AMBAL-M STATUS

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ABSTRACT

Investigation of the hot initial plasma created in an axisymmetric end system of the ambipolar trap AMBAL-M has been completed. In the end mirror we obtained the MHD stable plasma with the electron temperature of 50 eV, ion temperature 200 eV, and density about 10^{13} cm^{-3}. In an MHD anchor - the semicusp a transverse profile of the plasma pressure favorable for the MHD stability was obtained. Pulsed injection of fast atoms with the current of 100 A demonstrated sufficient accumulation rate of the ion population trapped into the initial plasma. The first experiments with ICR-heating of the initial plasma were carried out.

Two atomic injectors of the end mirror were prepared for work. In these injectors four quasistationary proton beams were obtained with the energy of 25 keV and current of up to 50 A per beam. After their charge-exchange the atomic beams were passed through an MHD stabilizing shell and the target plasma.

Principal vacuum units of the 2-nd stage of the installation were tested and prepaired for assembly. One-half of the magnet-vacuum system of the AMBAL-M central solenoid was assembled and tested for vacuum.

I. INITIAL HOT PLASMA IN WESTERN END MIRRORS

The studies of hot initial plasma obtained in the end mirror system of AMBAL-M were practically accomplished [1] (schematic drawing of this system is shown in Fig.1). Electrostatic oscillation with a broad spectrum are developed in the obtained initial plasma, leading to stochastic ion heating up to temperature of 200 eV. It was found that the substantial achieved electron temperature about 50 eV is maintained basically by the longitudinal electron current flowing from the source. The power transfered from hot ions to electrons does not exceed 25% of total power for electron heating.

Studies of the plasma turbulence demonstrated that the most intensive is the turbulence caused by development of Kelvin-Helmholtz instability, in the frequency range from tens of kHz to several hundreds of kHz and azimuthal modes up to the tenth. It was found that in the high-frequency range of the spectrum of the electric field oscillations dominates a "white noise" (it was detected up to several MHz). It was shown that origination of this noise is related with the behavior of cathode spots in the arc plasma source [2].

Considerable attention was given to experimental investigations of magnetic fluctuations in the initial plasma. In particular, the measured value of the magnetic diffusion coefficient in the transportation region was about 10^4 cm^2/s, which is an order of magnitude less than the electrostatic diffusion coefficient. Temporal and spatial characteristics of the magnetic field fluctuations were also studied. Analysis of the spectra and radial profiles of the fluctuations of the magnetic field and plasma density showed that the magnetic field fluctuations are induced by modulation of the plasma density during development of Kelvin-Helmholtz instability. The azimuthal mode spectrum of the magnetic fluctuations was estimated [3].

