*36th EPS Conference on Plasma Phys. Sofia, June 29 - July 3, 2009 ECA Vol.**33E**, P-5.153 (2009)*

High density regimes in Globus-M

M.I.Patrov[1], B.B.Ayushin[1], V.K.Gusev[1], F.V.Chernyshev[1] G.S.Kurskiev[1], N.A.Khromov[1], V.B.Minaev[1], M.I.Mironov[1], I.V.Miroshnikov[2], Yu.V.Petrov[1], V.V.Rozhdestvensky[1], N.V.Sakharov[1], S.Yu.Tolstyakov[1], V.I.Varfolomeev[1], A.V.Zabuga[3], E.G.Zhilin[4]

[1]A.F. Ioffe Physical-Technical Institute, RAS, St. Petersburg, Russia

[2]Saint Petersburg State Polytechnical University, St. Petersburg, Russia

[3]Saint Petersburg State University, St. Petersburg, Russia

[4]Ioffe Fusion Technology, Ltd., St. Petersburg, Russia

1. OH high density experiments

Essential technological improvements were made since last high density experiments on Globus-M [1] to obtain better target plasma performance. A set of error field correction coils has been installed to minimize the effect of locked modes. The set consist of four coils arranged symmetrically outside of the vacuum vessel, with each coil spanning 67,5^o toroidally (see fig. 1). Each coil consists of three turns and can carry a maximum of 6 kA·turns current. The intrinsic error field due to magnetic system misalignment was determined by a method described in [2]. For its compensation the coils are arranged in two pairs (AC and BD in fig. 1), with opposite coils wired in series to produce a non-axisymmetric magnetic field with an odd-n spectrum. The two pairs of correction coils are powered by independent power supplies, which allows an n=1 field to be applied at an arbitrary phase. The value and phase of the compensating field was determined by means of the mentioned above method [2]. Implementation of the error field compensation allowed us to essentially increase the discharge duration, restricted by the locked mode onset. Fig. 2 shows the waveforms of two discharges with (#23632) and without (#23633) error field compensation at low density, when the effect is more emphatic. The shot with compensation is by 20 ms longer at the same other conditions. At higher densities, better discharge stability regarding the locked modes allowed us to reach higher integral parameters in OH plasma. Fig. 3 demonstrates the waveforms of two high density OH discharges at I_p = 200 kA and initial B_t =0.4 T. The line averaged density reached in both the value $\langle n_e \rangle = 1\times10^{20}$ m^{-3}, close to the Greenwald limit. In the shot #23479 (at constant B_t) β_t obtained with EFIT reconstruction of magnetic measurements

[3, 4] reached the value of 14.5 %, while in shot 23497 (at decreased by 20 % B_t at the end of the shot) β_t reached the very high value for OH plasmas of 17 %.

2. NBI heating

That target plasma was used in experiments on heating by means of an NB with improved parameters. The renovation of the ion source IPM-1 [5] was performed. New set of grids for the ion optical system was installed. The curvature of the grids was increased to provide a smaller beam width in the area of launching port. The beam height was also reduced by means of ion optics tuning. As a result, the beam footprint does not exceed 4 cm in horizontal direction and 24 cm in vertical one. That corresponds to at least 2 cm gap between the beam edge and the docking unit wall. At the same time the power density on the beam axis became half as much again. About 20% rise of the beam power was obtained due to increasing of accelerating voltage up to design parameters (30 kV). Corresponding extension of the gap between electrodes in the ion optic system was made. Taking in account the efficiency of the ion beam neutralization we have achieved about 1.2 MW and 1.0 MW beam power for hydrogen and deuterium beams correspondently. Together with ohmic power, it corresponds to 2.5-3.0 MW/m^3 of specific power density in Globus-M plasmas. To prevent plasma contamination by heavy impurities, the inner surface of the tokamak vacuum vessel was fully coated with graphite tiles [6]. It improved the situation with impurity contamination, but simultaneously reduced the space between the plasma and outer wall that lead to worse fast particle confinement, because the 30 kV ion hyroradius from the low magnetic field side is higher than the characteristic gap between the separatrix and the vessel wall. In our previous experiments at moderate plasma density [7, 8] it was shown that NBI heating efficiency increased in the plasma column shifted towards the central stack. In recent experiments the same dependence was investigated at the high plasma density and increased NB power. Fig. 4 shows the waveforms of two high density shots heated by the hydrogen beam with the energy of 28 keV and the power of 1 MW. The shift of the plasma column centre inside from the geometrical centre of the vacuum vessel was $\Delta R = 3$ cm in shot #23757 and $\Delta R = 5$ cm in shot # 23764. One can see that in spite of high NB power, in shot #23757 there is no essential increase of $\beta_t = 15\%$ in comparison with OH shot #23479 (see fig.3). A bit higher $\beta_t = 17$ % was obtained in shot #23764 at higher inward shift.

