STUDY OF A PLASMA TARGET AS A PART OF MAGNETOHYDRODYNAMIC COMPLEX USING AN EXPLOSIVE MAGNETIC SOURCE OF PULSED POWER

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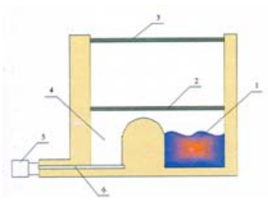
Introduction

In the last few decades the pulsed power experiments have made an important contribution to understanding of plasma state at an implosion of the current-conducting cylinders (liners) under the effect of magnetic field forces [1]. The common feature for all these experiments is that high pulse currents flow in the symmetric shell. As a result, the arising Lorenz force compresses plasma inside this shell. The Electro physics Division at VNIIEF has conducted experiments to study plasma state. The first stage of these experiments has produced the ionized, magnetized deuterium-tritium plasma and $4 \cdot 10^{13}$ thermonuclear reactions have been realized in it [2]. In addition the magneto-hydrodynamic experiments to study the phenomena occurring during the liner implosion have been carried out. The primary objective of such experiments is to attain symmetric high-velocity implosion of the liner meant for a plasma target compression.

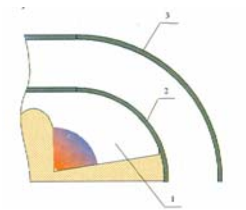
Explosive magnetic generators and peculiarities of magnetized plasma compression

Powerful electro physical facilities are used to study the pulse processes in high-energy density physics. However, their construction is rather expensive. The single-shot explosive magnetic generators (EMG) have been created at VNIIEF as an alternative to stationary facilities [3]. It is known that magnetic compression of plasma with preliminary heating of plasma inside a compressed target is one of the ways to explore a thermonuclear target [4]. High energy density in plasma inside the compressed volume can be achieved due to conversion of kinetic energy of high-velocity imploding liner. Unlike the direct hydrodynamic heating, the magnetic compression of plasma with a preliminary heating of plasma includes two stages: a) formation of warm (100 eV or more) magnetized (for example, 100 kGs) plasma inside the target; b) further quasi-adiabatic compression of plasma by a magnetically driven liner used as a piston. Such method has certain advantages over a standard compression. The magnetic field suppresses the losses for thermal conduction during compression. High initial heating of magnetized plasma and quasi-adiabatic compression of plasma make it possible to attain the temperatures of ignition under moderate compression rate and under moderate compression ratios as opposed to strong and very symmetric compression that is required for non-magnetized plasma. In comparison with non-magnetized plasma the magnetized plasma requires lower compression rate. Due to its quasi-adiabatic nature the compression across the target radius can be smaller than 10:1. As the magnetic field increases during compression, it may become high enough to confine the charged products of nuclear reactions that will improve the conditions for self-heating. Because of this the density required for ignition can be decreased significantly. A lower rate required for compression can be achieved reliably for the magnetically driven liners.

The schematic diagram of compression of the target with magnetized plasma is presented in Figures 1a, 1b, where the cylindrical and the quasi-spherical liners are used for compression [5].



a



b

Fig.1. 1-chamber (second compartment), 2-chamber wall, 3-liner, 4- chamber (first compartment), 5- EMG, 6-Insulator.

As mentioned above, VNIIEF conducted experiments to study the condition of plasma. The objective of such research was to obtain the preliminary heated plasma that could be further compressed to get the second pulse of neutrons. This pulse allows inferring the efficiency of plasma compression. The first stage of these experiments produced the ionized, magnetized deuterium-tritium plasma with the lifetime of 2 μs preliminary heated to the temperature of 0,2 keV; $4 \cdot 10^{13}$ thermonuclear reactions were realized in that plasma. The next step of the research will be to compress the preliminary heated magnetized plasma by the liner accelerated by the fast-increasing magnetic field from the powerful energy source to the velocity of 5-20 km/s.

Study of the liner system intended for plasma compression.

The calculations show that in the process of implosion of the solid liner the ends of the compressed liner interact with the elements of the chamber design. Figure 2 shows the results of two-dimensional calculations of the cylindrical liner interaction with the end walls of different shape [6]. As is seen, in the process of liner implosion one can observe the separation of the liner from the end walls with deterioration of conditions for the current flow in the near-wall zone; the cumulative ejections are present.

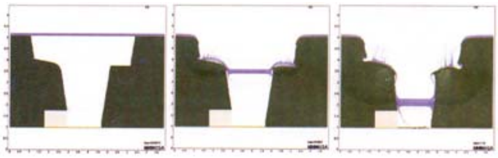


Fig. 2

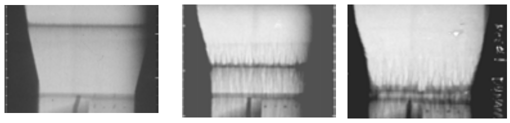
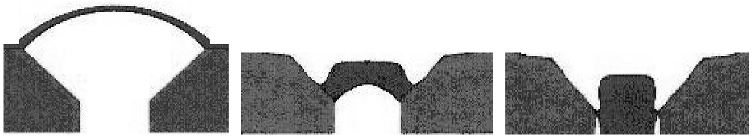


Fig. 3

The phenomena mentioned above depend on a number of factors: magnetic field intensity, strength properties of material of the liner and of the electrodes, the shape of the electrodes walls and other reasons [7]. As experiments show [8], the matter outflows from the outer and inner surfaces of the liner in the process of its implosion (see Fig.3).

In a number of cases, when solving the problems of thermonuclear fusion, it is necessary to get the spherically symmetric compression of a thermonuclear target by a quasi-spherical liner driven by the EMG azimuthal magnetic field up to high velocities. Fig.4 presents the images of the liner obtained in the calculations of the quasi-spherical liner implosion for two time moments t_1 and t_2 [5]. Fig.5 presents the x-ray images obtained in the experiment with the use of MHD complex [9]. The experimental and the calculated images of the liner differ in that the x-ray image in Fig.5 shows that at the time moment t_1 the matter outflows from the surface of the imploding liner.



t_0 t_1 t_2

Fig.4

t_0 t_1 t_2

Fig.5

At the present time the energy that can be obtained with the use of EMG is enough to realize compression of the preliminary heated magnetized plasma [10]. However, before conducting the full-scale experiment to compress magnetized plasma by a liner it is necessary to realize additional work to determine the optimal velocity of compression and the optimal shape of converging liner. The MHD complex can be used for this purpose.

The MHD complex allows studying the dynamic of the liner implosion in the experiment. The power part of the MHD complex was tested successfully in the experiment studying the implosion of the metal liner. The x-ray radiography included into the MHD complex can be used to study the peculiarities of the liner-electrodes interaction, to get the information on the state of the inner and outer surfaces of the imploding liner. At this, in the experiment the spectroscopic systems of the MHD complex are reliably protected from the damage and allow getting the information on the state of plasma in the plasma chamber.

Conclusion

The use of the experimental capabilities of the MHD complex allows moving forward in the understanding of the processes during the implosion of the solid liner and to approach to realization of experiments on compression of magnetized plasma by the magnetically driven liner.

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