

The SHIP Experiment at GDT: First Experimental Activities and Results of Recent Simulations

A.V. Anikeev, P.A. Bagryansky, S. Collatz*, A.A. Ivanov, K. Noack*

Budker Institute of Nuclear Physics, Prospect Lavrent'eva 11, 630090 Novosibirsk, Russia

** Forschungszentrum Rossendorf, Postfach 51 01 19, 01314 Dresden, Germany*

1. Introduction.

At present, the GDT facility of the Budker Institute Novosibirsk, which is an axially symmetric magnetic mirror device of gas dynamic trap type, is being upgraded. The first stage of the upgrade is the Synthesised Hot Ion Plasmoid (SHIP) experiment [1]. It aims, on the one hand, at the investigation of plasmas which are expected to appear in the region of high neutron production in a GDT based fusion neutron source proposed by the Budker Institute and, on the other hand, at the investigation of plasmas the parameters of which have never been achieved before in magnetic mirrors.

The concept of the Synthesised Hot Ion Plasmoid (SHIP) experiment at the GDT facility of the Budker Institute Novosibirsk was explained at the 29th EPS Conference [1]. In the last year several numerical simulations were made by means of the Integrated Transport Code System (ITCS) [2] to determine the best experimental scenario for getting high plasma parameters.

The experiments will be performed in a small mirror section that is installed at the end of one side of the GDT (see Fig. 1). The magnetic field on axis will be in the range of 1-7 Tesla and the mirror ratio will amount 1.2-1.4. The magnetic field strength will be varied by extending/shortening the distance between the coils. The mirror is filled with background plasma streaming in from the central cell. This plasma component with density of $5 \times 10^{19} \text{ m}^{-3}$ is maxwellised and has an electron temperature about 100 eV. Two neutral beam injectors perpendicularly inject a total current up to 120 equ. Amperes of hydrogen atoms with an energy of 25 keV as pulse with a duration of about 1 ms. Ionisation of the beams generates the high-energetic ion component with the estimated parameters of which have never been achieved before in magnetic mirrors: $n_{fi} \geq 10^{14} \text{ cm}^{-3}$, mean energy about 17 keV and plasma $\beta \geq 0.6$.

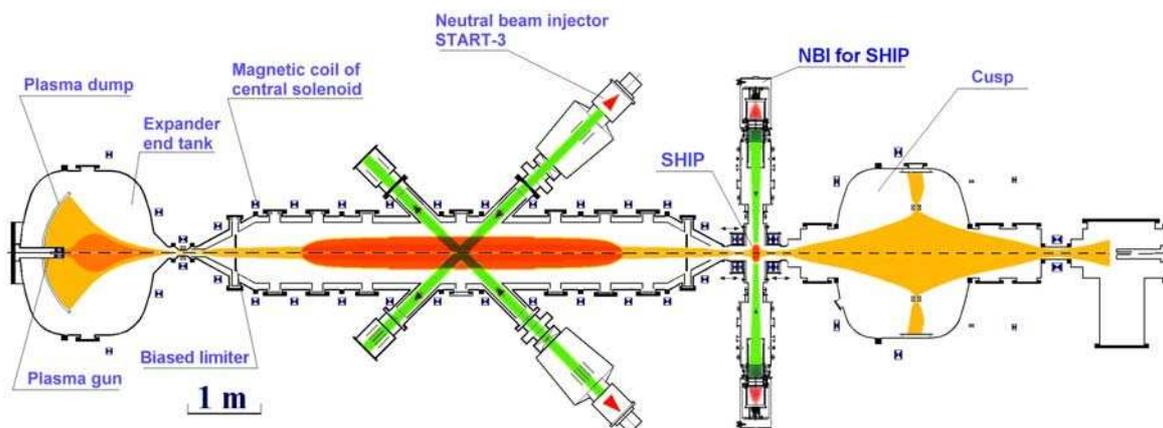


Fig. 1: GDT facility with the SHIP experiment.

2. Numerical Simulations of the SHIP.

2.1 Calculation of the neutral gas distribution in SHIP.

For the calculation of the density distribution of fast (high-energetic) ions in a gas dynamic trap it is necessary to take into account their interaction with the neutral gas inside the vacuum chamber. The computer code NEUSI [3] calculates the distribution of the neutral gas components in large devices like the GDT. It makes use of the approximative assumption that the radius of the chamber is small in comparison with its length. This approximation is not justified for the SHIP device. Therefore, the new neutral gas code NEUFIT has been developed which avoids this approximation.

