Neutral Beam Injectors for the GOL-NB Facility

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Abstract. An overview of the newly built neutral beam injection system is presented. This system is intended for creating a population of warm ions in the central cell of the recently developed GOL-NB facility. The system includes two neutral beam injectors and appropriate power supply and control means. Beam parameters are: energy 25 keV, total power 1.5 MW, pulse duration 5 ms.

INTRODUCTION

Neutral beam injection was considered as the additional plasma heating method in the concept of GOL-3 reactor application [1]. The 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 energy losses, caused by charge exchange process, and low NBI power. The new NBI system was intended to solve the second problem. Modeling shows [3] that vacuum conditions in GOL-3 are far from ones needed for efficient observation of longitudinal dynamics of fast ions in multi-mirror trap. The GOL-NB facility [4] was developed in order to solve this problem. It has improved vacuum chamber with large central and terminal cells and two multi-mirror section with maximum aperture consistent with existing magnetic system. Two NBIs developed for GOL-3 are considered to use in GOL-NB as a main source of fast ions in the central cell of the facility.

NBI SYSTEM DESIGN AND PARAMETERS

NBI system was originally intended for use in the GOL-3 facility. Now it has become functioning device including two NBIs which create neutral beams with focus distance F = 165 cm, particle energy 25 keV and total power up to 1.5 MW. The concept of GOL-3 facility in the same time has undergone significant modernization accompanying its renaming in GOL-NB. Large central cell chamber of GOL-NB makes a beam with focus distance F=230 cm most preferred. Estimated increase of beam diameter caused by not optimum focus of existing NBI is not large. It rises from 124 mm to 134 mm at the axis of central cell. It was decided to use existing NBI in GOL-NB despite the problematic beam dump (d=205 mm near output flange). NBI system overview is presented in Fig.1. Left part of the figure shows configuration of NBI in GOL-NB central cell that is currently being developed. Right part of figure presents NBI configuration in the existing GOL-3 cell, which initially will be used for experimental tuning of the injectors and plasma diagnostics. Two NBIs are connected to the special designed section of vacuum chamber 1 or 1a. The design of each NBI is similar of one was described in [5]. It includes the deuterium beam source with geometric focusing 2 and the vacuum chamber 3 with gas charge-exchange neutralizer 7. The ion source use arc discharge generator of plasma 4, the expander with multipolar magnetic walls 5. Unlike [5] it use the triode beam forming system 6 with thick copper grids. Red lines near the axis of NBI in Fig.1 present estimated 90% part of the beam. Diameter of 50% beam at focus is 5 cm. Each NBI will be equipped with individual turbo-molecular vacuum pump 8. Power system of NBI provides beam pulse duration up to 5 ms.

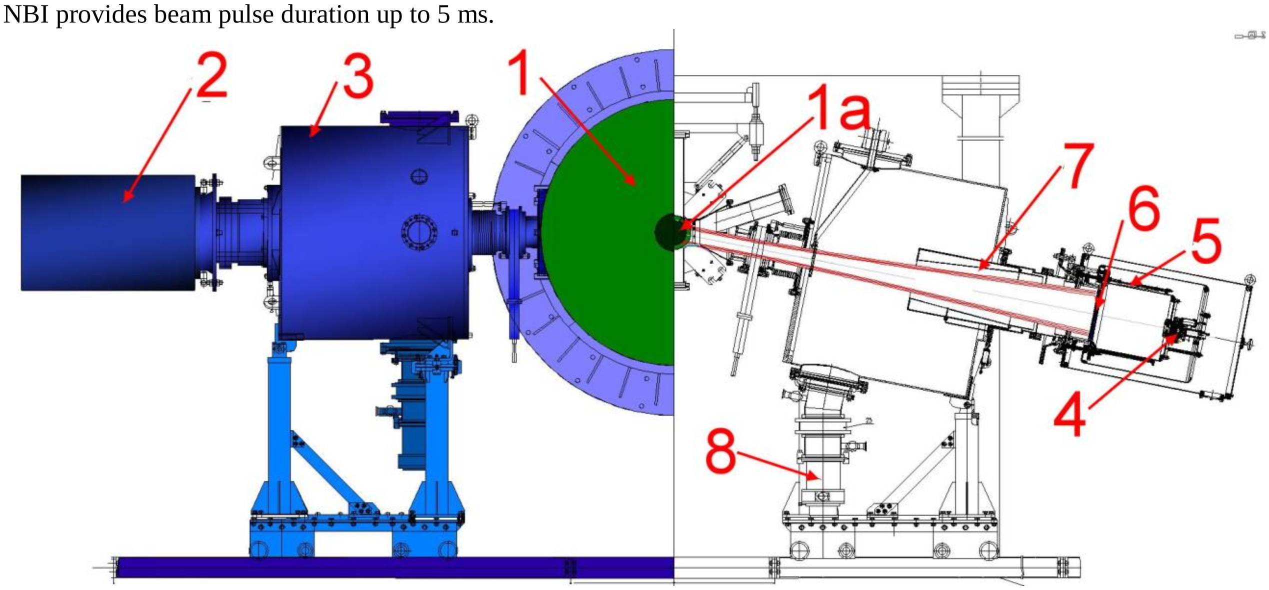

FIGURE 1. Neutral beam injection system overview: 1 – GOL-NB and 1a – GOL-3 central cell, 2 – beam source, 3 – NBI vessel, 4 – arc plasma source, 5 – expander, 6 – beam forming grid system, 7 – beam neutralizer, 8 – turbo-molecular pump

