INVESTIGATION OF ENERGY AND MASS BALANCE IN "TRIMYX-3M" GALATEA MULTIPOLE MAGNETIC TRAP

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In the work using Rogowski loop, measurements of the diamagnetic current, generating in the plasma volume of the "Trimyx-3M" Galatea multipole magnetic trap under its filling by plasmoids have been carried out. These measurements are confirmed by signals from diamagnetic probes. The mean value of the energy in plasma volume in the process of the trap filling by plasma and during plasma decay have been determined by the magnitude of diamagnetic current. These measurements are carried out simultaneously with the measurement of the time dependence of mean plasma density by microwave interferometer.
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1. INTRODUCTION

Energy confinement time and particles confinement time in magnetic plasma traps are determined by processes of leaving of particles (of working gas mass) and energy from plasma volume of a trap. In a general view, following [1] a balance of mass and energy can be written in the form:

$$\tau_p = \frac{n}{\left(I - \frac{dn}{dt}\right)}; \quad \tau_E = \frac{W}{\left(P - \frac{dW}{dt}\right)}, \qquad (1)$$

where: n is a average concentration of ions in plasma, W is total energy in plasma, I is speed of ionization, P is power incoming into plasma, τ_p, τ_E are particles and energy confinement time in plasma, accordingly. The presented dependences (1) show that for τ_p and τ_E determination it is necessary to measure not only the rate of change, but also value of concentration and energy in plasma. If the total energy and the volume V occupied by plasma are known, it is possible to determinate medium pressure: p = 2W/3V = nkT, where: k – Boltzmann constant, T – average temperature in plasma. Hence p is proportional to W. On the other hand, as it follows from the equation of magneto-hydrodynamics equilibrium (balance of magnetic and plasma pressure) [2], p is proportional to the electric current in plasma volume. The measurement of the toroidal magnetic flux allows to determine the pressure in tokamaks [3] and stellarators [4]. The magnetic flux is measuring by means of magnetic coil [5]. The confining magnetic field is only poloidal in magnetic plasma traps – Galatea [6] unlike tokamaks. The toroidal current I_D generating in plasma at the equilibrium state, is caused only by plasma diamagnetism and is proportional to average pressure. The results of measurement of a diamagnetic current value in multipole magnetic trap - Trimyx-3M [7] are presented in the given work. The values of W, p have been determined by I_D. The value of τ_E has been determined by the dependence of I_D from time. The concentration of plasma was measured by means of the microwave interferometer.

2. EXPERIMENT

Energy balance and mass measurement in multipole traps and particularly in Trimyx-3M trap, is based on following assumptions: a) $p = K I_D$ (average pressure is proportional to the value of diamagnetic current); b) $W = 3/2\ (nkTV) = 3/2(p \cdot V)$ (the relationship between plasma energy, its concentration n, temperature kT and volume V); c) M=nmV (plasma mass is proportional to the number of particles with mass m in plasma). The pressure p can be determined from the next treatment. Plasma volume V in Trimyx-3M trap has torus form of complex cross-section with Z as the axis (as all other Galatea traps) (Fig. 1). The outer boundary of the torus has the form of one of the closed magnetic surface γ [7].

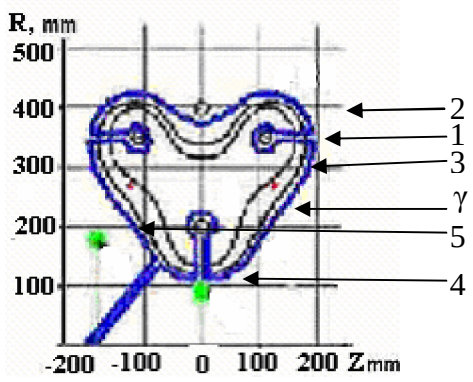

Fig. 1. Magnetic force lines 1 and cross-section of plasma volume γ for Trimyx-3M trap. Arrangement of Rogowski loop 2, magnetic probes 4, 5 and interferometer antennas 3