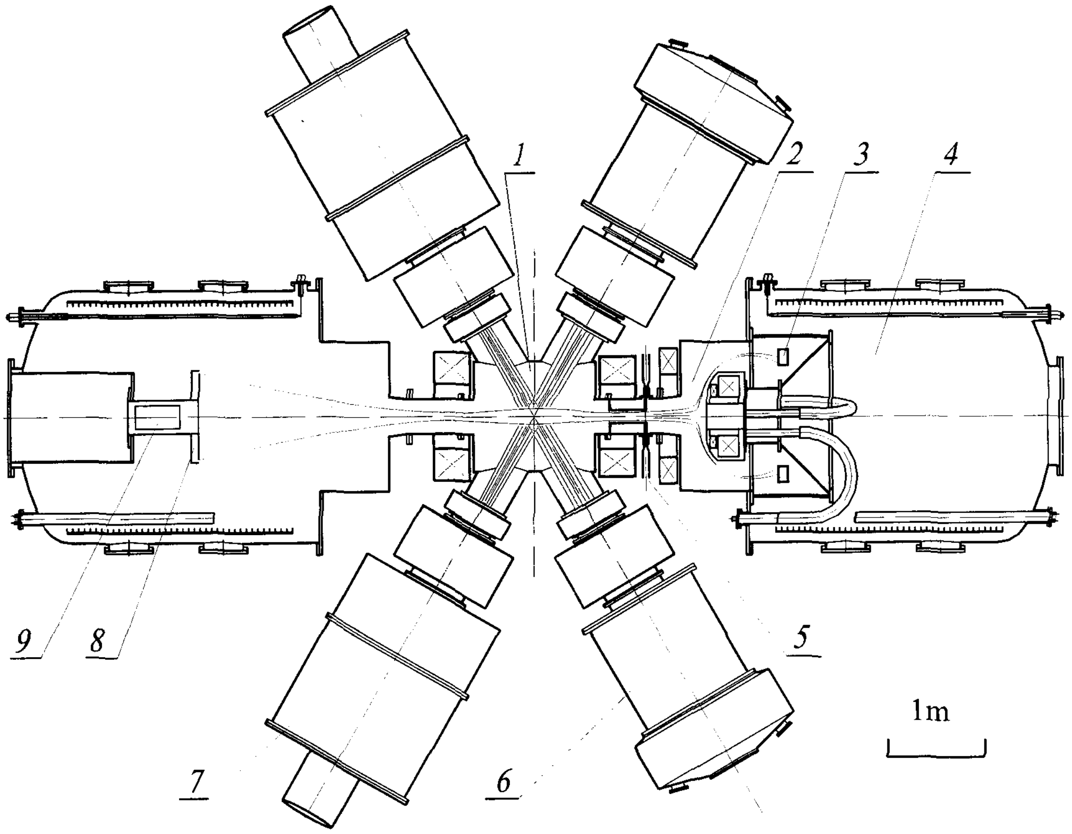

Fig. 1. End mirror system of AMBAL-M. 1-end mirror, 2-semicusp, 3-western plasma receiver, 4-end tank, 5-RF antenna, 6-beam adsorber, 7-atomic injector, 8-eastern plasma receiver, 9-plasma source.

The motion of the mass center of the longitudinal electron current flowing in the plasma was experimentally studied in the end mirror. It was revealed that the amplitude of radial displacements of the current mass center does not exceed 1 cm, and when the maximum current is achieved, quasicircular motion of the current mass center around the axis was observed [4].

MHD stability of the plasma in the end system was investigated [5]. The radial plasma pressure profile in the semicusp was measured using a diamagnetic probe (Fig.2).

There is a dip corresponding to the region where the ions lose their adiabaticity. Based on these measurements and parameters of the end mirror plasma determined previously, we compared contributions to the stability integral from the end mirror and from the semicusp with respect to global mode excitation. The stabilizing contribution of the semicusp was established to be 3-4 times larger than the destabilizing contribution of end mirror and thus the hot initial plasma of the end system has a sufficient stability safety factor.

The measurements of the plasma pressure profile in the semicusp showed that in the case the hydrogen input into it the energy content of the cusp plasma is increased by a factor of 1.7-1.8 without decrease of the electron temperature.

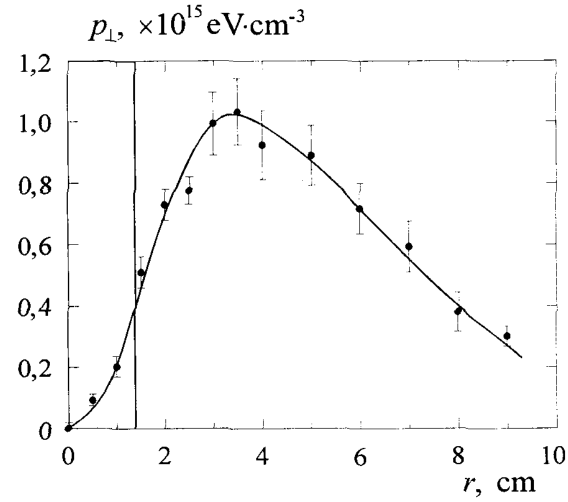

Fig. 2. Plasma pressure profile in the semicusp without ICR heating ($z = 168$ cm). The region of ion non-adiabaticity is dashed.

