THE DEVELOPMENT OF NEGATIVE ION BEAM PLASMA NEUTRALISER

FOR ITER NBI

V. A. Zhil'tsov, E. Yu. Klimenko, P. M. Kosarev, V. M. Kulygin,
V. V. Platonov, N.N.Semashko, A. A. Skovoroda, V. P. Ukhov
RRC Kurchatov Institute, Moscow, Russia

A. A. Mehed’kin
MRTI, Moscow, Russia

Abstract

The plasma neutralizer (PN) could be an attractive upgrade for the Neutral Beam Injection (NBI) system of the International Thermonuclear Experimental Reactor (ITER). A multicusp magnetic trap with microwave discharge plasma generation was proposed as a scheme for PN.The experimental investigation of the scheme is undertaken in Kurchatov Institute.

1. INTRODUCTION

Injectors of deuterium atom beams are developing now for ITER plasma heating and current drive are based on the idea of negative ion acceleration and further neutralization [1]. The maximal neutral fraction from the passage of a D^- beam through a gas, as proposed for a gas neutralizer of reference ITER NBI concept , is 60%. The replacement of the gas neutralizer by a plasma one must increase the maximum neutral yield to 80%.

As the plasma neutralizer must be able to replace the gas neutralizer in the ITER NBI of the reference concept its length, l , is defined and equal to 3 meters. So the necessary plasma density in neutralizer should be n_e~7 10^{12}cm^{-3}. The basic requirements to PN for the single ITER NBL module are specified in Table I.

l / V	3m / >10m^3
n_e / T_e	7 10^{12}cm^{-3} / <10eV
confinement	> 1 ms
dP/dV	~ 0.2 W/cm^3
ionization	> 0.3
divergence	< 5 mrad

The multicusp 3D magnetic wall configuration seems to be the best choice for PN plasma confinement system [2]. This system can provide the necessary plasma confinement and an acceptable beam ions deviation effect .

The plasma have to be produced in steady state mode of operation by the electrodeless microwave discharge at a low gas pressure and mainly collisionless character of microwave energy absorption.

The ECR could provide the most effective energy transfer to electrons and support their ionization ability for discharge plasma production. The value of the cut-off density is a major factor which determines the possibility to use the ECR mechanism in the discharge: at a more dense plasma microwaves cannot propagate through PN. This fact defines the necessity of use in ITER the microwaves with high frequencies, 20-30 GHz, i.e. the gyrotrons. Three types of the microwave discharge in multipole trap can be realized. The **type 1** is connected with an opportunity of bulk heating of electrons due to collisions with microwaves at multipass (1-2 wall reflections) propagation. For these purposes gyrotrons are planned to use. The **type 2** uses ECR for electron heating at plasma density close to the critical one. The ECR area is located close to gas boxes, therefore, microwave power is favorable for entering directly into these boxes. The **type 3** of discharge arrangement uses the excitation of circular *surface plasma wavequides* in conditions, when plasma density is higher then the cut-off density .Thus large interest represents the research of an opportunity of use of the klystron type generators with lower frequency, 7 GHz. The physics of such discharges in multipole traps isn't investigated rather well.

Another problem is to obtain a plasma with high ionization degree at low T_e. It is important also to reduce a gas flow from PN, this can additionally increase the advantages of PN. The magnetic system geometry allows to use the following opportunities: (a) gas near wall screening; (b) small gas pressure in the PN chamber at large pressure in gas boxes. So the main idea is to arrange the process of ionization in near wall region with plasma expansion to the center of PN.

2. EXPERIMENTAL INVESTIGATIONS

The experimental investigation of the questions described is undertaken in Kurchatov Institute. The first experiments were fulfilled at a little (70l of plasma volume) installation PNX-1. Then that was slightly modified into PNX-2. **PNX -1 experiment:** The experiment on PN-1 device has shown, that by stationary work in *70l* chamber the plasma density $5\ 10^{11} cm^{-3} = 7 n_{cut\text{-}off}$ was produced at low absorbed power density $0.02 W/cm^3$. Thus at $T_e = 4\text{-}10 eV$ the confinement time $t \sim 1\ ms$ was obtained at the plasma ionization degree *0.1*. The original surface type discharge was realized, when the microwaves were exited in *plasma wavequides,* formed by plasma surface and metallic chamber wall. The plasma was heated on periphery in conditions of upper hybrid plasma resonance. The gas ionization takes place on periphery. **PNX-2 experiment:** In this experiment on PNX-1 device the additional 7 GHz klystron generator was used. The frequency of this generator was greater than cut-off frequency. Thus we have investigated the additional volumetric heating. The additional absorbed power 0.5 kW leads to 30% density increase. Thus the scaling $n_e \sim P_{abs}$ is valid. We use the power modulation of 7 GHz klystron generator to measure the plasma life time in conditions, when plasma in multipole trap is produced in steady state mode by 2.45 GHz magnetron. **PNX-U experiment:** Plasma is created in a volume of 500 l. Microwave power of 35 - 50 kW (7 GHz klystron) was injected. The results was achieved at a moment are presented in the next paragraph ; the experiments are under continuation.

