.

Taking into account that the density of hydrogen molecules is $(3\ldots4)\cdot10^{11}cm^{-3}$, we estimate the n_e in the ergodic layer is $n_e \approx 8\cdot10^{11}$ cm^{-3}. The velocities of the desorbed radicals CH or OH type can be taken as $\approx 8\cdot10^4$ $cm\cdot s^{-1}$. Then the mean free path of such molecules for ionization in the ergodic layer is of the order of 1 cm. It was admitted in [5], that ergodic layer thickness (in dependence on the azimuthal angle) varies from 2 to 6 cm. Such length is enough for effective screening of the confining volume from mentioned impurities. Obviously, the screening effect of the ergodic layer has to depend on the level of RF power input and on the value of impurity influx. Namely, the too large flux of impurities can lead to the decrease of the electron temperature at the plasma periphery.

The experimental data of fig. 3 qualitatively support such explanation.

5. CONCLUSIONS

1. The assumption about screening properties of the ergodic layer do most completely explain the experimental data, mentioned above.

2. The screening effect of the magnetic configuration increases with increasing the RF power.

3. The growth of the screening properties occurs faster in the 180...240kW interval of the heating power.

It is worthy to note, that the screening properties of the periphery plasma in magnetic configuration of U-3M torsatron were firstly experimentally demonstrated in [7]. In that wor, it has been showen, that up to 70% of the carbon atoms injected into the plasma by the laser ablation, were diverted.

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ОСОБЕННОСТИ ПОВЕДЕНИЯ РАДИАЦИОННЫХ ПОТЕРЬ ПЛАЗМЫ ТОРСАТРОНА "У-3М"

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На торсатроне "У-3М" проведены измерения зависимости общих радиационных потерь от уровня вводимой в плазму ВЧ-мощности. Измерения показали немонотонную зависимость величины радиационных потерь от уровня вводимой ВЧ-мощности. При вводимой ВЧ-мощности на уровне 80...170 кВт величина радиационных потерь пропорционально возрастает. Доля радиационных потерь резко падает (до ~10% от вводимой ВЧ мощности) когда ВЧ-мощность достигает ≥200 кВт. Одновременно (более чем на порядок) уменьшаются интенсивности примесных линий, в то время как электронная температура в области удержания продолжает расти (ЭЦР радиометр). Авторы полагают, что объяснением приведенных выше экспериментальных фактов могут быть экранирующие свойства магнитной конфигурации торсатрона.

ОСОБЛИВОСТІ ПОВЕДІНКИ РАДІАЦІЙНИХ ВТРАТ ПЛАЗМИ ТОРСАТРОНУ "У-3 М"

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На торсатроні "У-3М" проведені вимірювання залежності загальних радіаційних втрат від рівня введеної у плазму ВЧ-потужності. Виміри показали немонотонну залежність радіаційних втрат від рівня ВЧ-потужності. При введеній ВЧ-потужності на рівні 80...170 кВт доля радіаційних втрат пропорційно зростає. Доля радіаційних втрат різко зменшується (до ~10% від рівня ВЧ-потужності) коли введена ВЧ-потужність досягає

рівня ≥200 кВт. Одночасно (більше ніж на порядок) зменшується інтенсивність ліній домішок, в той же час електронна температура продовжує зростати (ЕЦР радіометр). Автори вважають, що поясненням наведених вище експериментальних фактів можуть бути екрануючі властивості магнітної конфігурації торсатрону.