DEVELOPMENT OF NEW NEUTRAL BEAM INJECTION SYSTEM ON GOL-3 FACILITY

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This paper presents prospect of now developed new 2 MW neutral beam injection system on GOL-3 facility. It discusses results of numerical simulation based on data from experiments on GOL-3. Vacuum environment in GOL-3 must be improved in order to reduce injected particles loss by charge exchange and fast ions cooling by peripheral plasma. Paper discusses some appropriate measures: long term gas pumping discharge, lithium suppression of gas recycling.

I. INTRODUCTION

Neutral beam injection is considered as the additional plasma heating method in the concept of GOL-3 reactor application [1]. First prototype of neutral beam injector (NBI) was mounted in GOL-3 in 2008 [2]. The main result of those experiments is principal opportunity to adjust restriction of gas and plasma density in beam-line with conditions of dense plasma forming in multi-mirror trap. Neutral beam (NB) particles capture in GOL-3 plasma column was registered but further progress was retarded by low NBI power, absence of ports for diagnostics and beam environment equipment. New designed NBI system is intended to solve these problems.

II. NBI SYSTEM DESIGN AND PARAMETERS

The second generation NBI system for GOL-3 is now under development. It includes two NBI with total power up to 2 MW, particle energy 25 keV, which form neutrals beams focused at 180 cm. System overview is presented in fig.1. Two NBI are connected to the special designed section of GOL-3 vacuum chamber 1. Each NBI includes deuterium beam source with geometric focusing 2, large vacuum chamber 3 with gas charge exchange neutralizer 4, beam line 5. The beams are directed normally to the GOL-3 axis and by the angle 158° to each other. Near the axis of NBI lines present estimated 90% part of the beam. Central 50% of beam has at focus prospective diameter 5 cm. Particles, not captured in plasma column in the center of GOL-3 chamber 6 are mainly collected in beam dump 6. Modernize magnetic coils 7 provides neutral beam injection into the center of the serial magnetic cell with length 22 cm. Each NBI will be equipped with individual turbo-molecular vacuum pump 8. NBI system apparatus will maintain beam pulse duration 5 ms. New experimental chamber with multiple ports allows enriching local diagnostics. Charge exchange neutrals analyzer 9 will be the favorite one.

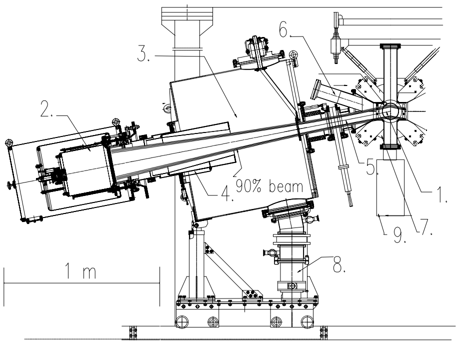

Fig1. NBI overview.

III. MODELING OF NBI OPERATION ON GOL-3

In first experimental campaign [2] with NBI on GOL-3 the main question was to push NBI device and to conduct neutral beam trough gas-filled beam line. Peripheral gas density was near the density of plasma core $2\text{-}5\cdot10^{14}$ cm^{-3}. Most of fast particles with Larmor radius ≈1 cm not only lost their energy by drag on cold coat plasma electrons, but they also ran away after charge exchange with neutral gas contained in partial ionized coat plasma. Second set of experiments will solve more delicate problem – we must improve vacuum condition in GOL-3 enough for radical reduction of charge exchange losses of energetic particles. The other goal is to diminish captured ions interaction with cold peripheral plasma coat. To assist this future activity numerical simulations were made.

We didn't use any universal and complex code such as [3,4] but prefer simple problem-oriented models. First of all we made 1d Monte Carlo simulation of ionization process during anticipated strait discharge and main plasma shot. Natural complex processes were replaced by the action of electron gas with tuned spatial and time alteration of temperature $T_e(r,t)$. Scenario begins in D_2 gas filled volume with low initial amount of electrons. It accounts dissociation, ionization, charge exchange and interaction with walls. There was found model function $T_e(r,t)$ consistent with experimental data of neutral beam attenuation in GOL-3 plasma column and observed H-α and D-α radiation. The result is shape of GOL-3 plasma column includes central 4cm diameter hot core were neutral gas dense reduce with depth with exponent 17 cm^{-1} and cold 1cm thick coat where gas reduction exponent is 1.4 cm^{-1}.