The experiments on ICR-heating of plasma were started [6]. The heating at a frequency of 11.7 MHz is performed by an antenna of "Nagoya-III" type installed in the transition region between the mirror and the semicusp with the voltage at the antenna up to 8 kV, power introduced into the plasma up to 200 kW and pulse duration up to 40 ms. In the end mirror there is observed an increase of the ion temperature by about 20% and some rise of the electron temperature up to 55 eV. ICR-heating leads to intensification of the transverse plasma diffusion. The diffusion coefficient is about 10^4 cm^2/s. ICRH does not result in any detectable distortion of the axial plasma symmetry.

II. NEUTRAL INJECTION SYSTEM

Early experiments with injection of two puls hydrogen atomic beams into the end mirror have been carried out at the following beam parameters: energy of atoms - 16 keV, summary equivalent current - 100 A, puls duration 200 μs. A linear growth of diamagnetic signal was seen. The characteristic time of plasma density decay was 1 ms. The accumulation rate of hot ions in the mirror was enough for transition to capture ions from atomic beam by accumulated hot plasma.

In present two neutral quasi-stationary injectors are completed (Fig.1). Each injector consists of two ion sources with recharge tube, mutual magnetic separator with ion absorber and vacuum pumps. The gas-shield vapor-magnesium supersonic stream generators are not installed into the injectors. The first specimen of this generator was prepared for the last test long ago, but it has not been tested.

Each of four ion sources was tested on the stand. The beams of deuterium ions with the following parameters: energy - 30 keV, current - 50 A and puls duration - up to 0.1 sec were obtained. After stand testing the ion sources were succeively set into the end mirror injectors. Three synchronous proton beams are working sufficiently reliable. The energy of protons was 25 keV, summary beam current was up to 140 A and puls duration was up to 80 ms. We have had some problems with reliability of work of four proton beams. Oscillograms of voltage and current from four synchronously working ion sources with pulse duration of 8-20 ms are shown on Fig.3. The ion source works in the multibreak regime. In the normal regime the breaks occur one time per 25-5 ms. It is seen that one source is distinguished by anamalously high frequency of breaks. As a rule unreliability of sources work deals with problem in some blocks of the power supply system.

The work with optimization of a beam passing through wall-stabilizing conducting jacket in the end mirror is continued. The diameter of the holes for beams

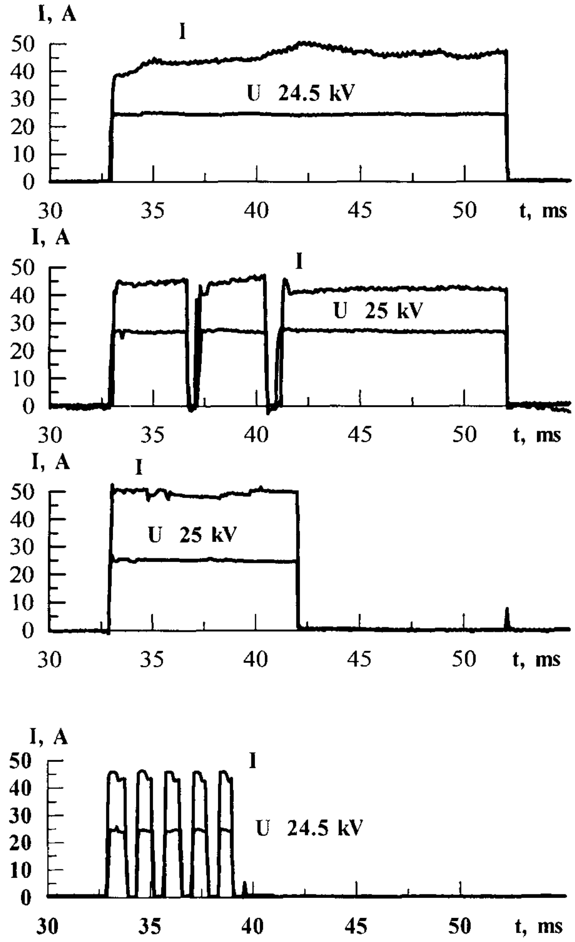

Fig 3. Oscillograms of voltage U and current I of four ion sources operated synchronously in the end mirror injectors AMBAL-M.