In SHIP the following sources of neutral gas components appear. The neutral hydrogen atoms injected as neutral beams interact with the ions of the thermal plasma. The charge exchange process produces the fast ions and slow neutral hydrogen atoms which represent the primary gas source. During their life histories the fast ions interact with neutral gas components and by charge exchanging with slow neutral atoms they will become fast neutral atoms. Also, the thermal plasma interacts with neutral gas components and produces fast and slow neutrals.

A part of the neutral atoms reaches the wall of the vacuum chamber. Some of them will be reflected with reduced energy. NEUFIT approximately assumes that all reflected atoms are slow ones. The other part accumulates on the wall surface as hydrogen molecules and returns with low energy into the chamber volume. In this way, we have three components of neutral gas in the facility: slow hydrogen atoms, fast hydrogen atoms and slow hydrogen molecules. NEUFIT calculates the density distributions of these three gas components over the time of an experimental shot with the help of a computation procedure for given time courses of fast and slow ion distributions.

In the first step, the density distribution of the slow hydrogen atoms emitted from the primary source without further charge exchange and the source distributions of the one time charge-exchanged or one time wall-reflected atoms are computed. In the second step (second generation), the density distribution of the one time charge-exchanged or first time wall-reflected atoms and the sources of the two times charge-exchanged or two times wall-reflected atoms are calculated. This converging generation cycle continues up to a sufficient degree. At the end, all calculated particle density portions are summarized. This is done for all time steps considered during a pulse. The influence of the neutral gas density distribution on the distribution of the fast ions can be taken into account by an iteration between gas and fast ion calculations.

In this way, NEUFIT calculates the densities of all generations of the three gas components for a certain group division of the energy scale. Generally, NEUFIT assumes that the problem is an azimuthally symmetric one. This is not the case for the primary gas source produced by the neutral beam injection. But, the fast ions show a strong azimuthal drift which reduces the effect of this approximative assumption.

In the Fig.2 the calculated density distributions of the neutral gas components in the midplane of the SHIP device are shown.

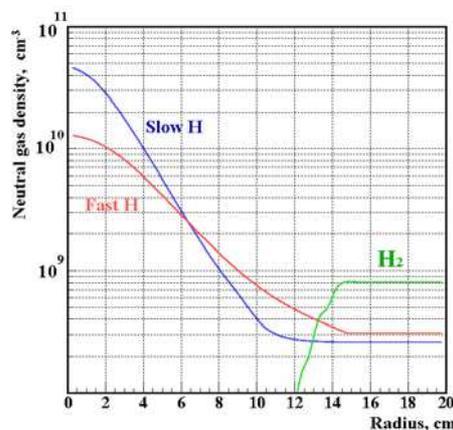


Fig.2 Neutral gas density distributions in the SHIP midplane.

2.2 Calculation of high β effects in SHIP.

The Monte Carlo code MCFIT [2] simulates the linear transport of neutral beam produced energetic ions in given magnetic field, target plasma and neutral gas. The code describes the relevant transport processes with a minimum of approximations. In the SHIP experiment and also in the GDT-Upgrade the high fast ion energy content results in a high value of β which reaches almost sixty per cent. The high- β effect causes a deformation of the vacuum magnetic field and, consequently, of the fast ion distribution too. To consider this non-linear effect the time and spatial distribution of azimuthal fast ion currents, calculated by MCFIT, were used to compute the correction of the magnetic field according to the Biot-Savart law. Then, this β -corrected, time dependent magnetic field was used by MCFIT in an iteration procedure.

For example, the comparison of high- β -corrected and vacuum magnetic fields in the SHIP is presented on Fig.3. The β -corruption of fast ion density profile is shown on Fig.4.