Second stage of modeling NBI on GOL-3 concerns injected fast atoms capture and store in plasma column. This task on GOL-3 has feature such as relatively large Larmor radius of fast ions and dense no uniform target plasma. The central part of plasma column was previously heated by intense electron beam but other part is cold. To use drift approximation in this conditions means to solve problem how particle interact with not uniform environment on its Larmor circle. For the purpose of simplify this task we propose target plasma image as cylinder with radius R_p filled with plasma of uniform density n_p. Core part of cylinder with radius R_c has electron and ion temperature T_e and T_i other part - T_{ec} and T_{ic}. Time averaged interaction of fast ion with such plasma is considered as precise geometric task. We account only two particle interaction resulting energy loss, angular scattering and Larmor circle shift. Plasmoid of injected ions is proposed to be a little addition to the target plasma – interaction between fast particles is neglected. Fast ions behavior is considered as dynamics of paraxial trajectories population. Trajectories reflex different bounce-oscillations and are indexed by the end magnetic field. The top trajectory is infinite – particle hit on this trajectory means its loss. The other channel of particles losses is their charge exchange with neutral gas. This opportunity is estimated by probability of ion neutralization without back charge exchange. With the purpose to reduce dimension of model we allow only trajectory, not particle, to have its individual energy and Larmor circle center. After particle jump this values are calculated as arithmetical means.

Fig.2 present typical axial distribution of injected energy as a result of simulation described above. Continues curve show diamagnetic signal in conducting chamber with radius 7 cm from loop calibrated by uniform plasma column. Target plasma has T_e=200 eV, T_i=100 eV, T_{ec}=T_{ic}=5eV, n_p=$2 \cdot 10^{14}$ cm^{-3}. Fig.3 shows behavior of maximum of such values at different gas conditions measured by n_{gas}/n_p where n_{gas} is peripheral gas density.

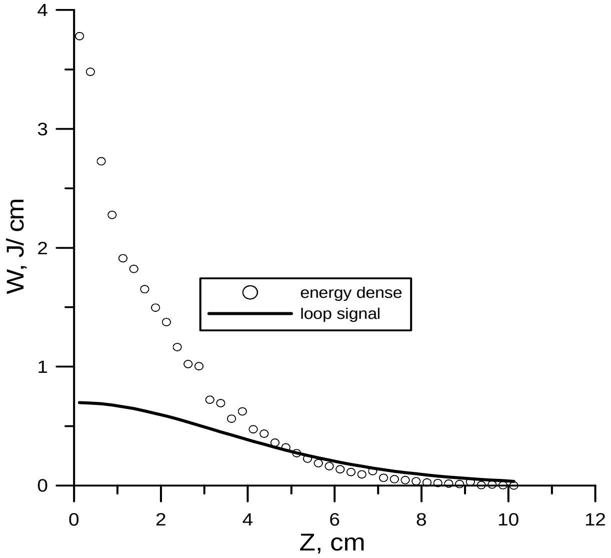

Fig2. Axial energy dense and measurable diamagnetic signal after 100 mks two beams injection.

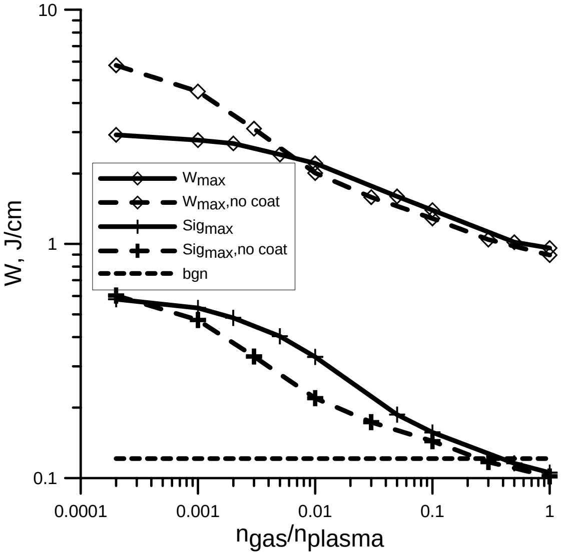

Fig.3. Maximum axial energy dense and diamagnetic signal at different gas condition after 100 us two beams injection.

Inside plasma with R_p=3 cm and R_c=2 cm gas dense reduce with exponent first 1.4 cm^{-1} and then 17 cm^{-1} (see above). Two NBI with energy 25 keV and current 2*30A are used. Dash line show what occur if you cut out cold plasma coat and leave only 2 cm radius hot plasma. Horizontal dotted line is energy dense of target plasma. If gas content is significant positive effect of isolation core plasma from gas by plasma coat is greater then negative effect of drag on its cold electrons. Other hand is that core radius 2 cm is too small for effective use of proposed NBI.

