On the possibility of spontaneous magnetic field observation in turbulent laser plasma.

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Abstract.

The powerful laser pulse, interacted with low density porous matter (an average density is less than critical plasma density), produces a hot turbulent plasma. The plasma whirls are formed in the results of impacts of currents from the evaporated walls. These whirls stimulate the growth of the huge spontaneous magnetic fields (≥10 MG). But these fields have a small scale and arbitrary vector of orientation in space. We are considering the two methods of these field investigations in hot turbulent laser plasma. The first method is based on the constrained orientation of magnetic moments of whirls and use of the special magnetic probes. The second method is based on the scattering of the relativistic electron bunch in the fields.

1. Turbulent whirls and magnetic field generations in laser plasma from porous targets.

In a number of different countries laboratories the interaction of high-power laser radiation (the intensities I ~ 10^{13}-10^{15} W/cm^2) with porous media has been studied [1–5]. We developed the physical-mathematical model of energy transport in the turbulent plasma formed through interaction of high intensity laser beam with a foam (when an initial average density lower then plasma critical density [6–7]).

Figure 1 illustrates a formation of turbulent plasma. Because of the solid strings occupy ~ one thousands part of pore volume, such matter is almost transparent for laser beams in initial stage of plasma formation. But the strings are run hot and imploded. The current collisions of evaporated matter lead to eddy formations. The main part of laser flux hits aluminum base and evaporate it.

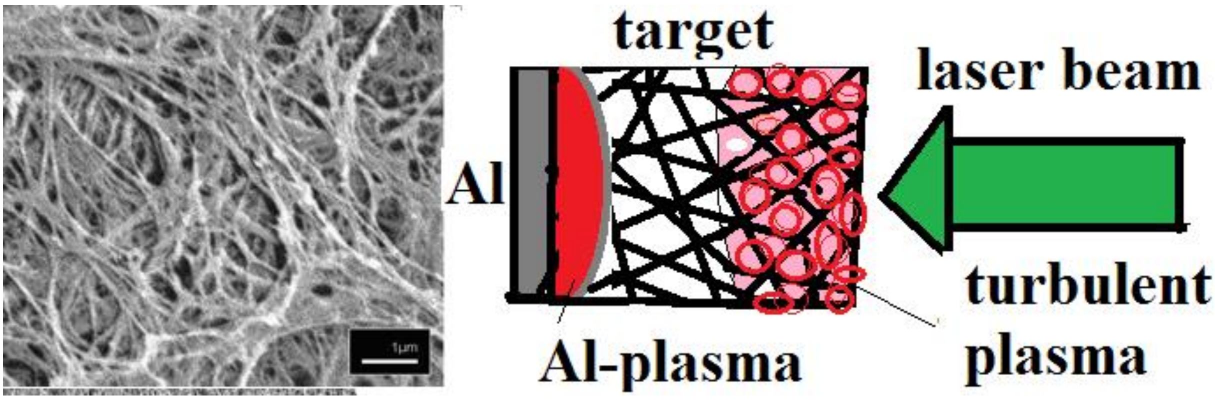

Fig.1. Left side: image of cellulose triacetate (TAC) matter with ρ~10 mg/cm^3, right side: scheme of laser beam– foam interaction, formation of hot turbulent plasma formation. A foam matter placed on thin aluminum base.

As the result, the turbulent low density laser plasma is created (see Fig.1, right side). In the next stage the laser beam comes through the plasma and heats it. Previously [4, 5], we offered the physical-mathematical model and carried out numerical simulations, modelling the experiments at "PALS" (in Prague) installation [6-7]. The model is based on the basic hypothesis that the 3D eddy currents are developed in hot plasma. We have introduced an effective rate of the turbulent pulsations (ν_p) in the transport coefficients, when $\nu_p > \nu_e$ (electron collision frequency) for such turbulent plasma. The scale of turbulent pulsation is $l_p = c/\nu_p$, where c is the speed of light ($l_p \sim 1\mu$m).

In order to verify the model we offer two types of the experiments for the study of the turbulent laser plasma.

It is known, that eddy currents induce spontaneous magnetic fields in the conducting matter [8].

$$\frac{d\vec{B}}{dt} \sim \frac{c \cdot m_i}{e \cdot Z} rot \frac{\nabla P_e}{\rho} + rot[\vec{V} x \vec{B}] + ... = \frac{c}{e(1+Z)} \frac{\nabla P x \nabla \rho}{\rho^2} + \nabla x [\vec{V} x \vec{B}] + ...$$

$$\frac{d\vec{\omega}}{dt} \sim -rot \frac{\nabla P}{\rho} = \frac{\nabla P \times \nabla \rho}{\rho^2}, \quad \vec{\omega} = rot\vec{V} \qquad (1)$$

Here is $\vec{B}$, $\vec{\omega}$ - magnetic field strength and curl.