in this jacket is 20 cm. The essence of the work is decreasing of beam divergence by regulating the source working parameters. We have been able to pass 17 A equivalent current of atom through jacket and initial plasma from one source. This is about 50% of expected full atomic beam. The work with improvement of some units of injection system is in progress. We hope to perfect this system to reliable functioning.

III. SEMI-AMBIPOLAR TRAP

We have revised our nearest plan for cutting down our expenses. Our plan is not to complete the creation of the eastern end mirror system with neutral injection and ECR-heating. The plasma losses from eastern end of solenoid will be constrained by one end mirror throat coil with high peak magnetic field up to 6 T. The eastern part of the central solenoid is schematically shown on Fig.4. The new arragement will consist of central solenoid, eastern end

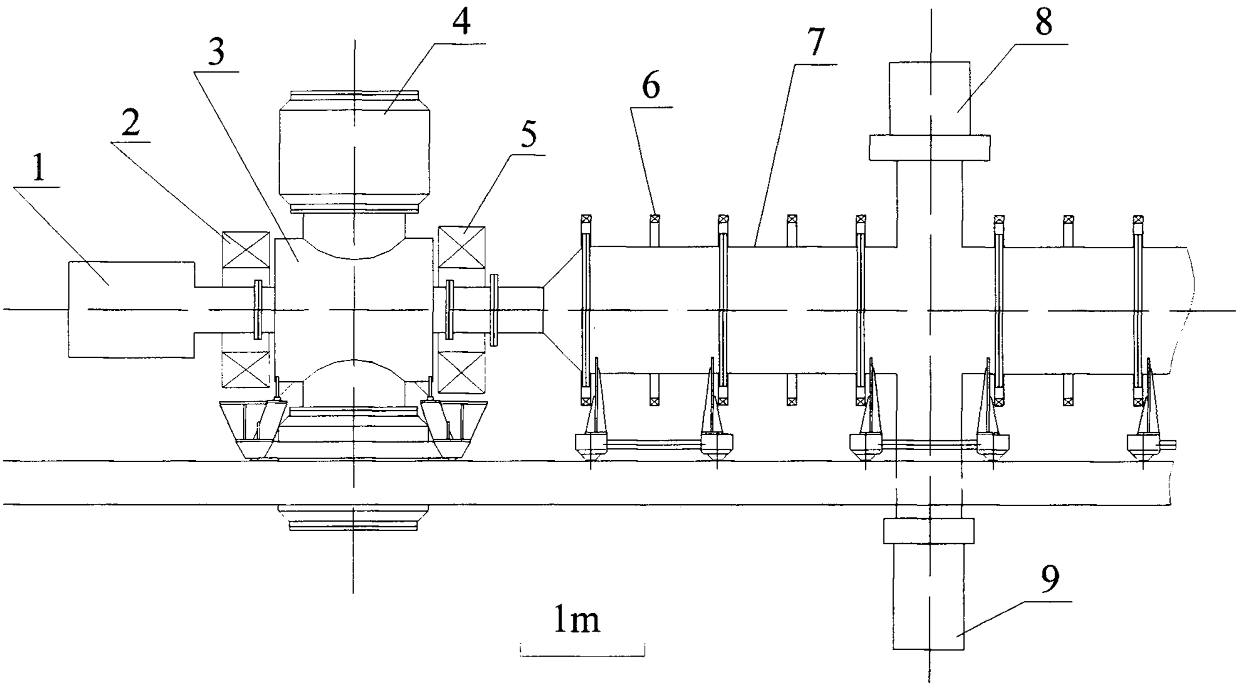

Fig 4. Eastern part of the instalation
1- plasma gun, 2-the plasma gun coil, 3-the end mirror vacuum chamber, 4-titanium getter pump, 5-the end choke coil, 6-solinoidal coil, 7-the section of solinoidal vacuum chamber, 8-the helium cryopump, 9-turbomolecular pump.

mirror vacuum chamber and currently available ring plasma gun.