If we assume that all diamagnetic current runs along plasma boundary surface with constant current density, then Ampere force acting on plasma surface (F_A) is equal to: $F_A = I_D/L\int B(l)2\pi r(l)dl = 2\pi I_D \langle rB \rangle$ (integration along force line from 0 to L). Then:

$$p = \frac{F_A}{S_\gamma} = \frac{I_D < rB >}{< r > L} = K \cdot I_D = \frac{2W}{3V}, \qquad (2)$$

where B is magnetic field induction, < > - average value. Coefficient K for the trap barrier magnetic field 0,1 T is 0,114 Pa/A. Plasma volume V in the trap measured by electric probes [7] is 0,09 m^3. The equation (2) allows to calculate the average pressure and energy in plasma using known value of I_D. In this work the value of current I_D was measured by Rogowski loop (RL). The plasma density was measured by microwave interferometer with λ=8 mm. RL was installed so as trap coils do not cross loop contour area (see Fig. 1). Therefore signal from the RL is proportional to the time derivative from I_D. Main trap coils currents do not generate electromotive force in RL. Diamagnetic effect generating in Trimix-3M trap was also measured by magnetic coils of diamagnetic probes (DMP). The arrangement of DMP and interferometer antennas is shown in Fig. 1. As it is seen from Fig. 1 diamagnetic probes don't cross plasma volume, unlike RL. The signal from these probes is proportional to the time derivative of I_D and current in trap main coils.

The trap filling by plasma has been carried out by plasmoids generated by plasma gun [7]. Plasmoid, having passed through the outer magnetic barrier into zero magnetic field region, fills the trap. The dependences I_D and n from time are determined by the process of energy and mass leaving from the trap. Oscillogram of signals from RL and DMP are represented in Fig. 2. These signals integrated on time are represented in Fig. 3. The start of signals in Figs. 2 and 3 corresponds to the moment of plasma gun firing.

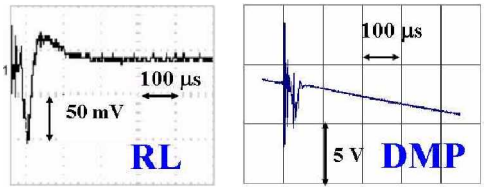

Fig. 2. Oscillogram of signals from RL and DMP

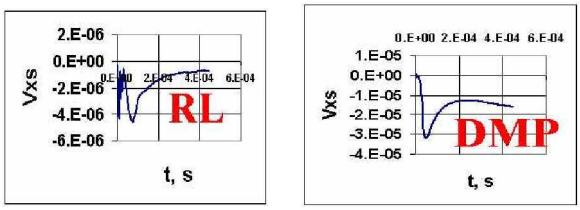

Fig. 3. Signals from RL and DMP integrated on time

These data are evidance of the diamagnetic current is generated in plasma. Ampere force, directed into the plasma volume, arises under the interaction of this current with the magnetic field of the trap. Changing of the direction of the trap magnetic field to the opposite one has leaded to the change of the diamagnetic current direction. It is seen from Fig. 3 that RL and DMP signals change identically because of both of them are proportional to the change of I_D in time. The dependences p(t) and W(t) have been determined using data from Fig. 3 for RL and equation (2). The temperature has been determined by the concentration and pressure values. Ionization speed I has been calculated in assumption of the Maxwell distribution.

The measurement of dependences of $I_D(t)$ for different values of magnetic field barrier at the Trimyx-3M trap has been carried out in this work. The results of these measurements are shown in Fig. 4.

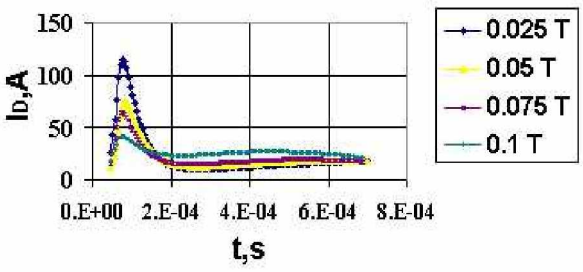

Fig. 4. Averaged dependences of diamagnetic current for different values of magnetic field barrier of Trimyx-3M trap

Dependences are obtained by RL signals averaging for 5 – 10 shots of plasma gun under the same magnetic field. The obtained dependences show the following: the increase of current I_D starts at 35 μs after voltage feeding onto plasma gun. During the next 35…40 μs I_D increases. Then I_D begins to decrease. This behavior of I_D shows that the process of plasma trap filling is finished at 70…80 μs. Since 300th μs I_D became too insignificant for measurement carrying out. The energy confinement time τ_E has been determined by the rate of the decrease of the diamagnetic current. For the given trap the value of P is equal zero in formula (1). Values of plasma pressure in the trap for the different barrier values of magnetic field at 77th μs and at 202nd μs have been calculated by data of Fig. 4 and equation (2). This dependence is shown in Fig. 5.

