UDC 533.9

PLASMA SHIELD DYNAMICS UNDER HIGH-POWER PLASMA STREAM IRRADIATION OF TARGET SURFACE.

Chebotarev V.V., Garkusha I.E., Makhlaj V.A., Mitina N.I., Solyakov D.G., Tereshin V.I., Trubchaninov S.A., Tsarenko A.V. and H.Wuerz*

Institute of Plasma Physics of the National Science Center "Kharkov Institute of Physics and Technology", Akademicheskaya St. 1, 61108 Kharkov, Ukraine,
****)Forschugszentrum Karlsruhe, IHM, Postfach 3640, D-76021, Karlsruhe, Germany.***

High-power quasi-steady-state plasma stream was applied for current disruption simulation in ITER tokamak and testing divertor materials. Plasma shielding layer was formed during the high-power plasma stream interaction with the target surface.

The main aim of present work was analysis of plasma shield dynamics at the vicinity of target during the plasma stream irradiation. High-power plasma stream was generated by powerful quasi-steady-state plasma accelerator QSPA Kh-50 [1] and injected into longitudinal magnetic field with strength up to 1T. Plasma stream parameters in place of target position were follows: average electron density $(2\text{-}4)\cdot 10^{16}$ cm^{-3}, maximum power density up to 20 MW/cm^2, maximum proton energy 200 eV, pulse duration 150-170 μs, average $\beta \approx (0{,}1 \div 0{,}2)$ [2]. Graphite targets with diameters 5, 13 and 22 cm were used.

1. Analysis of energy of plasma flowing around the target

Experiments were performed in magnetic field B_{z0}=0.54 T. Energy density distributions in the free plasma stream, in the plasma shield and behind the targets were measured by copper local movable calorimeter with diameter 5 mm. The scheme of experiment is shown in fig.1.

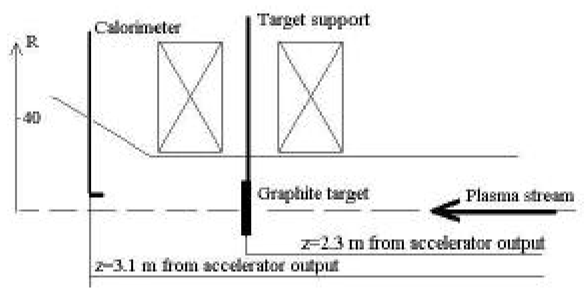

Fig.1. The scheme of experiment

We assumed that shielding effects at the process of measurements by local calorimeter are the same for both cases with and without targets and for different target diameters. One can see from fig.2 that the radial distribution of energy density in free plasma stream is symmetrical. The value of $Q = \int r_w(r)dS$ in a free plasma stream is equal 53 kJ (no correction for calorimetric measurements in magnetic field was done). Unsymmetrical distributions of energy density behind the target (fig. 3, 4 and 5 (■)) can be explained by influence of target supporting bar on the results of measurements as far as calorimeter was moving behind

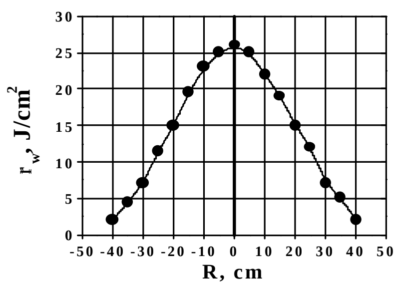

Fig.2.Energy density radial distribution in free plasma stream. Magnetic field H=0.54T.

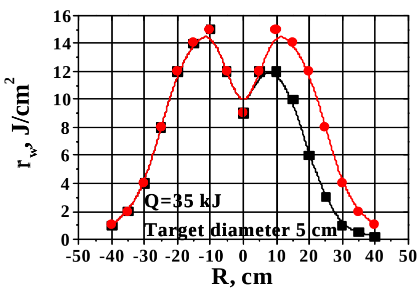

Fig.3. Energy density radial distribution behind the target. Magnetic field H=0.54T

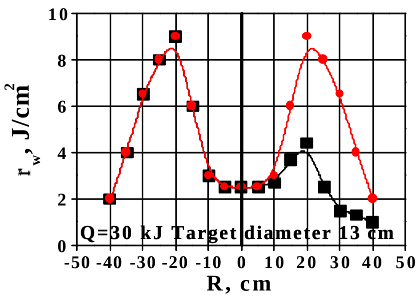

Fig.4. Energy density radial distribution behind the target. Magnetic field H=0.54T.

supporting bar. The local minimum at the vicinity of the axis was observed for all radial distributions of plasma energy measured behind the targets. For estimation of the total energy of plasma, flowing around the targets,