The plasma gun will be located in the magnetic field produced by second end mirror throat coil. This second coil will have only half of double-pancakes switched on. Fig.5 shows the longitudinal profile of the magnetic field on the axis of arrangement depicted in Fig.4. The magnetic field of the central solenoid will be matched with magnetic field of plasma gun as the diameter of plasma in the solenoid will be about 40 cm.

The plasma source has a capability to provide the

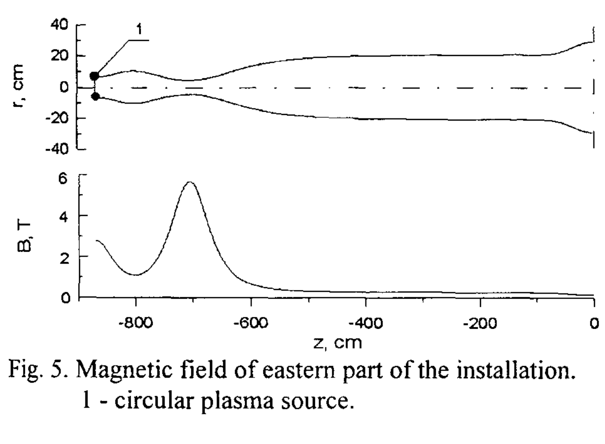

Fig. 5. Magnetic field of eastern part of the installation.
1 - circular plasma source.

entire central solenoid by plasma during 10-20 ms. Moreover it is possible to create the plasma heating with a help of the energy from Kelvin-Helmholtz instability and electron current [1]. In this case the .ion and electron temperature in the central solenoid will be about 200 and 50 eV respectively.

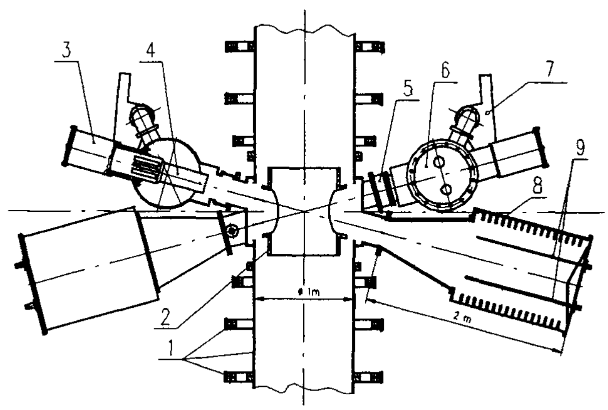

Fig 6. The built-in mirror.
1-solenoidal coils, 2-conducting jacket, 3-the ion sours, 4-charge-exchange tube, 5-the vacuum valv, 6-the helium cryopump, 7-turbomolecular pump, 8-the beam dump, 9-the titanium rod for gettering.

The additional mirror with mirror ratio of 1.8 and length of about 1.5 m will be built in the middle part of central solenoid. This mirror is destined for additional heating and the wall MHD stabilization of solenoidal plasma. Fig.6 shows the arrangement of this built-in mirror. A hot ion population will be captured and will be sustained in this additional mirror by neutral injection with the currently available INAK ion sources. These sources enable to give beams of hydrogen ions with energy up to 25 keV, current about 20 A and puls duration up to 0.1 s.

After connection of the solenoid with the new arrangement described before to the operating western end mirror now we will have the semi-ambipolar trap. We will have an opportunity to investigate a confinement of solenoidal plasma by western ambipolar barriers and influence of solenoidal plasma on parameters and microinstabilites of the west end mirrors plasma.

