High Energy Densities and MAGO/MTF

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Summary: The energy density level, which is required to achieve in the MAGO/MTF approach, can be characterized by the pressure of tens of megabars. The progress of that approach must rely on the research results in the field of high energy density (HED) physics and the investigations in the frames of this system contribute to different fields of HED physics.

Introduction

The MAGO/MTF (MAGO is Russian abbreviation for MAGnetic Compression and MTF is Magnetized Target Fusion) approach [1, 2] consists of two phases:

First, magnetized plasma suitable for further compression (with the closed-field-line magnetic field ~0.1 MG, the density ~10^{18} cm^{-3}, the temperature ~300 eV, and low impurity percentage, since impurities increase radiation losses) is generated.

Then, the plasma is quasi-adiabatically compressed by liners (at velocities ~10 km/s) using powerful drivers [e.g. explosive magnetic generators (EMG's)] and its parameters are brought to the ones meeting the Lawson criterion.

The DT plasma obtained in MAGO experiments in the volumes of ~1-3 l had density ~$10^{18}$$cm^{-3}$ and temperature ~300 eV and the obtained neutron yield was up to 4-5×10^{13} . The simulations of MAGO plasma compression with a solid liner, which parameters were characteristic for yet achieved in experiments (energy ~25 MJ, velocity ~8 km/s), gave the following plasma characteristics at compression:

DT plasma density	3.9×10^{20} cm^{-3},
Energy density	2 MJ/cm^3, and
Neutron yield	3×10^{18}.

Other MTF approach uses Field Reversed Configuration (FRC) and its compression by a solid liner [3]. FRC has closed configuration of poloidal magnetic field inside plasma. The FRC obtained in the experiment has the density ~0.5 $10^{17}$$cm^{-3}$, temperature 200-300 eV, and size ~2 cm. The Al liner proposed for plasma compression was also experimentally studied. In these experiments the liner gained the velocity of 4 km/s.

Application of the MAGO/MTF Researches for the Studies in the Field of HED Physics.

HED's are typical for MAGO/MTF systems. This allows using the methods and various elements developed in these systems for different HED problems. Among these problems we can name the study of material dynamic properties [4] [equations of state (EOS's), dynamical strength, damage phenomena, etc.], the study of surface discharges in strong magnetic fields [5] (including study of interaction of strong magnetic fields with the metal surface [6, 7], which paved the way for the study of warm dense matter properties [4, 8]), the study of hydrodynamic and MHD instabilities [9, 10], the study of different hydrodynamic and MHD flows behavior for the calibration of numerical techniques, as well as the investigation of new fields of HED physics such as mechanisms of plasma heating with collisionless shock waves, anomalous heating in the near-electrode plasma flows, 2D turbulent viscous heating, etc. An example of such a problem:

TPa scale EOS experiments based on imploding liner. Powerful EMGs and energetic liners developed for the MAGO system can be used for the EOS study in the HED area. Now LANL and VNIIEF are collaborating [11] in designing a TPa scale EOS experiment based on imploding liner driven by the DEMG

current of 60 MA. The experiment relies on strong (~6 MG) magnetic fields to produce implosions in condensed matter liners at velocities of ~20 km/s above those achievable by gas guns or direct HE.

Conclusions

- The progress of the MAGO/MTF systems relies on the results of the investigations of HED physics. These are the data on the EOS's and the radiation/matter interaction, kinetic coefficients, the data on shock waves and their structure, the data on the interaction of ultrahigh magnetic fields with matter and surface discharges in such fields, the research results for different hydrodynamic and MHD-instabilities, etc.
- The methods, as well as multiple elements, developed in the MAGO/MTF systems can be used for solving different HED physics problems. Among such problems we can list the study of material dynamic properties the study of surface discharges in strong magnetic fields, the study of hydrodynamic and MHD-instabilities, the study of behavior of different hydrodynamic and MHD flows for the calibration of numerical techniques, as well as new fields of HED physics, such as mechanism of plasma heating using collisionless shock waves, 2D turbulent viscous heating, etc.

References

[1] S.F. Garanin, V.I. Mamyshev, V.B. Yakubov, "The MAGO system: current status," *IEEE Trans. Plasma Sci*., **34**, pp. 2273-2278, (2006).

[2] I.R. Lindemuth, R.E. Siemon, "The fundamental parameter space of controlled thermonuclear fusion," *Am. J. Phys.*, vol. 77, no. 5, pp. 407-416, 2009.

[3] C. Grabovski, J. Degnan, M. Babineau, et al. "FRC compression heating experiment (FRCHX) at AFRL," Dig. Tech. Papers, Pulsed Power & Plasma Science 2007 Conf., eds. E. Schamiloglu, F. Peterkin in Cooperation with IEEE Nucl. and Plasma Sci. Society, 2007, vol. 2, p. 1728.

[4] R.E. Reinovsky, W.L. Atchison, S.F. Garanin, A.M. Buyko, et al. "Pulsed high magnetic fields for exploring the dynamic properties of materials," presented at XIII Int. Conf. on Megagauss Magnetic Field Generation and Related Topics, Suzhou, China, 2010.

[5] S.F. Garanin, "Surface discharges in strong magnetic fields," IEEE Trans. Plasma Sci. 38, pp. 1850-1855 (2010).

[6] T.J. Awe, et al., "Threshold for thermal ionization of an aluminum surface by pulsed megagauss magnetic field," Phys. Rev. Lett., 104, no. 3, p. 035001, 2010.

[7] S.F. Garanin, W.L. Atchison, T.J. Awe, et al., "Numerical simulations of thick-aluminum-wire behavior under megaampere-current drive," IEEE Trans. Plasma Sci., 38, pp. 1815-1821 (2010).

[8] A.M. Buyko, S.F. Garanin, S.D. Kuznetsov, R.E. Reinovsky, "Numerical simulations of wire and foil electrical explosion under megaampere current drive for warm dense matter generation," presented at this Conf.

[9] W.L. Atchison, R.J. Faehl, I.R. Lindemuth, et al., "Dependence of solid liner stability on drive conditions during magnetic implosion," in Proc. IX Int. Conf. Megagauss Magnetic Field Generation and Related Topics. Moscow-St.-Petersburg, 2002. eds. V.D. Selemir, L.N. Plyashkevich (Sarov. VNIIEF, 2004), p. 710.

[10] A.M. Buyko, S.F. Garanin, D.V. Karmishin, et al., "Analysis of the liner stability in various experiments," IEEE Trans. Plasma Sci., 36, pp. 4-9, 2008.

[11] A.M. Buyko, S.F. Garanin, W.L. Atchison, R.E. Reinovsky, et al., "Explosive magnetic liner devices to produce shock pressures up to 3 TPa," in Dig. Tech. Papers, IEEE Pulsed Power Conf., Washington, DC, USA, 2009, p. 215.