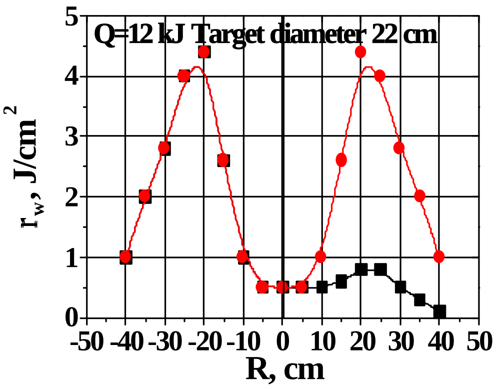

Fig.5. Energy density radial distribution behind the target. Magnetic field H=0.54T.

the energy density profiles were approximated by symmetrical curves (fig. 3, 4 and 5(●)). In this case the values of $Q = \int r_w(r)dS$ estimated behind the targets were 35 kJ for target diameter ∅ = 5 cm, 30 kJ for ∅ = 13 cm and 12 kJ for ∅ = 22 cm correspondingly.

The total plasma energy measured behind the targets with different diameters normalized by total energy in free plasma stream as a function of target diameter are presented in fig 6. As we can see from this figure, the ratio $Q_{behind\ target}/Q_{free\ plasma\ stream}$ is decreased with increasing the target radius from 0.6 (for target diameter 5 cm) till 0.2 (for target diameter 22 cm).

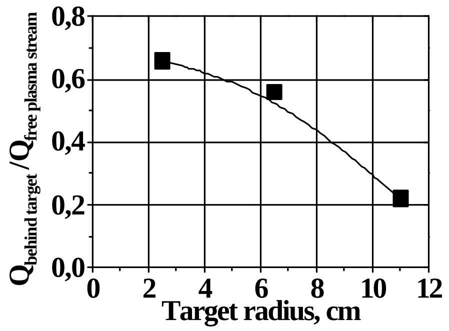

Fig.6. Total energy measured behind the targets with different diameters normalized on total energy in free plasma stream as function of target diameter.

It follows from fig. 6 that up to 50-60 % of incident plasma stream energy flows around the target placed in magnetic field B_{z0} = 0.54 T. As we can see from those experimental results plasma flows around the targets and doesn't move to the axis.

The radial distribution of energy density in a free plasma stream without magnetic field is symmetrical fig.7. The value of $Q = \int r_w(r)dS$ in a free plasma stream is equal 66 kJ. The distributions of energy density in plasma stream without magnetic field behind the target also symmetrical (fig. 8 (■)) and local minimum of energy density feebly marked. In magnetic field B_{z0} = 0.36 T the distribution of energy density behind the target is unsymmetrical (fig. 8( )) and can be

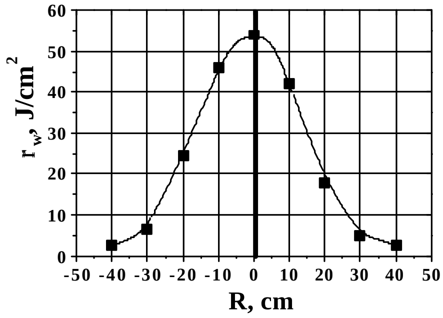

Fig.7.Energy density radial distribution in free plasma stream. Magnetic field H=0.

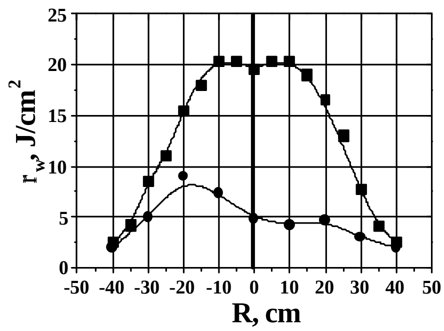

Fig.8. Energy density radial distribution behind the target. - magnetic field H=0; -magnetic field H=0.36 T.

explained by influence of target supporting bar.

Without magnetic field about 80-85% of incident plasma energy flow around the target (fig.8). In this case (B_{z0} = 0) plasma, flowing around the target, moves to the axis behind the target (the local minimum in energy density distribution at the vicinity of the axis was not observed). Local maximum of energy density behind the target was observed. This maximum moved outward the axis with increasing the target diameter.

2. Electron temperature and electron density in plasma shields.

Electron temperature was evaluated on the base of measurements of the ratio of CIII and CII spectral lines intensities. The monochromator MDR 6 of Russian trade mark with photomultiplier as a recorder was used for carbon lines intensities measurements. Spatial resolution was about 5 mm in radial and axial directions. Intensities of spectral lines were measured for different distances from the target surfaces.

Electron density was measured by using Stark broadening of H_β spectral line. High-speed photo camera was used for radiation recording. Spatial resolution in radial direction was about 1-2 mm and in axial direction 8-10 mm.

Typical waves forms of CIII and CII spectral lines are shown in fig. 9.

