On a new approach to the experimental study of hydrodynamic instability development in compressed laser targets.

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Abstract. A new approach to the experimental study of hydrodynamic instability development in compressed laser targets on base on electron tomography of spontaneous magnetic fields (SMF) measurement is discussed in the paper.

1. Introduction.
The spontaneous magnetic fields (SMF) $\sim 10^2$ MGs are generated in compressed laser thermonuclear targets due to hydrodynamic instability development [1]. They can be observed with help of relativistic electron bunches (beams), which scatters in the SMF of compressed laser targets [2]. Such electron bunches could be produced by the additional picosecond high power laser pulses synchronized with the main driven laser pulses and special targets [3]. The configuration of SMF is defined by the curls distributions in compressed plasma. As the results, there is opportunity to create the map of such curls in dense plasma on base on magnetic field measurement. The results of 3D numerical simulations using “AURORA”-code [4] are presented in the paper.

2. The advantages of this approach for SMF measurement.
2.1. It is possible to observe SMF in the dense plasma.
The electron scattering angle due to Coulomb collisions during passage through a plasma layer of thickness $R_m$ is [5]:

$$\langle \phi^2 \rangle = \frac{8\pi L_Q e^4 (N \cdot R_m)}{E_e^2} = 0.31 \frac{Z (\rho R_m) L_Q}{A E_e^2 [MeV]}$$

where $Z$, $A$ – the charge and atomic mass of ions; $L_Q$ – the Coulomb logarithm; $E_e$ – electron energy, $N$ – electron concentration in plasma. For expanded supercritical laser plasma ($\rho R_m \sim 10^{-4}$ g/cm$^2$, $L_Q \sim 10^{-1}$, $E_e \sim 0.2$ MeV $\phi \leq 0.1$ rad and Larmor radius $R_L = 10 \mu$m for $B=1$ MGs; in the compressed
thermonuclear targets: $\phi \leq 0.1$ rad, if $E_e \sim 10$ MeV and $R_L \approx 3 \mu$m for $B=100$ MGs. The electron free path $l_e \sim E_e^2$, while the Larmor radius $R_L \sim 1/\sqrt{E_e}$. It is possible to select electron beam parameters such that the electrons will not undergo substantial scattering due to Coulomb collisions but will undergo the effect of fields exceeding.

2.2. If you have a power two beams laser system (long plus short pulses) it’s possible to carry out the following experiments (see Fig.1).

2.3. It is possible to generate in 3D nonuniform plasma not only ‘toroidal’ fields (see Fig.1), but also ‘poloidal’ fields (see Fig.2). ‘Poloidal’ fields are extremely difficult to observe using the traditional optical technique, because the probe laser beam will encounter an opaque target. When an electron beam is used, in a ‘poloidal’ field it will deflect primarily in the plane perpendicular to that in which the beam deflects in the case of ‘toroidal’ fields (see Fig.2).

Fig.1 Schemes of experiment to observe SMF’s in a plasma plume (a) and electron trajectories in the scattering by plasma SMFs (b): (1) driven laser pulse; (2)-target; (3)-plasma; (4)-magnetic field $B$; (5)-picosecond laser pulse; (6)-auxiliary target intended for electron beam generation; (7)-electron beam; (8)–magnetic line of force.

Fig.2. Schemes of electron propagation through the plasma in the case of ‘toroidal’ (a) and ‘poloidal’ (b) magnetic fields as well as scheme of electron distribution in the incident electron beam and emerging from the plasma (c): 1-plasma plume; 2-target; 3-laser pulse; 4- electron beam entering the field; 5-beam scattered by the field.
2.4. It is possible to make the electron tomography of spherical compressed target (see Fig.3.). If you have the 3D map of magnetic force lines, it is possible to reconstruct the field of curls in compressed plasma.

3. Brief description of the “AURORA” code.
We solve numerically the 3D system of equations of motion for $N_0$ particles. We assume below, that the Coulomb collisions and radiative electron energy losses can be neglected.

Then, the basic dimensionless parameters of the problem are:

$\delta_B = R_m/R_L; \Delta = (R_m - R_1)/R_m; X_0 = R_0/R_m$. $R_m$ - radius of plasma (we assume for simplicity that plasma have spherical shape), $R_L$ - Larmor radius, $R_0$ - initial radius of electron beam. At the first time a total number $N_0$ of the particles is uniformly ‘scattered’ inside a circle of radius $R_0$ with help of a random number generator.

The trajectories of every particle are computed by means of the Runge-Kutta method. The leaving plasma particles ($r > R_m$) are ‘sorted’ according to their deflection angles and then the distribution function $N(\Psi, \Phi)$ is constructed. (The plasma scale is much less then the distance from plasma to measuring devise. $\Psi, \Phi$ - the deflection angles of particle trajectory, $\Psi = \arcsin(V_z/V), \Phi = \arcsin(V_x/V)$ (if initial direction of beam along OY axis). Usually, we use $N_0 = 10^5 - 10^6$ particles and $(1 - 3) \cdot 10^2$ angle sectors in our simulations.

4. Results of simulations.

4.1. 1 problem: the modelling of the electron beam scattering in the ‘toroidal’ SMF of plasma plume.

At the first time all particles possess the same initial velocity aligned with the y axis.
In the absence of the field, all particles would assemble into point. Fig.4 illustrates the distribution function $N(\Psi, \Phi)$ of particle scattering for different field strength ($\delta_B=2, 1, 0.5$).

The existence of some spreading in electron velocities will not lead to catastrophic consequences. Fig.5 shows the results of calculations in the case when the initial particle dimensionless velocities were randomly varied in the velocity range $V_0^\phi = [1, 1 + \Delta V]$ for different values of $\Delta V$.

4.2. 2 problem: the modelling of the electron beam scattering in the ‘toroidal’ SMF of compressed spherical target (see Fig.6).

The axial symmetry in compressed in compressed target is when the target is irradiated on both sides. For an indirect target irradiation, when the laser beams are to be converted to X-ray radiation, consideration is commonly given to laser radiation input into the converter through two openings. In these case, SMFs will also have a toroidal topology and the harmonic numbers will be even $n=2-10$.

5. Acknowledgements.
The author thanks P.V. Konash and O.A. Zhitkova for assistance for paper preparation.

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