It was assumed that a poor increase of β_t during NBI is associated with orbital losses of fast particles. The mechanism of orbital losses is as follows. Beam particles are ionized in plasma and follow the trajectories which cross the plasma boundary, where the particles undergo losses in wall-plasma region. The spherical tokamak Globus-M is characterized by low magnetic field. Therefore the beam particles can significantly deviate from magnetic field surfaces where they were ionized. As the result the number of lost particles can be high. To estimate the level of these losses the beam particle trajectory simulations in magnetic field, reconstructed by the EFIT code [3], were performed. The spatial regions of orbital losses were determined (Fig. 5). As one can see, the increase of particle energy leads to expansion of regions of orbital losses. This could be the reason why the increase of NBI power due to rise of beam energy does not result in increase of plasma heating efficiency. Combining the results of particle trajectory simulations with the modeling of beam penetration into the plasma, the quantitative estimates of orbital losses were obtained. The value of orbital losses together with "shine-through losses" can reach the level of 30-40% for 30 keV hydrogen beam. It was demonstrated that inward plasma shift in radial direction reduces the orbital losses [8].

Summary

The using of new error field correction coils allowed to operate closer to Greenwald limit and to achieve β_t = 17 %. The ion source IPM-1 renovation enabled 1.2 MW and 1.0 MW beam power for hydrogen and deuterium beams correspondently for NB heating experiments. It was experimentally ascertained that NBI heating efficiency increases with the plasma column shift towards the central stack. Nevertheless, in NBI regime β_t was not essentially higher than in OH due to "orbital losses" of fast particles.

The work is supported by Ministry of education and science of Russian Federation and the RFBR grants: 08-02-13537-ofi_c, 08-02-13530-ofi_c, 08-02-00511-a, 07-02-13557-ofi_c, 09-02-01336-a.

References

[1]. Gusev V.K., et al. Nuclear Fusion, 2006, v. 46, p. S584
[2]. Howell D.F., Hender T.C. and Cunningham G., Nuclear Fusion, 2007. v. 47, p. 1336
[3]. Lao L.L., John H.S., Stambaugh R.D., et al, Nuclear Fusion. 1985, v. 25, p. 1611
[4]. Gusev V.K., et al. Technical Physics, 2006, v. 76, #8, p. 25.
[5]. Gusev V. K., et al., Technical Physics, 2007, v. 52, p. 1127.
[6]. V.K. Gusev, et al., Proc. of 13th Int. Conf. on Fusion Reactor Materials, 2007, Nice, France, P2.055.
[7]. Minaev V.B. et al., Proc. of 35th EPS Plasma Phys. Conf., 2008, Hersonissos, Crete, Greece, 2008, P1.110.
[8]. Chernyshev F.V., et al. Proc. of 35th EPS Plasma Phys. Conf., 2008, Hersonissos, Crete, Greece, 2008, P-2.097.

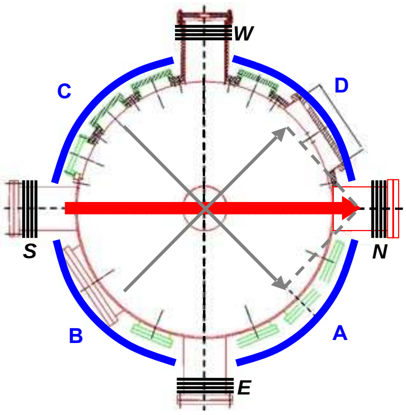

Fig. 1. Globus-M top view with resulting magnetic field (→) produced by two pairs of error field correction coils (A,C) & (B,D).