These fields would be able to attain up 10 - 30 MG in turbulent high temperature laser plasma [9]. It is easy to estimate, that the magnetic field could grow up to $B \le \frac{c}{e} \frac{\nabla T}{l_p} \frac{L}{u} \approx 30$ MG

Where c is light speed, e is electron charge, ∇T is temperature gradient, l_p is scale of turbulent pulsation ~ d is scale of pore, u is plasma flow velocity, L is scale of plasma inhomogeneity.

From numerical simulations (see [9]): $\nabla T \approx 1.6\cdot10^{-7}$ erg/cm, $d \approx 1$ μm, $u \approx 300$ km/s, $L \approx 100$ μm.

But these fields have a small space scale and arbitrary vectors of magnetic moments in space/ The traditional methods of spontaneous magnetic field observation are challenging.

2. On the possibility of the constrained orientation of magnetic moment in laser plasma.

Fig. 2 illustrates the concept. The external strong regular magnetic field (~ 0.1 MG) is produced with help of powerful charge in the two special electrodes (see Fig.1a). The porous target is placed between the electrodes. The laser beam comes through the coil and produces hot plasma. This turbulent laser plasma contains the whirls and magnetic moments with arbitrary vectors of orientation in space (see Fig.2b). The external field regularizes the magnetic moments orientations (see Fig.2c).

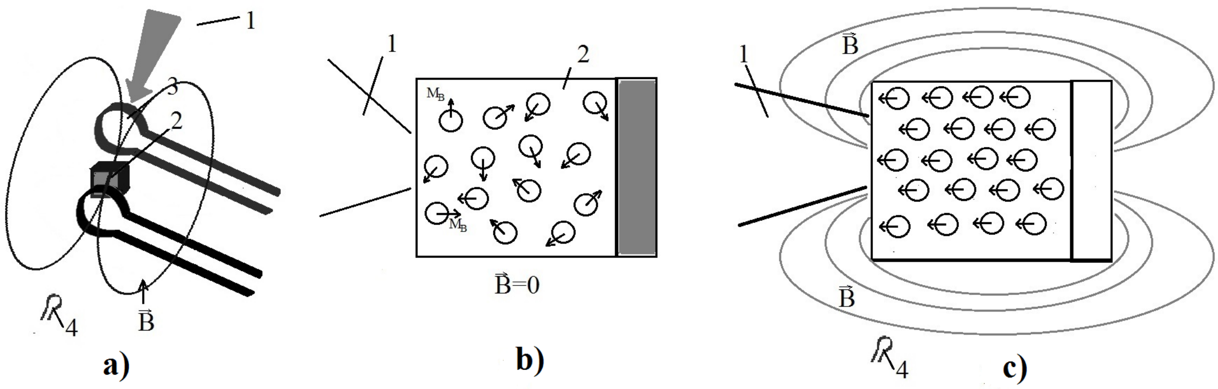

Fig.2. A scheme of external magnetic field production near laser target (a), porous target on mount and magnetic moments (M_B) distribution in turbulent laser plasma without external field (b), magnetic moment reorientation under action of external magnetic field into turbulent plasma (c). 1 – laser beam, 2 – target 3- installation, which has produced the external field, 4 – diagnostic probe, B – magnetic strength lines of magnetic field.

It needs to realize the three series of experiments: 1) measurement of external magnetic field in vacuum; 2) measurement of magnetic strength near plasma jet, which has been formed as the result of laser - foam target interaction, without external magnetic fields; 3) measurement of magnetic strength near plasma jet, which has been formed in the result of laser - foam target interaction, with external magnetic fields (see also [10]).

3. The physical principles of the diagnostic e-bunch generating.

It is possible to study the spontaneous magnetic field into laser plasma with help of the diagnostic electron bunches [11, 12]. We have offered the concept of "laser-plasma diode" [13] for formation of such e-bunches. Fig. 3 illustrates the scheme of production of the e-bunch. A first laser beam is diagnostic one (Laser1). It has intensity $I \sim 10^{16}$-10^{17} W/cm^2, a pulse duration is ~ 10-100 ps, diameter of focal spot is d ~ 10-50 μm. The basic laser beam intensity (Laser2) is $I \sim 10^{14}$-10^{15} W/cm^2, pulse duration is ~ 1 ns and focal spot with diameter is d ~ 200-500 μm. The diagnostic e-bunch is created in special device, which consists of cathode and two anodes. The electrical voltage between cathode and the first anode (wire mesh) is about 10 kV. The electrical voltage between the first and second anode (wire mesh too) is about 200-300 kV. Perhaps, it needs to place an additional plate with small hole between two anodes to form narrow e-bunch). The intensive laser pulse creates hot plasma. The e-bunch is created with help of the electrical voltage in gap about 10 kV. In order to enhance of electron energy the potentials difference in the second gap has to exceed 200 kV. This diagnostic e-bunch comes through laser plasma, which has been created by second laser pulse (see Fig.3).

