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MAGNETIC FIELD DISTRIBUTIONS IN A PLASMA SHIELD LAYER DURING HIGH-POWER PLASMA STREAM-TARGET INTERACTION

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The distributions of magnetic field in the shielding plasma layers, created during the powerful plasma stream interaction with the graphite sample were carried out. Plasma streams, generated by plasma accelerator QSPA Kh-50, irradiated graphite targets of 5,13 and 22cm in diameter in longitudinal magnetic field of strength up to 0.54 T. It was shown that distributions of the magnetic field in front of sample were strongly depended on the target diameter. The value of magnetic field displacement from the target plasma was increased with decreasing the target diameter (the magnetic field displacement achieved 0.135T for the target diameter of 5 cm and 0.46 T the target with diameter of 22 cm). The size of the shielding layer in radial direction was determined by a flow of plasma stream around the target.

1. Introduction

During the thermal phase of tokamak plasma disruption the divertor plates are heated by the intense plasma streams. To simulate the processes that can be occurred on the divertor plates surface during their bombardment with plasma the powerful magnetized plasma streams, generated by the QSPA (quasi-steady-state plasma accelerator), can be used.

It was shown earlier that shielding plasma layers of high density were formed near the surface of target irradiated with the powerful plasma streams. At the process of the plasma streams interaction with a target placed in magnetic field the latter was displaced from the shielding plasma layer. This effect of strong magnetic field displacement by the plasma might play an important role at the process of the energy deliver to the sample surface and plasma stability of shield layer.

The results of the measurements and analysis of distributions of the magnetic field at the near-surface region of the graphite target, irradiated with magnetized plasma streams are presented in this paper. The full-block quasi-steady-state plasma accelerator QSPA Kh-50 was used as the plasma streams source [1].

2. Experimental installation

The plasma streams were injected into a magnetic solenoid of 1.6 m in length and 0.44 m in inner diameter. The magnetic solenoid consists of 4 separate magnetic coils. The vacuum chamber of magnetic solenoid was joined by means of the conical input and output chambers with the main vacuum chamber of the QSPA device. The magnetic field strength achieved 0.54 T. The parameters of the plasma streams flowing in the magnetic solenoid were as follow: the plasma stream density - (1-3)·10^{16} cm^{-3}, maximum power density 20 MW/cm^2, maximum proton energy 200 eV, power pulse duration (150-170) μs, average $\beta \approx (0.1 \div 0.2)$ [2].

The distributions of the magnetic fields in front of the target were measured by the local movable magnetic probe with the maximum diameter of 6 mm. The magnetic probe was located at the distance of 2.3 m from the accelerator QSPA Kh-50 output [2].

For measurements of the magnetic field distributions at the different distances from the target surface a special system for target displacement along the axis of the vacuum camber was utilized. This system consists of a cog-wheel, a rack and a supporting bar. It was placed inside the output conical vacuum chamber of the QSPA Kh-50 device. The minimum distance between the accelerator output and the target position was 2.25 m and the maximum one - 2.7 m (the maximum spacing of measurements was 45 cm). The scheme of experiments is presented in the Fig.1.

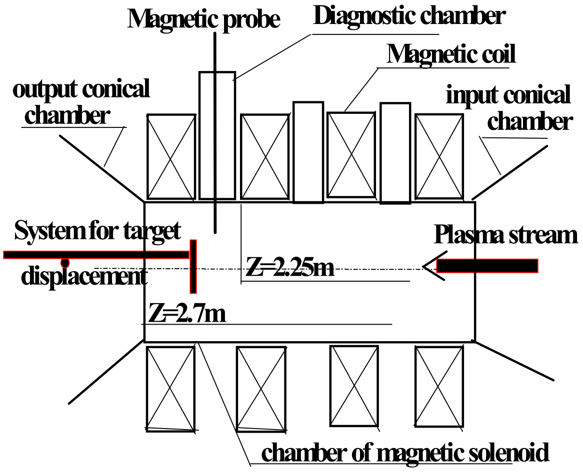

Fig.1. The scheme of experiment

The MPG -7 graphite targets with diameter of 5, 13 and 22cm were used.

3. The magnetic field distributions at the vicinity of a target

The radial distributions of the magnetic field were measured for the different distances from the target surface and for the different moments of time. The measured radial distributions of the magnetic field in plasma shield, normalized by the value of a vacuum magnetic field, are shown in Figs. 2, 3, 4 and 5 for the moment of time of (170-180) μs. This moment corresponds to the maximum power density in the plasma streams, generated by the QSPA device [2].