It will be possible to explore the longitudinal back pumping of central ions from thermal barrier at parametric resonances [7]. The study of MHD stabilization of plasma semi-ambipolar trap, in particular the suppression of slow instability, will be usefull as well.

Principal vacuum units of complete installation were tested and prepaired for assembly. All sections of the vacuum chamber were sanded, baked at temperature of 400°C and tested for vacuum. One half of the magnet-vacuum system of central solenoid was assembled. The turbomolecular pump, helium cryopump, heaters and eight titanium rods for evaporation of titanium by arc discharge for the wall gettering were set at this assemblage. The tests for high vacuum and partial heating up to 180°C of this assemblage were carred out.

All solenoidal coils are prepared. Two mirror throat coils are manufactured by 80%. The manufacture of the injector lines for the built-in mirror began.

IV. CONCLUSION

Our goal for the nearest time includes obtaining and study of the hot ion population in the end mirror with high β by neutral injection, exploration of the wall MHD-stabilization of the end mirror plasma and the investigation of microinstabilites in this plasma. The system of two-frequency ECR-heating on the basis of two gyrotrons with summary power up to 0,8 MW have been mounted a long time ago along with testing of principal units. This system is developed in collaboration with the Institute of Applied Physics RAS (N. Novgorod) [8]. Putting this system into operation and obtaining the hot electron population in the end mirror is our next goal.

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REFERENCES

1. T. D. Akhmetov, V. S. Belkin, E. D. Bender, V. I. Davydenko, G. I. Dimov, A. N. Dranichnikov, E. A. Gilev, V. G. Igoshin, A. A. Kabantsev, Yu. V. Kovalenko, M. B. Persov, V. B. Reva, V. Ya. Savkin, V. G. Sokolov, and S. Yu. Taskaev "Production of a hot initial plasma in the end cell of the AMBAL-M device," *Fiz. Plasmy*, **23**, 988 (1997) [*Plasma Phys. Reports* (Engl. Transl.), **23**, 911 (1997)].
2. A. A. Kabantsev, V. B. Reva, "Investigation of pecularities of plasma potential and density fluctuations of AMBAL-M device," *Abstracts of XXIV Zvenigorod's Plasma Phys. Conf.*, Zvenigorod, Russia, p. 218 (1997).
3. T. D. Akhmetov, V. I. Davydenko, A. A. Kabantsev, V. B. Reva, V. G. Sokolov, and S. Yu. Taskaev, "Magnetic fluctuations in the initial plasma of the AMBAL-M open trap," Submitted to *Fiz. Plasmy.*
4. T. D. Akhmetov, V. I. Davydenko, A. A. Kabantsev, V. B. Reva, V. G. Sokolov, and S. Yu. Taskaev, "Longitudinal current in the initial plasma of the AMBAL-M open trap," *Fiz. Plasmy*, **24**, (1998) [*Plasma Phys. Reports* (Engl. Transl.), **24**, (1998)].
5. T. D. Akhmetov, and V. I. Davydenko, "MHD stability of the plasma in the end system of AMBAL-M", *to be presented in this Conf.*
6. T. D. Akhmetov, V. S. Belkin, E. D. Bender, V. I. Davydenko, V. G. Igoshin, Yu. S. Khramov, Yu. V. Kovalenko, A. S. Krivenko, V. B. Reva, and V. G. Sokolov, "Experiments on ICR heating at the end system of AMBAL-M," *to be presented in this Conf.*
7. G. I. Dimov, "Ambipolar trap: experimental results, problems and perspectives," *Fiz. Plasmy*, **23**, 883 (1997) [*Plasma Phys. Reports* (Engl. Transl.), **23,** 813 (1997)].
8. M. Yu. Glyavin, G. S. Nusinovich, T. B. Pankratova, E. B. Suvorov, and M. D. Tokman, "Physical and technique aspects EC-heating in the end mirror of the ambipolar trap AMBAL-M," *Voprosy Atomnoi Nauki i Tekhniki, Ser.: Termoyadernyi Sintez,* **4**, 65 (1990).