The scattering of e-bunch has been observed with help of photo-electronic device (recorder).

4. The observation of Spontaneous Magnetic Field (SMF) with help of e-bunch scattering.

Figure 4 illustrates a scheme of proposed experiment. The main laser beam irradiates the foam target and produces a turbulent plasma plume. The other picosecond laser pulse produces e-bunch. This bunch propagates perpendicular to the incident main laser beam and is scattered by the spontaneous magnetic fields. The Larmor radius of electron $R_L \sim \sqrt{\varepsilon_e}$, but it's collision path is $l_e \sim \varepsilon_e^2$, here ε_e is electron energy in bunch. So it is possible to choose ε_e to scattering would be only on SMF.

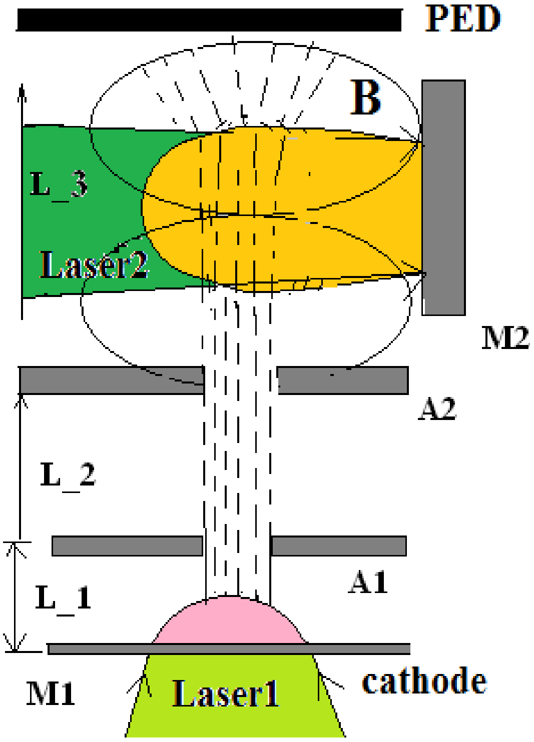

Fig.3. A design of diagnostic e-bunch formation. Laser1 – laser beam, which has formed hot plasma for e-bunch formation, M1 – target for hot plasma formation, A1, A2 – the first and the second anodes. Laser2 – laser beam, which has formed turbulent plasma. M2 – porous target, which has formed turbulent plasma with internal magnetic fields, PED-Photo-electronic device, L_1, L_2, L3 – interspaces between electrodes

The electron scattering angle due to Coulomb collisions during passage through a turbulent plasma with an effective thickness $< \rho L >$ is

$\langle \phi \rangle = 0.55 \cdot \sqrt{\frac{Z}{A} \frac{\langle \rho L \rangle \cdot \Lambda_Q}{\varepsilon_e^2 [\mathrm{MeV}]}} \leq 0.005$ [rad]. Here is Z, A – average charge end atomic ion mass in plasma, $\langle \rho L \rangle = \int_0^L \rho dx$ - "integral" parameter of plasma density along the e-bunch direction [in g/cm^2], Λ_Q – Coulomb logarithm, ε_e - electron energy in bunch [in MeV].

If B ~ 10 MG, Larmor radius ~ 1 μm, e-deviation in the magnetic fields much more than 0,005 rad. We propose the following experimental scheme (see also [10]).

