Advances in Development of GOL-NB Program

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I. INTRODUCTION

The progress in the development of the GOL-NB multiple-mirror trap is discussed. This device will be created in BINP in several years as a deep conversion of the existing GOL-3 facility. The main physical task of GOL-NB will be the direct performance demonstration of multiple-mirror magnetic sections attached to a central confinement zone [1].

In a multiple-mirror confinement system [2], plasma expansion along a corrugated magnetic field is slowed down due to an effective friction force between populations of locally-trapped and transiting particles. Under optimum conditions (i.e. at the free path length of ions λ_i is close to the corrugation period l), the particle confinement time τ scales as the square of the device length L: $\tau \approx R^2(L^2/\lambda_i v_{Ti})$, where v_{Ti} is the ion thermal speed and $R = B_{max}/B_{min}$ is the mirror ratio.

The multiple-mirror approach to fusion was experimentally studied in Novosibirsk in the experiments with sub-fusion plasma in the GOL-3 facility [3]. The plasma was heated by a high-power electron beam; it was highly turbulent therefore. For more than four decades since the introduction of the multiple-mirror idea, GOL-3 was the only experiment that provided data on hot plasma confinement. GOL-3 experiments have demonstrated a better than expected confinement at sub-fusion plasma parameters. However, the use of the high-power electron beam for plasma heating challenges scalability of the system to truly reactor-grade steady-state parameters, though visions of such systems exist [4].

Currently, fusion prospects of multiple-mirrors are related to their use as special end sections attached to a main confinement system in order to reduce axial particle and energy losses. In this paper, we discuss current status and future plans of GOL-NB project.

II. GOL-NB PHYSICS

Current mainstream in open magnetic systems for plasma confinement is implemented in the project of the next-generation GDMT device [5] that integrates features from both the gasdynamic (GDT) and multiple-mirror traps. NBI-heated two-component plasma will be confined in GDMT in a GDT-like central magnetic section. Two multiple-mirror end sections will slow down the axial plasma flow. The fusion efficiency depends on electron temperature that is maintained by the balance between the drag for the fast ions and power loss through the mirrors. The latter can be reduced by multiple-mirrors thus improving the confinement.

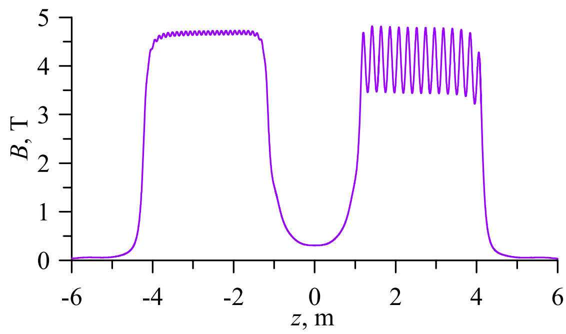

Fig. 1. The magnetic field profile at the axis. The right solenoid is shown in the standard multiple-mirror mode, the left one is with the uniform field.

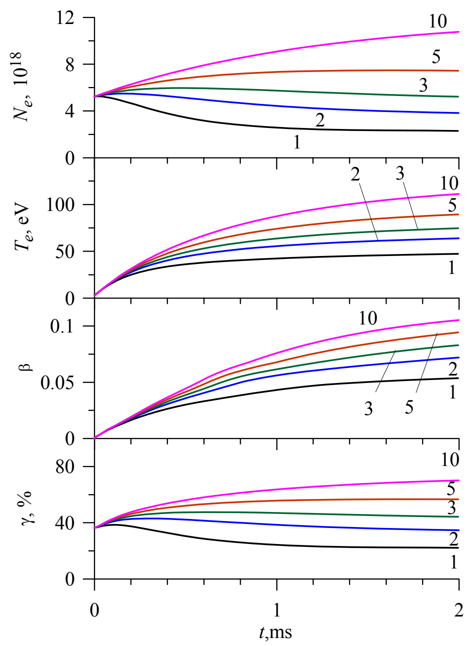

Fig. 2. Dynamics of plasma parameters at different suppression of plasma flow by multiple-mirror field (indicated by numbers near curves, unity corresponds to no confinement improvement). Top to bottom: total number of electrons in the trap, electron temperature, relative pressure and beam capture efficiency.

GOL-NB is designed as a fast-track low-cost prototype that will share the main GDMT physics at lower plasma parameters. Its magnetic configuration is shown in Fig. 1. GDT-type central trap with the mirror ratio $R = 15$ for $B(z{=}0) = 0.3$ T will confine plasma heated by 1.5 MW, 25 keV NBI system. Two 3-meter-long solenoids can produce either a uniform magnetic field of 4.5 T thus creating "long mirrors" or a multiple-mirror field with 14 mirror cells with $l = 22$ cm, $B_{\max} = 4.5$ T, $B_{\min} = 3.4$ T, and $R = 1.4$.

The main operation point was chosen from the condition $\lambda_i \approx l$. This corresponds to the density $n \approx 3\times10^{19}$ m^{-3} from initial estimates with a simple energy balance model [1]. Recently, more detailed simulations [6] with the kinetic code DOL provided more detailed analysis of experimental scenarios. Figure 2 shows dynamics of main plasma parameters for the baseline scenario (start parameters were $n = 3\times10^{19}$ m^{-3}, $P = 1.5$ MW, $E = 25$ keV) at varied efficiency of multiple-mirrors. Simulations were revealed the importance of a plasma fueling system that for the case of Fig. 2 should provide a steady flux of cold plasma with the equivalent current of 1 kA.