NBI COMPLEX OVERVIEW

The last stage of progress in the development of NBI on GOL-3 is the completion of schematic design and commissioning of the NBI power system. Its scheme is shown in Fig.2. Each injector is connected through a snubber 2 across the high-voltage cable 3 to the rack 5 of high potential equipment including 0-1 kA arc current generator, the power supply of solenoid of magneto-insulation of anode, the drivers of gas valves. High voltage on the cart of equipment is created by the cascade voltage source, mounted in two racks 4.

While the power supply systems of two injectors are separated, their control is integrated. Single dedicated server mounted in rack 7 controls NBIs. Amplitude parameters of the system are managed through embedded analog and digital input-output boards and buffer devices. Timing of power systems of both NBIs is realized with a series of light pulses, which are generated by special controller and transferred by optic fibers. Timing controller based on the STM32F4DISCOVERY board is connected to the server computer by USB interface. It provides single or serial injection events starting synchronously after optic fiber 14 signal or asynchronously.

NBI server is connected by fiber optic data cable to the information network. NBIs can be manually controlled from any computer with installed special application (named InjNB) and connection to the network. Manual control is optional. The system allows operator to change position right during NBI working cycle. Two copies of the single executable InjNB provide functions of resident server program and client program.

The scheme of power supply system is shown in Fig. 3. The source of accelerating voltage (AV) 1 is made of full-featured modular sources of 1 kV voltage. They have power and control circuits insulated on the full voltage of 25 kV. The desired amplitude and front of voltage pulse is provided by means of not-simultaneous switching of modules. AV control implements the function of system restart after the electrical breakdown with 2 ms delay. It comprises three parallel circuits of global current overload protection. This function complements individual module protection and provides failure-free running of accelerating voltage source.

The arc discharge power unit (2 in Fig.3) uses 4 parallel chopper circuits with phase shifted pulse-width modulation (PWM) to form pulse of stabilized current with up to 1 kA amplitude. Discharge ignition is performed by interrupting the current in the resistive load connected in parallel to the discharge gap.

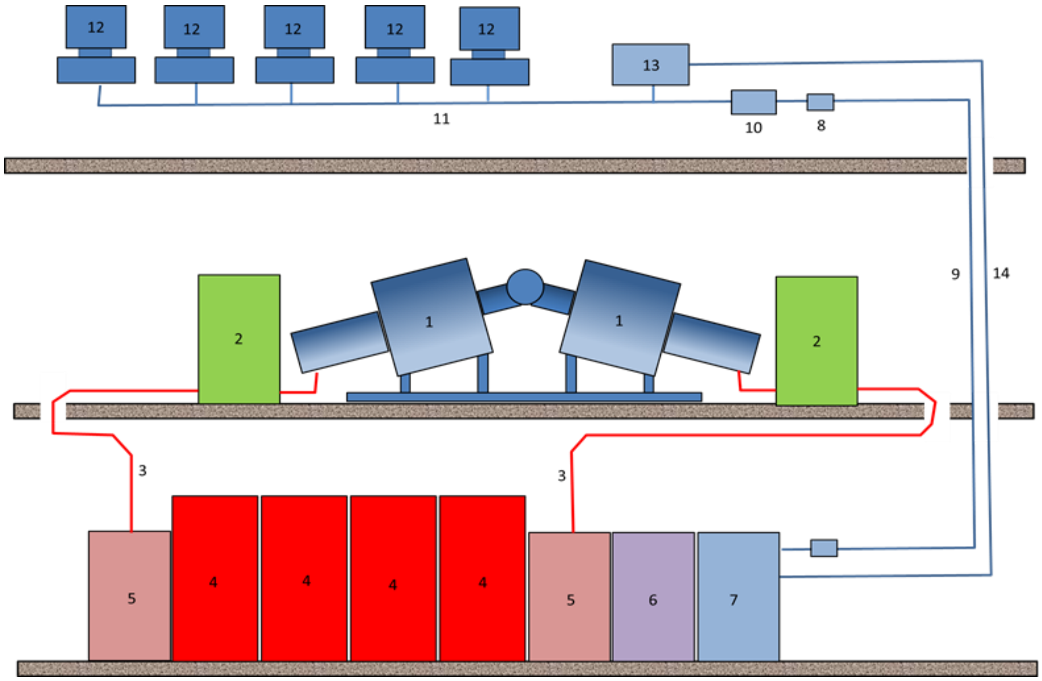

FIGURE 2. NBI system scheme: 1 – NBI, 2 – snubber, 3 – high voltage feeding cable, 4 – accelerating voltage source (25 kV, 50A, 5 ms), 5 – rack of high potential equipment, 6 – rack of low voltage equipment, 7 – rack of server and peripherals, 8 – media-converter, 9 – fiber optic data cable, 10 – router, 11 – information network, 12 – workstations, 13 – synchronization controller, 14 – synchronization fiber optic