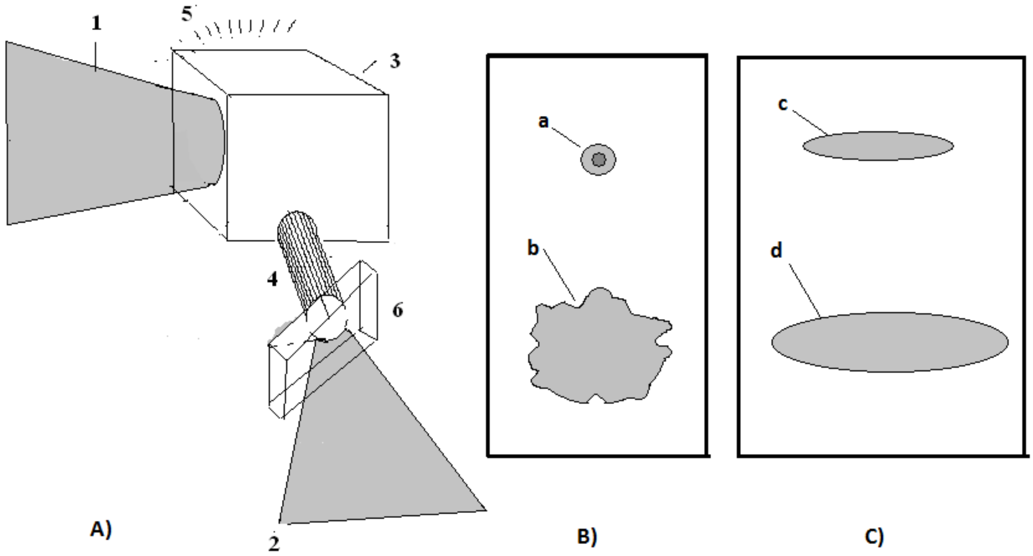

Fig.4. Scheme of SMF observation in plasma with help of e-beams (A). 1- Main heating laser beam (laser2) of nanosecond duration, 2 – laser beam (laser 1) picosecond duration, which has formed e-bunch, 3 – porous target, 4 – diagnostic e-bunch, 5 – scattering electron bunch, 6 – diagnostic device for e-bunch formation. B). Image of diagnostic e-bunch in photo-electronic device without porous target (upper figure a) and with porous target (bottom figure b). C). Image of diagnostic e – bunch with take into account of external magnetic field (without porous target- c), and with porous target - d)

5. The main results.

1. The external magnetic field would be able to regularize the magnetic moments in turbulent plasma.
2. It allows to observe the spontaneous magnetic fields (SMF) with help of the probes, which placed near the plasma jet.
3. We have proposed the method of SMF study in turbulent laser plasma with help of diagnostic e-bunch. We have considered the design of such diagnostic scheme.

REFERENCES.

1. M. Dune, M. Borghesi, A. Ivase et al. Evalution of a foam buffer target design for spatially uniform ablation of a laser-irradiated target. // Phys. Rev. Letters. V.75.N21, pp. 3858-3861, 1995

2. J.A. Koch, K.G. Esterbrook, J.D. Bauer et al. Time-resolved X-ray Imaging of High-Power Laser-Irradiated Underdense Silica Aerogels and Agar Foams. // Phys. Plasmas, V.2, pp.3820-3831, 1995

3. A.E. Bugrov, I.N. Burdonskiy, I.K. Fasakhov et. Al. Laser-plasma interaction in experiments with low-density volume-structured media on the "Mishen" facility. // Proc. Of SPIE. 2003, v.5228,. Ed. By O.N. Krokhin, S.Yu. Gus'kov, Yu.A. Merkuliev, Bellingham. WA

4. N.G. Borisenko, A.A. Akunets, A.M. Khalenkov et al. Particular features of the transmission of laser radiation with wavelength 0.438 μm and intensity (3-7)1014 W/cm2 through an undercritical plasma from polymer aerogels. // Journal of Russian Laser Research. V.28, N.6, pp.548-566, 2007

5. N.G. Borisenko, Yu. A. Merkuliev. Preheating of a target by laser radiation through plasma and polymer aerogel. // Jour. Of Russian Laser Research. V. 31, N3, 256-269, 2010

6. A.I. Lebo, I.G. Lebo. Interaction of High-Power Laser Pulses with Low-Density Targets in Experiments with the PALS Installation. // Mathematical Models and Simulations, v1(6), 75-91, (2009)

7. A.I. Lebo, I.G. Lebo. A model of the energy transport in turbulent plasma of porous targets. // IOP Publishing. Phys. Scripta, T142 (2010), 014024 (4pp).

8. 1. Batchelor G. On the Spontaneous Magnetic Field in Conducting Liquid in Turbulent Motion. // Proceedings of the Royal Society of London, Ser. Math. And Phys. Sciences, v.21, London, Cambridge Univ., 23 May, 1950

9. A.I. Lebo, I.G. Lebo. Possibility of Eddy Currents and Spontaneous Magnetic Fields Observations in Plasma Formed through the Interaction of High-Power Laser Pulses with Porous Targets. // Mathematical Models and Simulations, v2(3), 359-361, (2010)

10. A.I. Lebo, I.G. Lebo. On the possibility of spontaneous magnetic field observation in turbulent laser plasma. // Electronic journal "MSTU MIREA Herald", N3(4), pp.215-222, 2014 – in Russian, (https://www.mirea.ru/science/vestnik-mirea).

11. S.S. Kotel'nikov, I.G. Lebo, V.B. Rozanov. Interaction between an electron beam and magnetic fields in laser plasma. // Soviet Physics – Lebedev Institute Reports. Allerton Press. Inc. N12, pp. 95-100, 1986,

12. P.V. Konash, I.G. Lebo. Simulations of electron-beam scattering by spontaneous magnetic fields in laser plasma. // Quantum Electronics, 36(8), 767-772, (2006)

13. Yu. V. Korobkin, A.I. Lebo, I.G. Lebo. Investigation of the foreplasma parameters of a laser-plasma diode. // Quantum Electronics. 40(9), 811-816, 2010