In this project, we assume that methods of MHD stabilization used in GDT experiments [7] will also work in GOL-NB case. In the initial configuration, the stabilization will be provided by plasma biasing. Preliminary analysis of the baseline scenario reveals that this configuration will be stable in respect for the Alfvén ion cyclotron and the drift-cyclotron loss-cone instabilities.

III. GOL-NB HARDWARE AND RESEARCH PROGRAM

Layout of GOL-NB is shown in Fig. 3. The project was optimized under the existing funding constraints that led to some important compromises in its technical and physical parameters. The device will reuse some infrastructure and hardware from GOL-3. It will occupy a part of current GOL-3 experimental area. The central trap is designed for 0.6 T maximum field in the midplane. Multiple-mirror sections will reuse 56 magnetic coils from GOL-3 with a new vacuum chamber inside. A start plasma source will be mounted in the axial port on one of expander tanks. Recently a plasma stream from a prototype source was successfully transported through ~3 m distance in test experiments that imitate the conditions of GOL-NB multiple-mirror sections [8]. Power supply of the magnetic system will be provided with the existing GOL-3 capacitor bank that will require minor modifications. Two 0.75 MW 25 keV injectors [9] are now in the commissioning stage. Four pumping units are already assembled.

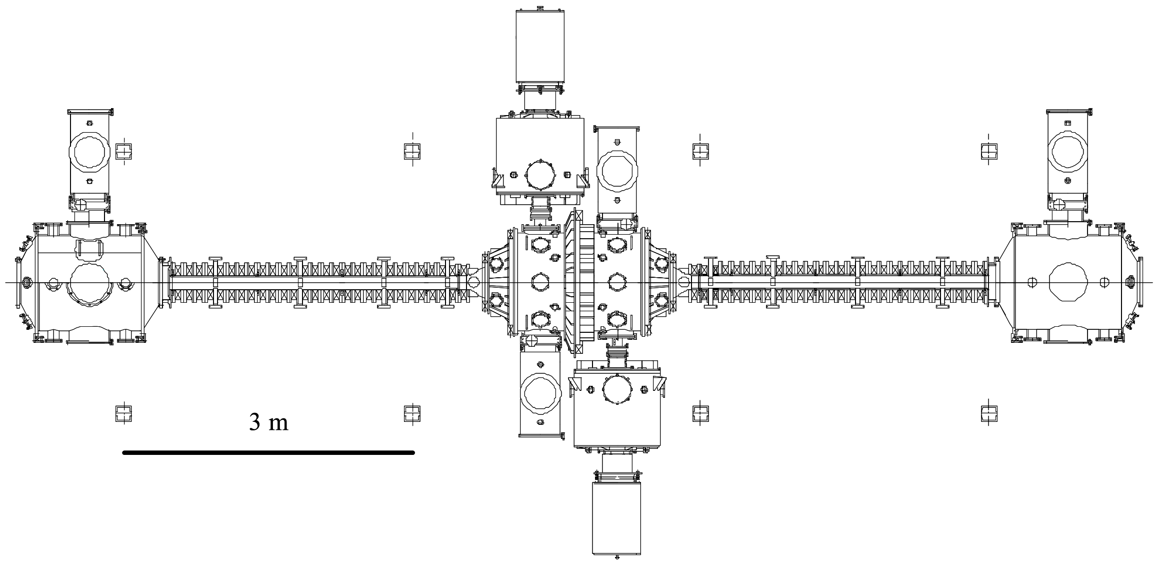

Fig. 3. Layout of GOL-NB after the proposed reconfiguration of GOL-3 (top view). The device consists of the central trap with two neutral beams, two multiple-mirror solenoids, two expander tanks (one with a plasma gun), and four pumping units. Spacing between structural columns is shown for scale.

Operation of GOL-NB in full configuration shown in Fig. 3 will be possible after completion of the central trap with its magnetic system. Before this, the initial configuration of GOL-NB will be assembled with a short dummy section of vacuum chamber mounted between two multiple-mirror sections. In this configuration, performance checks of the start plasma source as well as of other technical systems will be done. Later the full configuration will be assembled. The neutral beam injectors will be mounted at the central trap.

The baseline physical program in full configuration includes the following. Task 1: demonstrate a stable GDT-like confinement in the central trap. Task 2: demonstrate the confinement improvement in the multiple-mirror configuration. Task 3: extend the achievable parameter space to higher temperatures with control of the particle free path length. Task 4: improve the plasma parameters with other plasma heating methods.

VI. SUMMARY

New linear trap GOL-NB will be created in Budker Institute of Nuclear Physics in a timeframe of several years. This device will combine physics of two existing linear magnetic configurations, namely gas-dynamic in the central trap and multiple-mirror in attached high-field solenoids. Plasma of 3×10^{19} m^{-3} density will be heated by 1.5 MW neutral beams. The central section will work as a miniaturized GDT trap with the same well-established physics. Depending on the magnetic configuration of the adjacent multiple-mirror solenoids, the baseline plasma losses through mirrors will change thus changing the confinement. GOL-NB project is designed as a low-cost supporting experiment that should improve the knowledge base required for the fusion-grade next step GDMT project.

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