The next step in this experimental activity ought to be the **PNX-SU** which is now under designing for joint testing at JAERI beam test stand. This is planned close to parameters are demanded for **PN-ITER**. The general table for the series of the devices is given below.

Device	Status	$n_e l$, $10^{15} cm^{-3}$	V, m^3	P_{mw}, kW	f, GHz	B_s, T	ionization	Type of mag.system
PN-1	exp.95-96	0.03	0.07	1.5	2.45 magnetr	0.18	0.1	Perm.Mag
PN-2	exp.07.96	0.04	0.07	1.5+0.5	2.5+7	0.18	0.1	Perm.Mag
PNX-U	design	0.14	0.5	50	7 klystron	0.5	0.2	Copper
PNX-U	exp.02.98	0.1	0.5	15	7	0.36	0.1	Copper
PNX-U	exp. 06.98	0.1-0.2	0.5	35-50	7	0.36	0.2	CopperCoils
PNX-SU	beam exp. proposal	1	1	150	7	1	0.3	SuperCond.+Copp.
PN-ITER	design	>2	>10	>500	>18 gyrotron	>1	>0.3	SuperCon

3.THE LAST TIME PNX-U RESULTS

The experiments were fulfilled with argon and hydrogen plasmas. The gases were puffed in to provide a pressure at a level of **10^{-5} Tor**. (A residual gas pressure was of **(7 - 8) x 10^{-7} Tor**).A microwave power was introduced with a tangential input.

Argon plasma experiment:

- a plasma density at a central region achieved **(7-8) x 10^{11} cm^{-3}** at injected microwave power about **35 kW**. (See Fig.1) This value is slightly more than the «cut off» density for 7 GHz **(6 x 10^{11} cm^{-3})** which was accepted as a design value.
- so the target thickness, nl, along the PNX-U axis achieved **2 x 10^{14} cm^{-2}** (l = 250 cm).
- gas burn-out symptoms were observed clearly.

Hydrogen plasma experiment:

- a plasma density at a central region achieved **(3-4) x 10^{11} cm^{-3}** at injected microwave power about **50 kW**.
- the target thickness, nl, along the PNX-U axis achieved **1 x 10^{14} cm^{-2}** .
- gas burn-out symptoms are not doubtless.

General comments:

- an electron temperature was of few eV in central region and increased up to **20 - 30 eV** at a plasma periphery (Fig.2). This provides an additional abipolar plasma confinement during microwave injection.
- a microwave power could be introduced without breakdowns was increased with gas pressure decreasing (Fig.3).
- any symptoms of microwave power absorption decreasing at plasma densities close to the cut off one were absent(at the tangential microwave input) And what is more the linear low of the dependence of plasma density on the injected microwave power was confirmed (Fig.1, 3).
- an optimal (from plasma density increasing point of view) value of magnetic field was discovered (Fig.4). Probably this is connected with the conditions of the microwave absorption.

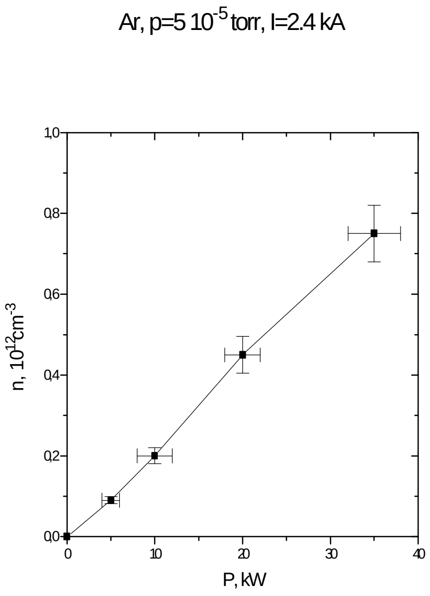

Fig.1 Plasma density as a function of injected microwave power.

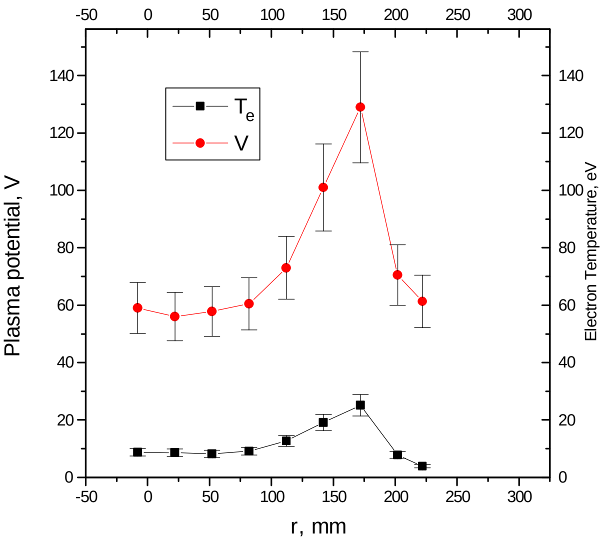

Fig.2 Plasma potential and electron temperature distribution across the plasma (the axis is at r=0)