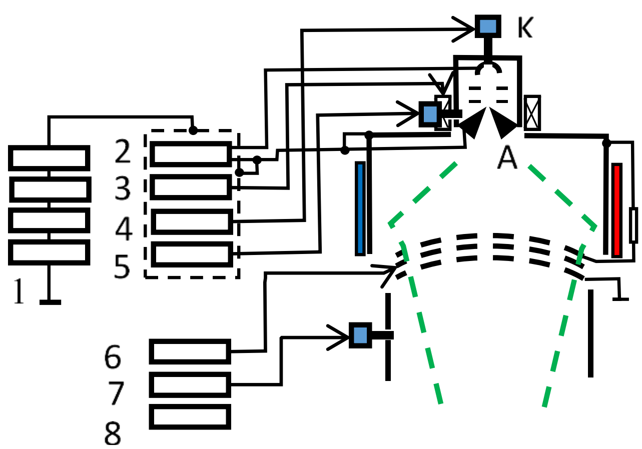

FIGURE 3. Power system scheme: 1 – source of accelerating voltage, 2 – arc discharge power source, 3 – anode magnetic insulation solenoid feeding, 4 and 5 – cathode and anode gas valve drivers, 6 – the source of pulse voltage on electron blocking grid, 7 – neutralizer gas valve driver, 8 – power invertor

Conventional PWM source 3 supplies current of anode magnetic insulation solenoid. Special drivers 4, 5 control cathode and anode gas valves. Unit 6 supplies voltage on electron blocking grid. It forms voltage pulse of adjustable amplitude in the range of -1000 - 0 V.

Control NBI application provides simple graphical interface. All adjustable parameters of NBI are placed into single text table in any format. A part of this parameters marked by operator are demonstrated in the editor window. Operator can correct them or write any other existing parameter and computer processes his commands. Configuration tables at client and server side are synchronized in the cloud disk manner. Readable text with configuration parameters is written to data bank with measured results. It provides simple manual or automated access to experimental conditions.

FIRST RESULTS

Fig.4 presents NBI control signals in operational moment of injector training process. These are accelerating voltage, current in accelerating gap, current of arc discharge and current from the electrons blocking grid. At time t <2000 μs arc power source (2, Fig.3) generate stabilize current in parallel to the discharge gap resistive load. At t = 2000 μs load is switched off and current is thrown to the arc. This action is preceded with the opening of cathode and anode gas valves. During the time interval 2000-4000 μs arc is burning and plasma jet formed by the arc source fills expander volume. After the discharge process has reached a steady state, arc current is reduced for a short time, voltages that accelerate ions and block electrons are applied to appropriate grids and ion beam begins. The results are presented for beam energy 24 keV, beam current 30A, beam duration 3 ms.

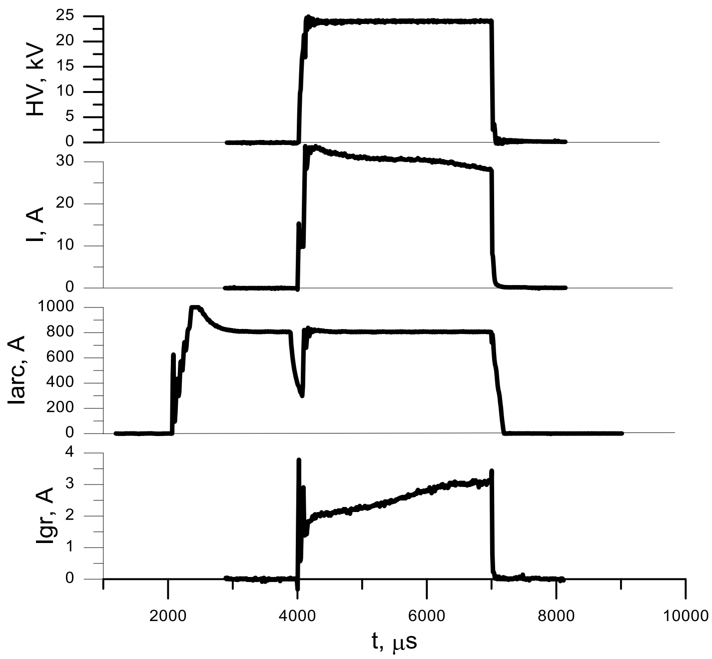

FIGURE 4. NBI control signals: HV – accelerating voltage, I – beam current, Iarc – arc discharge current, Igr – current from the grid blocking electrons

ACKNOWLEDGMENT

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