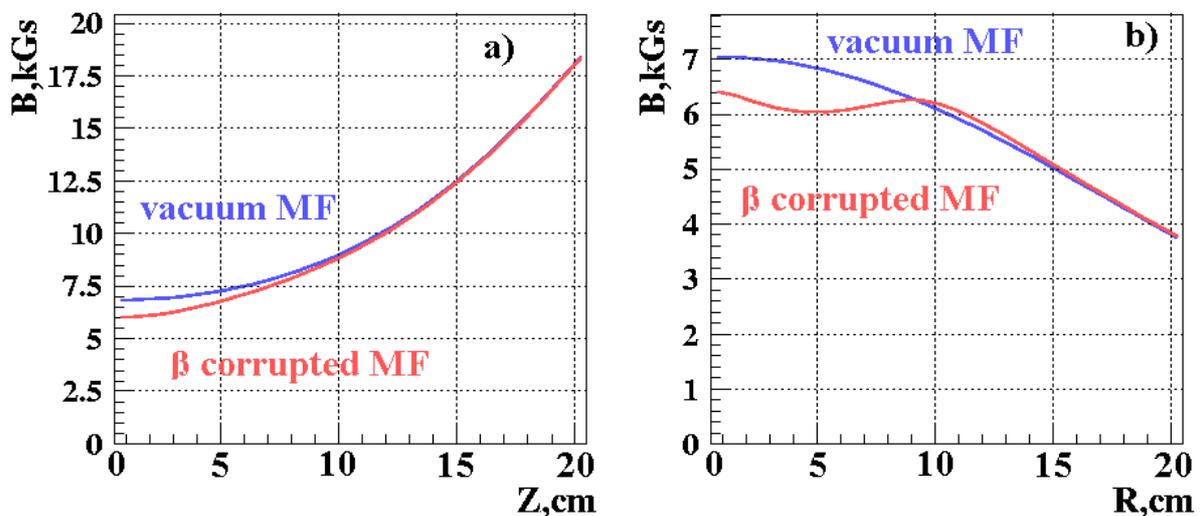


Fig.3 The β -corrupted magnetic field: a) on-axis profile; b) radial profile. The blue curves are correspond to vacuum magnetic field. $Z=0$ is the midplane of the SHIP device.

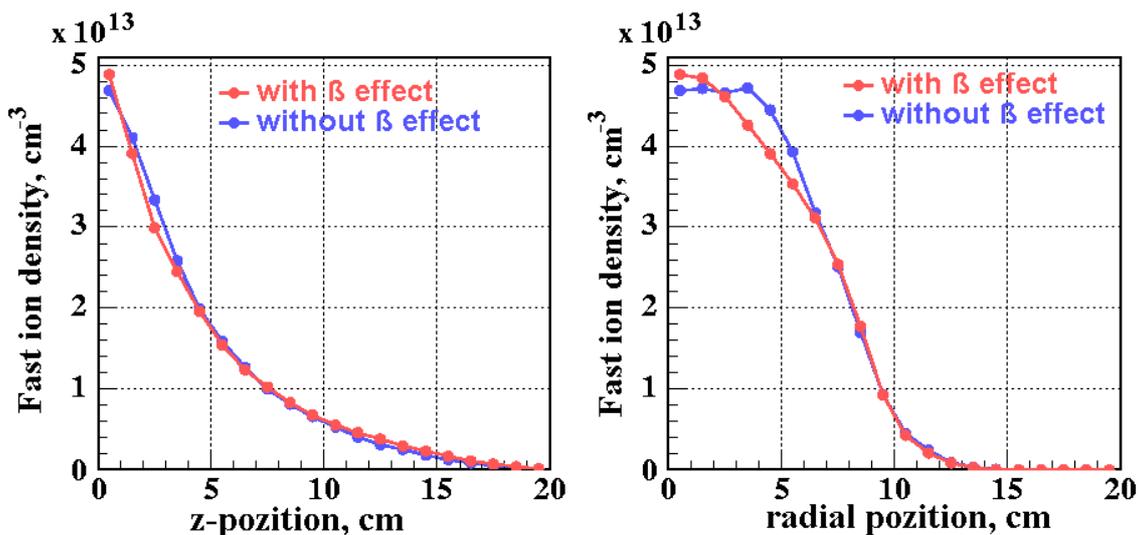


Fig.4. Influence of the high- β on fast ion density profile in the SHIP.

3. Results.

Up to now the four regimes with different input parameters were considered. The parameters of this four numerical SHIP-experiments are presented in the Table (blue – input, pink – output parameters).