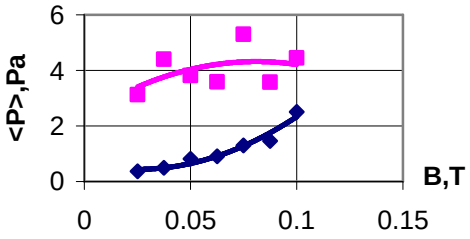

Fig. 5. Plasma pressure for different values of magnetic field barrier of Trimix-3M trap: ■ - 77μs, ◆ - 202μs

It is seen, that just after trap filling by plasma (77th μs) pressure is approximately the same for all values of magnetic field. This fact points out that parameters of plasmoid having penetrated through the barrier do not depend from magnetic field. The dependence p(B) at 202nd μs shows the improvement of energy confinement under the increase of magnetic field value. This conclusion is confirmed by results of calculation of τ_p and τ_E , which are shown in Fig. 6. The time τ_p has been determined by equation (1) and by the dependence n(t) measured by interferometer. The estimation of value kT by simultaneous measurement of p and n gives value of 15...25 eV.

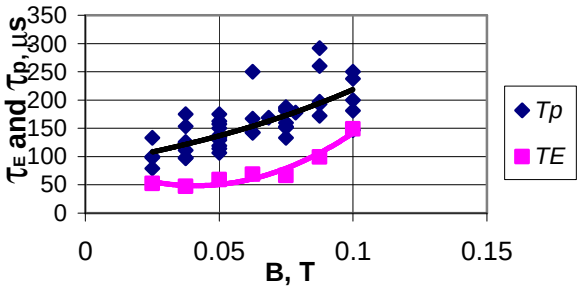

Fig. 6. Dependence of τ_E and τ_p from barrier value of magnetic field of Trimix-3M trap

CONCLUSIONS

The carried out researches have shown:

1. It is possible to measure value of the total diamagnetic current generating in plasma volume in Galatea multipole magnetic traps with the help of a Rogowski loop.
2. Simultaneous measurement of value of a diamagnetic current and average concentration of plasma allows to determine the energy and mass balance in a trap and also plasma temperature.

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ИССЛЕДОВАНИЕ БАЛАНСА ЭНЕРГИИ И МАССЫ В МУЛЬТИПОЛЬНОЙ МАГНИТНОЙ ЛОВУШКЕ- ГАЛАТЕЕ «ТРИМИКС-3М»

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С помощью пояса Роговского произведены измерения диамагнитного тока, возникающего в плазменном объеме мультипольной магнитной ловушки- Галатеи «Тримикс-3М» при наполнении ее плазменными сгустками. Эти измерения подтверждены сигналами с диамагнитных зондов. По величине диамагнитного тока определялась величина энергии в плазменном объеме и ее изменение в процессе заполнения ловушки плазмой и её распада. Измерения проведены одновременно с измерением с помощью СВЧ-интерферометра временной зависимости средней концентрации плазмы.

ДОСЛІДЖЕННЯ БАЛАНСУ ЕНЕРГІЇ І МАСИ В МУЛЬТИПОЛЬНІЙ МАГНІТНІЙ ПАСТЦІ- ГАЛАТЕЇ «ТРІМІКС-3М»

А.М. Бішаєв, А.І. Бугрова, М.В. Козінцева, А.С. Ліпатов, В.В. Савельєв, А.С. Сігов, І.А. Тарелкін, В.А. Терехов, А.В. Десятських

За допомогою поясу Роговського здійснено виміри діамагнітного струму, що виникає в плазмовому об'ємі мультипольної магнітної пастки-Галатеї "Трімікс-3М" при наповненні її плазмовими згустками. Ці виміри підтверджені сигналами з діамагнітних зондів. За величиною діамагнітного струму визначалася величина енергії в плазмовому об'ємі і її зміна в процесі заповнення пастки плазмою і її розпаду. Виміри проведено одночасно з виміром за допомогою СВЧ- інтерферометра часової залежності середньої концентрації плазми.