Neutron flux indicates straight fusion effect of NBI. So, we derived neutrons production rate by reaction D+D->H_e^3 +n from simulation results.

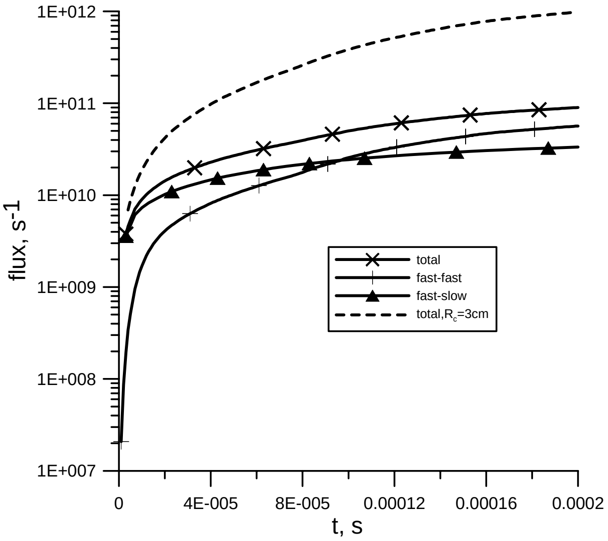

Fig.4. Neutron flux vs time. Continues curves show total neutron production and its parts from interaction between fast ions and from fast and slow ones supplied by target plasma. R_p=3cm, R_c=2cm. Dash curve – total flux if R_p=R_c=3cm. Gas is negligible.

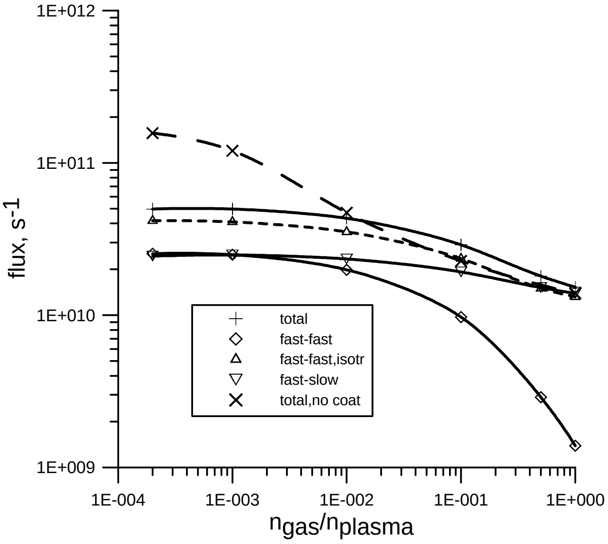

Fig.5. Total and partial neutron production rate at different gas conditions. R_p=3cm, R_c=2cm. 100us two beam injection. Dotted curve – neutrons from fast particles if to neglect angular anisotropy. Dash curve – total flux if R_p=R_c=2cm.

Fig.4 and fig.5 show neutron flux versus time and peripheral gas dense. Dash curve in fig.4 presents approach to ideal condition which uncovers the facilities of developed NBI. If plasma column entirely is hot, it has enough radius, and gas is absent, neutron flux exceeds 10^{12} s^{-1}. Observing neutron flux we see the same as in fig. 3 – positive effect of plasma core undress may be achieved only in clean vacuum condition. Dotted curve in fig. 5 shows results obtained in isotropic approximation. The others are the result of summing up contribution of pairs of captured ion trajectories. Differences between anisotropy account an ignoring result rise with gas dense. In dense gas environment only central ions survive. Their motion is angular correlated and impact energy is low.

IV. DISCUSSION AND CONCLUSIONS

Simulation shows that the main problem in NBI development on GOL-3 will be to improve vacuum environment. In narrow view this means achievement differential vacuum condition near NBI port. Preserving plasma creation by straight discharge in gas one can try sequence measures. Such are short time multi-point gas puffing, gas throttling and local chamber surface activation. The last gives low effect because of low surfaces. Gas flow simulation shows that total ideal result of these efforts is an order decrease in local gas pressure. It’s not enough. More perspective way is to improve plasma creating schema. One must try long duration precursory discharge which advances in pumping gas from vacuum chamber. It is possible to approach to this activity in particular experiment by explore local discharge in NBI segment of GOL-3 vacuum chamber. What one must do is to fight against recycling. The well known method to do it consists in lithium activation of chamber walls.

ACKNOWLEDGMENTS

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