Parameters	v.1	v.2	v.3	v.4
Mirror-to-mirror distance	43 cm (short)	43 cm (short)	58 cm (long)	58 cm (long)
Magnetic field SHIP midplane/mirrors	2.3 T / 5.2 T	2.3 T / 5.2 T	0.7 T / 2.5 T	0.7 T / 2.5 T
Target plasma:				
electron temperature	0.1 keV	0.1 keV	0.1 keV	0.1 keV
unperturbed density, n_0	$0.5 \times 10^{14} \text{ cm}^{-3}$	$0.5 \times 10^{14} \text{ cm}^{-3}$	$0.5 \times 10^{14} \text{ cm}^{-3}$	$0.5 \times 10^{14} \text{ cm}^{-3}$
warm ion density, n_w	$0.23 \times 10^{14} \text{ cm}^{-3}$	$0.18 \times 10^{14} \text{ cm}^{-3}$	$0.35 \times 10^{14} \text{ cm}^{-3}$	$0.3 \times 10^{14} \text{ cm}^{-3}$
electron density, n_e	$1.08 \times 10^{14} \text{ cm}^{-3}$	$1.38 \times 10^{14} \text{ cm}^{-3}$	$0.7 \times 10^{14} \text{ cm}^{-3}$	$0.8 \times 10^{14} \text{ cm}^{-3}$
NBI System:				
energy	20 keV	25 keV	20 keV	25 keV
total equivalent current	50 eq. A	120 eq. A	50 eq. A	80 eq. A
injected power	1 MW	3 MW	1 MW	2 MW
duration	1 (2) ms	2 ms	2 ms	2 ms
Fast ions				
maximal density	$0.85 \times 10^{14} \text{ cm}^{-3}$	$1.2 \times 10^{14} \text{ cm}^{-3}$	$0.35 \times 10^{14} \text{ cm}^{-3}$	$0.5 \times 10^{14} \text{ cm}^{-3}$
mean energy	10 keV	15 keV	11 keV	12 keV
total energy contents	43 J	132 J	70 J	120 J
Trapped power	230 kW	680 kW	360 kW	650 kW
Drag power	180 kW	480 kW	270 kW	520 kW
CX loss power	50 kW	200 kW	90 kW	106 kW
maximal local β	8 %	12 %	33 %	62 %

The interest was focused on the experimental scenarios with the maximal fast ion density (*Variant 2 in Table*) and maximal local β parameter (*Variant 4*) for numerical study of high- β effects in SHIP. Variant 1 and 3 correspond to first experimental step on SHIP device with low NBI power. The time dependences of the main SHIP parameters for the last variant (v.4) are shown on Fig.5. It turned out, that the fast ion population reached its steady states very quickly, already in about 1 ms.

4. Conclusion

- The new code NEUFIT was developed for SHIP gas simulation.
- The numerical experiment with high β was made by iterations on β -corrupted magnetic field. Maximal $\beta=0.62$ in magnetic field $B \sim 1$ Tesla.
- A simulation of high NB power regime gives the maximal fast ion density of $1.2 \times 10^{20} \text{ m}^{-3}$ with mean energy of 15 keV
- The SHIP experimental activity is started in Summer 2003.

References

- [1] A.V. Anikeev *et al.* In Proc. of the 29th EPS Conference, ECA Vol. 26B, P-4.098 (2002)
- [2] Anikeev A V *et al.* Trans. Fusion Technol. 39, 183 (2001)
- [3] S. Collatz, K.Noack Trans. Fusion Technol. 35, 375 (1999)

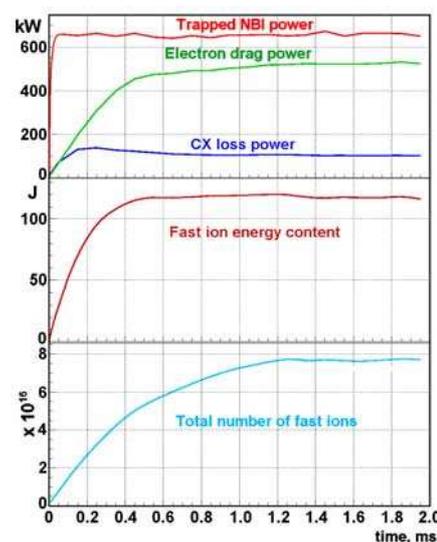


Fig.5 Dynamic of the SHIP parameters.