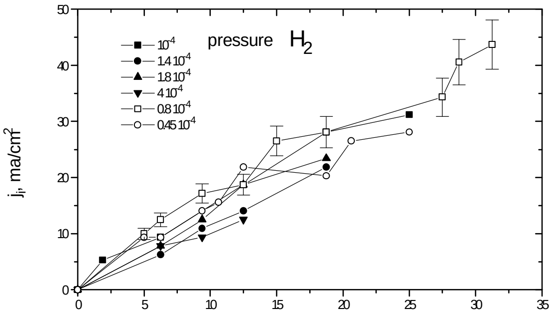

Fig. 3. Ion current to a probe versus power at the different initial gas pressure. The end of each curve is the end of a stable operation.

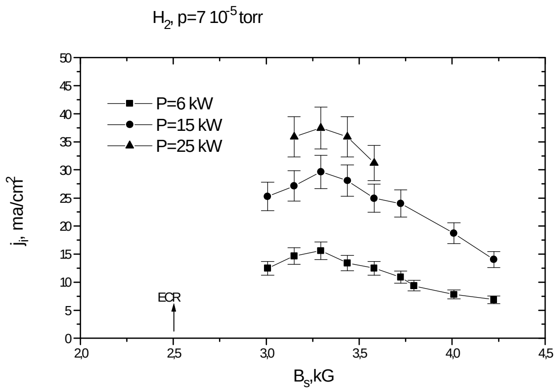

Fig.4. Ion current to a probe as a function of magnetic field at the different injected power.

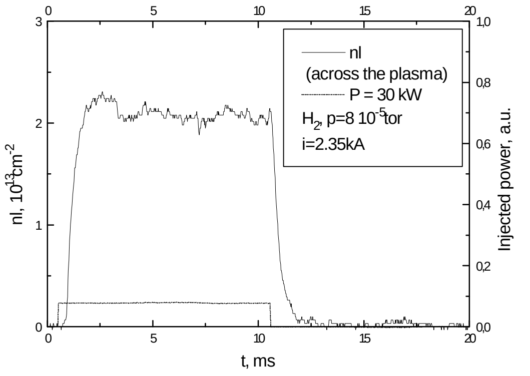

Fig.5. Interferometer (3.36 mm) measurement of transversal nl (l ≈ 40 cm).

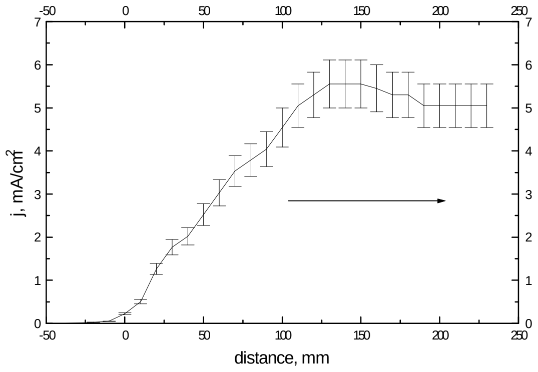

Fig.6. Ion current density distribution. The arrow - direction to the center of plasma

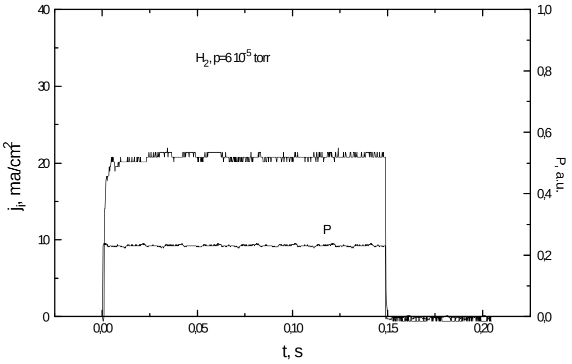

Fig.7. Ion current density on the central probe and microwave power pulse form.

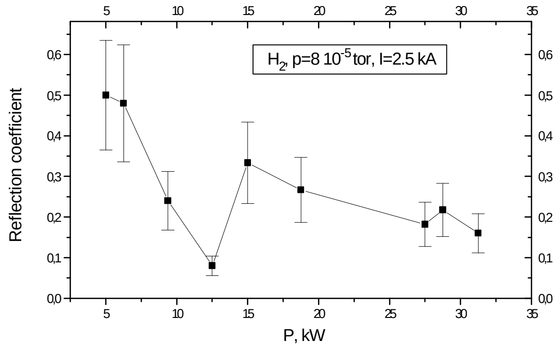

Fig.8. Microwave reflection coefficient as a function of generated power.

Acknowledgements. The authors would like to thank V.A.Abramov, V.F.Arsent’ev, R.Hemsworth., I.D.Karpushov, S.I.Novikov, A.A.Panasenkov, G.E.Shatalov for fruitful discusions and supporting of this work.

References

[1] ITER Design Description Document, N 53 DDD 15 97-11-30 W 0.2
[2]. A.A. Skovoroda ,Preprint IAE-5544 / 6, Moscow (1992)