Electrophysical Research Methods for Materials at Extreme Conditions with the use of Explosive Magnetic Generators

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Introduction. It is possible to achieve high energy density during modeling of hydrodynamic processes at conversion of kinetic energy of a high-speed shell-liner. The magnetic drive of the shell has a number of advantages in comparison with the explosive drive or the drive with the use of light-gas guns. By virtue of the fact that the mass of the magnetic field is equal to zero the attainable velocity of the shell is not limited by the detonation rate or sound speed. For the same reason the side damages of the studied specimens have been minimized.

1. When is the liner material in the condensed state? At magnetic drive the velocity is proportional to the integral of current action and to the liner thickness h, and is inversely proportional to the density of its substance. On the other hand, the aggregate state of the liner is determined by the value of current action integral. The fact that the ratio of current action integral to density at the moment of melting weakly depends on the liner material allows getting the limiting velocity of the solid liner v_S [km/s]@30×h [cm]. It should be pointed out that the liner can as well be in the condensed state at higher velocities. The experiments on Z-machine, where the aluminum liner ~ 0,1 cm thick was driven to velocities more than 30 km/s, testify to this. This is possible in case of acceleration in a high magnetic field, where ρ_0, e_{cr} are density and critical energy of the liner material. Hence there is no limit to the condensed liner velocity at magnetic acceleration.

2. Current sources requirements. In practice, the velocity is limited by the growth of the Raleigh-Taylor instability. The liner acceleration is stable when it travels several own thicknesses. Evaluating the traveled distance s in liner thicknesses $s=N\times h$ we get at N=10 - $v\,[\text{km/s}] \approx 10/\sqrt{\rho_0}\,J[\text{MA/cm}]$. To increase the velocity, it is necessary to increase the current linear density. One of the ways is to increase the value of current. The second way is to reduce the linear dimensions of the liner at constant current. To increase J by a factor of n at constant current in the liner I, the liner dimensions r_0, as well as its thickness h, should be reduced respectively. At this the current rise time should be reduced by a factor of n^2.

3. Capabilities of the explosive magnetic generators (EMG). Figure1 shows the dependence of energy density e on liner velocity v. At e £10 kJ/g (velocity £6 km/s) the studies of the rheological properties of the matter, as well as of the instabilities growth, are traditionally carried out with the use of HE. High energy densities ³ 10 MJ/g (v ³ 100 km/s) are obtainable in full-scale tests. The laser facilities can help to compensate the lack of knowledge near the lower boundary of this zone. The area of these studies is the EOS of materials, propagation of radiation, compression of thermonuclear targets, etc. The zone of intermediate e from ~10 kJ/g to ~10 MJ/g (10 km/s£v£100 km/s) is of interest to explore the EOS of materials and turbulent mixing. It is accessible for the laser complexes. The studies of the properties of materials and modeling of the physical processes throughout the entire range, up to a lower boundary of high e, can be realized with the use of EMG. The e zone to 30 kJ/g is accessible for the HEMG. The DEMG are able to drive the liners to ~40 km/s (e~0.5 MJ/g). We hope that the DEMG of a new generation, with a two-cascade system of current pulse peaking, will allow achieving the high energy density boundary. The scheme presents some of the experimental series realized jointly with LANL.

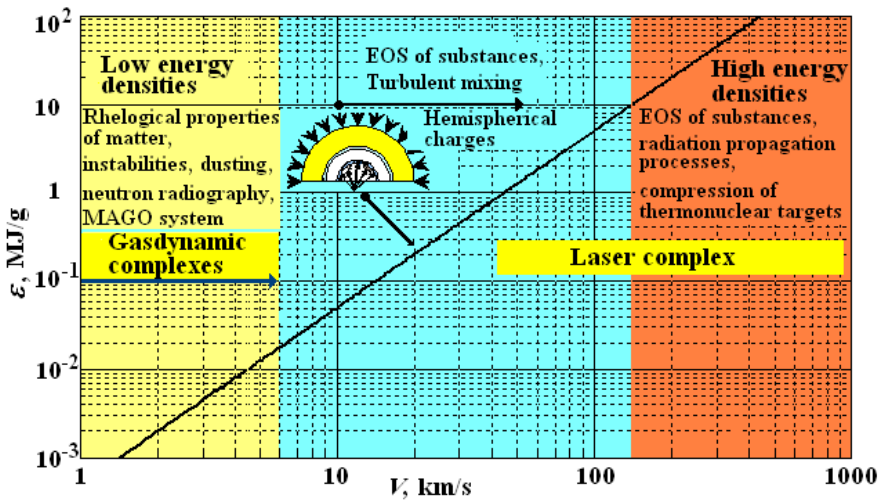

Figure 1. EMG application area.

4. Low energy densities. The VNIIEF-LANL *R-Damage* experiments have become the first experience of application of the HEMG to study the rheological properties of the materials. The aspects of application of HEMG in these studies are discussed in the presentation by Duday P.V. and Tyupanova O.A. "Helical EMG Application for Material Rheology Studies: Opportunities, Results, and Perspectives".

The presentation by Vasyukov V.A. et al. is devoted to the possibilities of ejecta studies "Research of Ejecta Processes in Case of Shock Wave Coming to Metal Surface Using Electrophysical Facilities".

5. Intermediate energy densities. VNIIEF and LANL conducted the experiments ALT-1,2, where the AL-liners of 50 g mass were driven to velocities of 12 km/s. To test a possibility to realize shock-wave measurements in the reference patterns the ALT-3 experiment is planned for 2012 to drive a ~100 g mass liner to a velocity of ~20 km/s. The presentation by Kraev A.I. et al. is devoted to possibilities of achieving the velocities of ~40 km/s and pressures to 10 TPa "Disk EMG Application to Study the Equations of State of Materials". The perspectives of studies of turbulent mixing are discussed in the presentation by Grinevich B.E. et al. "On EMG Use for Experimental Defining of Turbulent Mixing Zone Width in Case of Heavy Metal Deceleration against Light One at ~10^8 g".

6. High energy densities. The aspects of creation of the current source for ~80 MA with the rise time of ~100 ns and the perspectives of achieving thermonuclear ignition are discussed in the article by Garanin S.G., Ivanovskiy A.V. and Mkhitariyan L.S. **«**An ICF system based on Z-pinch radiation produced by an explosive magnetic generator» Nucl. Fusion **51** (2011) 103010.