One can see the presence of a local minimum of the magnetic field in the plasma at the radius R = 8 cm for the target with a diameter of 5 cm and at the radius (13-14) cm for the target with a diameter of 13 cm (Fig. 2 and 3). This local minimum was caused by plasma flowing around the target. The coordinate of this local minimum of the magnetic field (local minimum outside the target) moves outward the axis with increasing the target diameter.

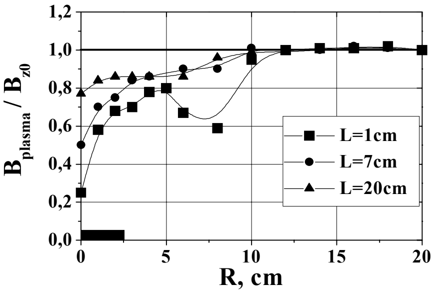

Fig.2 The radial distributions of the normalized magnetic field at the different distances from the target with the diameter of 5 cm

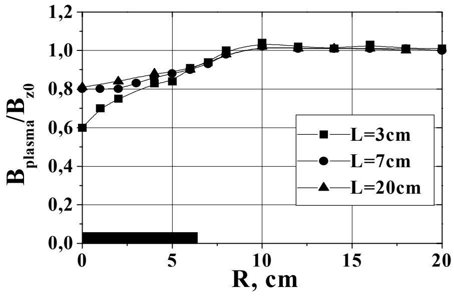

Fig.3. The radial distributions of the normalized magnetic field at the different distances from the target with the diameter of 13 cm

The value of the magnetic field minimum was decreased with increasing the target diameter. The local minimum in the radial distributions of the magnetic field near the target with diameter 22 cm was not found (Fig. 4).

Thus, the maximum radius of the plasma shield (radius of the plasma shield is the point where $B_{plasma} = B_{z0}$) was decreased with increasing the target diameter from 12-13 cm (for the target diameter of 5 cm) down to (7-8) cm (for the diameter of 22 cm).

The radial distributions of the magnetic field at the distance l = 0,5 cm from the targets surface are also not monotonous and have two extremums (Fig.5). The existence of two local maximum in the dependence of the magnetic field can be explained by interaction of incoming plasma stream with the magnetic field of the skin current, generated at surface of the target.

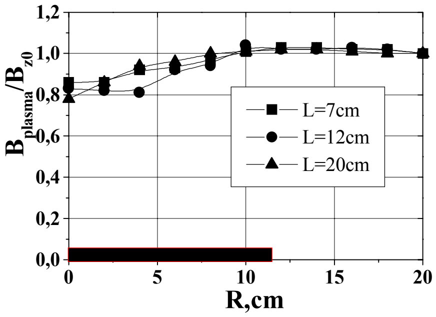

Fig.4. The radial distributions of the normalized magnetic field at the different distances from the target with the diameter of 22 cm

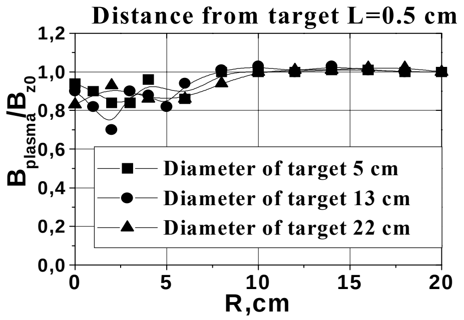

Fig.5.The radial distributions of the normalized magnetic field at the distance of 0.5 cm from the targets with diameters of 5,13 and 22 cm

It was shown in present experiments that the magnetic field in the plasma shield is in strong dependence on both the target diameter and the distance from its surface. The dependencies of magnetic field in plasma, normalized by the vacuum magnetic field, on the distance from the target surface are shown in Fig. 6.

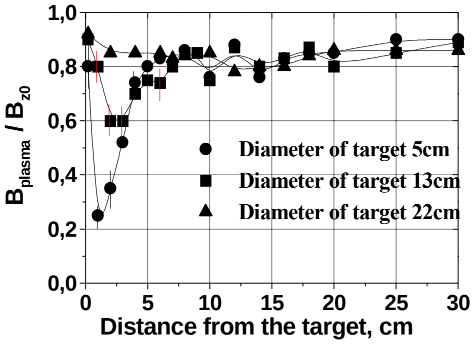

Fig.6. The dependencies of the magnetic field in a plasma, normalized by the vacuum magnetic field, on the distance from the target surface

It follows from this picture that the magnetic field in the plasma shield is increased with increasing the distance from the target. The minimum value of magnetic field was found in front of the target at the distance L = (1÷3) cm from its surface. The magnetic field in this region of the shielding plasma layer is increased with increasing the target diameter from 0.25xB_{z0} = 0.135 T (for the target diameter of 5 cm) up to 0.85xB_{z0} = 0.46 T (for the diameter of 22 cm). The effect of the target presence was seen in the distributions of the magnetic field in the shielding layer measured up to the distances of 20 cm from the surface of the sample (Fig. 6).