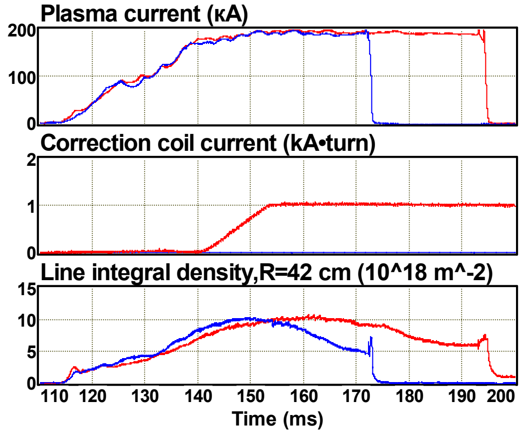

Fig. 2. OH shots with (#22632) and without (#22633) error field correction coils.

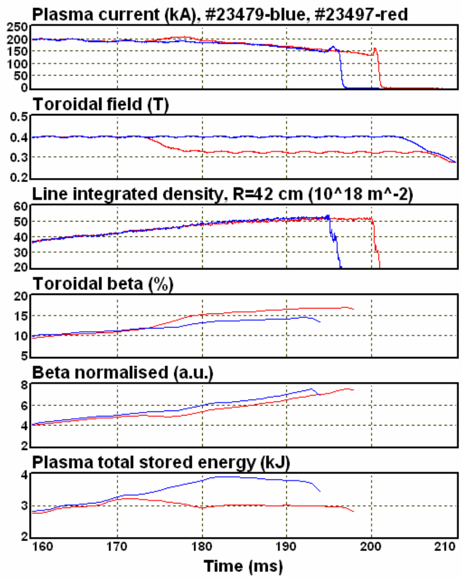

Fig. 3. High density OH shots with (#23497) and without (#23479) toroidal field ramp down.

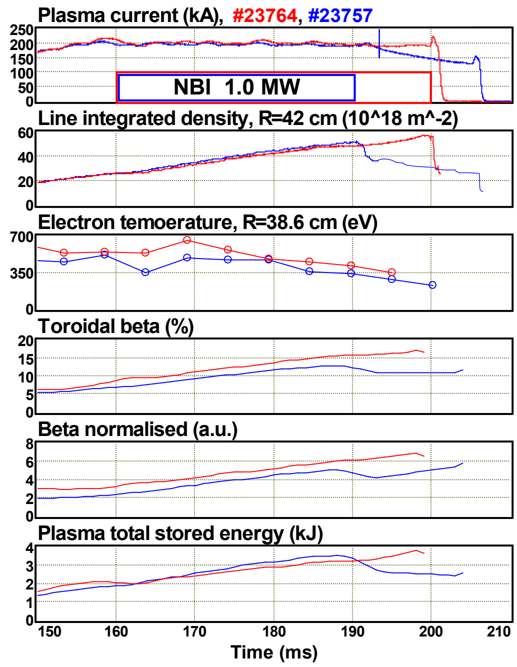

Fig. 4. High density NBI shots:

ΔR=3 cm (#23757), ΔR=5 cm (#23764).

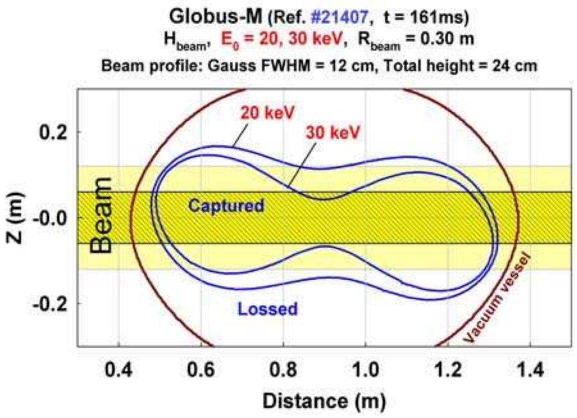

Fig. 5. Simulated regions of orbital losses of beam particles, mapped on the vertical cross section of Globus-M along the NBI direction.