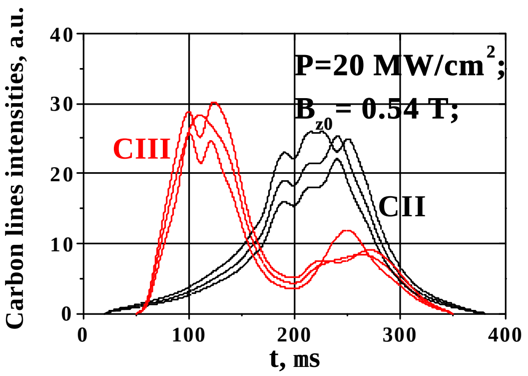

Fig.9. Time evolution of CII and CIII spectral lines at the distance of 7 cm from the target surface with diameter 13 cm.

Numerical results, presented in [3] were used for electron temperature estimation in plasma shield.

The distributions of electron temperature and electron density along the axis, evaluated from experimental data, are shown in fig. 10 and 11.

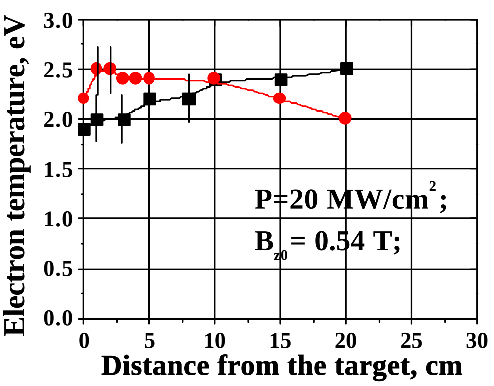

Fig.10. Electron temperature distribution along the axis. - target diameter 5 cm; - target diameter 13 cm.

As one can see the electron temperature, evaluated by ratio CIII/CII carbon spectral lines intensities, weakly depends on target diameter and equals (2-2.5) eV for both targets and for distances up to 20 cm from the target surface.

Plasma shield densities are comparable for targets with diameters 5 cm, 13 cm and 22 cm. Close to the target surface the electron density was equal (2-3)x10^{17} cm^{-3}. But at the vicinity of (2-3) cm from the surface it was decreased down to 9x10^{16} cm^{-3} for both targets with diameter 5 cm and 13 cm. While the plasma density close to the target with diameter 22 cm weakly depends on distance from the target and equals (1-3)x10^{17} cm^{-3}. At the distances from the target more than 10 cm the electron density was weakly decreased down to 4x10^{16} cm^{-3} at the distance (25-30) cm from the target surface.

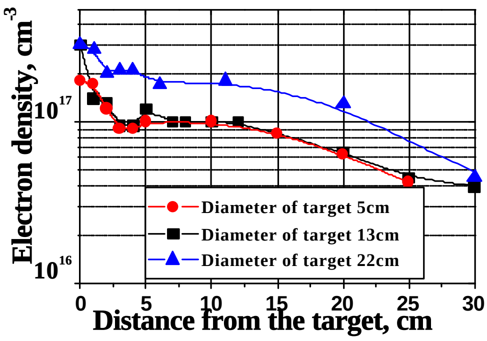

Fig.11. Electron density distributions along the axis.

This value was comparable with the density of incident plasma stream. Thus the thickness of shielding layer at vicinity of the sample with diameter a 5 cm was 10-15 cm and close to sample with diameter 22 cm was 25-30 cm.

3. Conclusions.

On the base of presented experimental results one can conclude that plasma shield dynamics and its parameters are strongly depended on target size.

The plasma flow around the target was observed. Part of incoming plasma stream and plasma shield flows around the target. Total value of energy, measured behind the target was about (50-60)% of energy of incoming plasma stream in magnetic field 0.54 T and about 80-85% without magnetic field.

The plasma density value in shielding layer was by one order of magnitude higher to compare with plasma density value in a free plasma stream and depended on size of target.

The thickness of shielding layer was 10-15 cm for target diameter 5 cm and increased up to 25-30 cm with increasing the target diameter up to 22 cm.

The value of electron temperature, measured by ratio of intensities of CIII and CII spectral lines, was about 2-2.5 eV and practically not depended on target diameter and distance from the target surface.

This work was partly supported by the Science and Technology Center in Ukraine (STCU), Grant #881, and Ministry of Education and Science of Ukraine, International Collaboration, Grant #2M/92-2000.

References

[1]. O.S.Pavlichenko, V.I.Tereshin, V.V.Chebotarev et. al., // *Plasma Devices and Operations, Vol. 2,1992, pp.155-165*.

[2]. V.I.Tereshin, V.V.Chebotarev, H.Wuerz at al. // *Problems of Atomic Science and Technology. Series «Plasma physics» 3(3) , 4(4), 1999, ð. 194 .*

[3]. Hans R. Griem *Plasma spectroscopy*. Moscow. «Atomizdat», 1969.