The magnetic measurements carried out inside and behind the graphite target had shown that the magnetic field force lines are frozen into the target. The value of the magnetic field inside and behind of the target with the diameter of 13 cm was up to 0.95xB_{z0} (Fig.7).

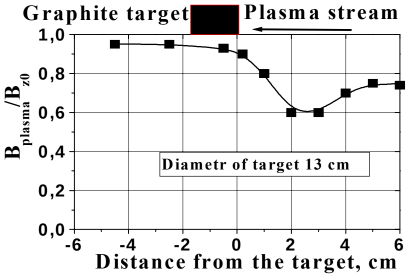

Fig.7. The dependencies of the magnetic field in a plasma, normalized by the vacuum magnetic field, on the distance from the target surface

4. Discussion and conclusions

An ordinary pressure balance equation was used for an estimation of the maximum value of the plasma temperature $T_{plasma} = (T_e+T_i)$:

$$\frac{1}{S_{plasma}}\left\{\int_0^{R^*} n(r)T(r)dS + \int_0^{R^*}\frac{B^2_{plasma}(r)}{8\pi}dS\right\} = \frac{1}{S_{vacuum}}\int_{R^*}^{R_{vacuum}}\frac{B^2_{vacuum}(r)}{8\pi}dS$$

Here: S_{plasma} – the square of the plasma stream cross-section; S_{vacuum} – the square of cross-section between the wall of a vacuum chamber and the plasma boundary; B_{plasma} – the magnetic field in a plasma; R^* radius of the plasma boundary; B_{vacuum} – the magnetic field with no plasma; *n(r)* – the radial distribution of the plasma density; *T(r)* – the radial distribution of the plasma temperature. The radial distributions of the plasma density and temperature are approximated as follows:

$$n(r) = n_0\left(1-\frac{r}{R^*}\right) \qquad T(r) = T_0\left(1-\frac{r}{R^*}\right)$$

Here n_0 – the plasma density at R = 0 and T_0 – the plasma temperature at R = 0. These distributions were chosen as far as the linear (or very close to linear) dependence of the plasma density on the radius was measured in our previous experiments with using the interferometer with a large area of view [3]. The experimental data of the radial distributions of the magnetic field and the n_0 value, evaluated by Stark broadening of the H_β spectral line at the different distances from the target surface were used for an estimation of the average plasma temperance.

The estimations of the plasma temperature were performed for the distance from the sample where the minimum magnetic field in the plasma shield exists. The results of the plasma temperature estimation (with using pressure balance equation) for the targets of the different diameters are shown in the table.

Tab1e. The parameters of the shielding plasma

Diameter of the target, cm	5	13	22
Distance from the target, cm	1	2-3	2-4
Magnetic field , kG	1.35	3.24	4.6
Pressure in the shielding plasma layer, x10^{17}, eV/cm^{-3}	4,8	1,9	2,2
Plasma density, x10^{16}, cm^{-3}	17	10	20
$T_{plasma} = (T_e + T_i)$, eV	16-17	11-12	7

On the base of these determinations of the electron temperature the degree of the plasma shield magnetization was estimated. The local plasma temperature (T_e + T_I) in the near-axis region, estimated from the pressure balance equation, was about (15-20) eV for the target with the diameter of 5 cm. It was decreased up to 6-7 eV with increasing the target diameter up to 22 cm.

It is well known that the plasma is magnetized and can't be moved across the magnetic field lines for the parameter $\omega_e\tau_e$ >> 1. In our experiments the Hall parameter $\omega_e\tau_e$ was about 0.4-0.5 for all targets. In this case the plasma shield can propagate across the magnetic field lines.

Thus, the obtained experimental results showed that the distributions of the magnetic field in the plasma shield are strongly depended on the both the target diameter and the distance from its surface. The plasma flowing around the target is the reason for the local minimum magnetic field presence in the plasma shield.

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References

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