**Engineering Physics**
2018; 2(2): 53-57
http://www.sciencepublishinggroup.com/j/ep
doi: 10.11648/j.ep.20180202.14
ISSN: 2640-1010 (Print); ISSN: 2640-1029 (Online)

# On the Possibility of Spontaneous Magnetic Field Observation in Turbulent Laser Plasma

**Alexandra Lebo[1], Ivan Lebo[2]**

[1]Faculty of Business Informatics, National Research University Higher School of Economics, Moscow, Russia

[2]Institute of Cybernetics, Russian Technologic University MIREA, Moscow, Russia

## Email address:
lebo@mirea.ru (I. Lebo)

## To cite this article:
Alexandra Lebo, Ivan Lebo. On the Possibility of Spontaneous Magnetic Field Observation in Turbulent Laser Plasma. *Engineering Physics*. Vol. 2, No. 2, 2018, pp. 53-57. doi: 10.11648/j.ep.20180202.14

**Received**: August 29, 2018; **Accepted**: November 1, 2018; **Published**: December 4, 2018

**Abstract:** It has been discussed the opportunity of the spontaneous magnetic field (SMF) observation in turbulent hot plasma which formed as the result of power laser beam interaction with porous low density matter. The sources of SMF appearance are the crossed gradients of electron pressure and plasma density, which arise in the turbulent zone and increase with its development. It has been proposed two diagnostic methods for investigation of SMF generation in turbulent laser plasma. The first method bases on the idea of the constrained orientation of magnetic moments with help of the external strong regular magnetic field (~ 0.1 MG). The second method bases on the idea of bunch electron scattering observation in the magnetic fields. The Mega Gauss SMF could effect on energy transport in laser plasma. The generation of SMF up to 100 MGs in low density substance could suppress the electron heat conductivity into the wall of cone target and improve the conditions of "dynamical confinement" of compressed DT fuel.

**Keywords:** Turbulent Laser Plasma, Spontaneous Magnetic Fields, Two Methods of SMF Observation

## 1. Introduction

In several developed countries in the world (USA, France, China, Russia and other) active efforts are being made to construct power laser system for initiating thermonuclear implosions. In such facilities, thermonuclear micro explosions give rise to high-power fluxes of thermonuclear neutrons, charged particles, hard electromagnetic radiation and strong spontaneous magnetic field generation. The huge magnetic fields (~10-100 MG) can affect the transfer of energy by charged α-particles and electron heat conductivity in laser fusion targets. The achievement of giant fields under laboratory conditions is of independent scientific interest.

The powerful laser pulse ($I \cdot \lambda^2 \sim 10^{14}$-$10^{15}$ [(W/cm$^2$)·μm$^2$], I – intensity, λ – laser wavelength), 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 observation of the scattering of the relativistic electron bunch in the field.

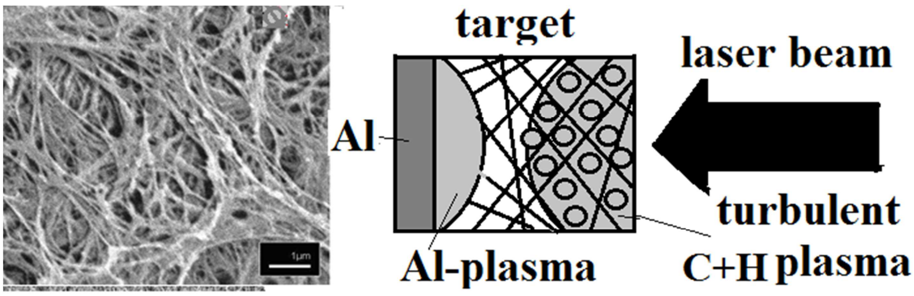
## 2. Turbulent Whirls and Magnetic Field Generations in Laser Plasma from Porous Targets

The spontaneous magnetic fields (SMF) in laser-induced spark [1] and in the laser irradiation of condensed target [2, 3] were first observed with help of wire probes more than forty years ago. The theoretical studies carried out in 1970-1980s have shown that field of a mega-Gauss value can be generated into laser plasma, produced by laser radiation with intensity ~$10^{14}$-$10^{15}$ W/cm$^2$ [4 - 10]. The optical experimental techniques used to observe SMFs directly in plasma were developed. These techniques were manly based on the known Faraday effect asserting that by the propagation of a plane-polarized laser beam along the magnetic field line, the rotation of the polarization plane around the axis, which coincides with the magnetic field line direction, occurs. The measurements have shown the fields ~ 1MGs in under critical expanded plasma [11, 12].

In a number of different countries laboratories the interaction of high-power laser radiation (the intensities $I \sim 10^{13}$-$10^{15}$ W/cm$^2$) with porous media has been studied [13-17]. The irradiation of porous matter by power laser pulse has leaded to hot turbulent plasma formation.

Figure 1 illustrates the process of plasma formation. 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. In the initial stage the main part of laser flux hits aluminum base and evaporate it. Aluminum plasma expands towards laser beam.

But the strings are run hot and imploded. The collisions of evaporated matter currents lead to eddy formations. As the result, the turbulent laser plasma is created (see Figure 1b, right side).




a) b)

***Figure 1.*** *Left side (a): image of cellulose triacetate (TAC) matter with ρ~10 mg/cm$^3$, right side (b): scheme of laser beam– foam interaction, formation of hot turbulent plasma formation. A foam matter (irregular grid) placed on thin aluminum base Al). The cycles illustrate the whirls.*

In the next stage the laser beam comes through the turbulent plasma and heats it. In [18, 19], we offered the physical-mathematical model and carried out numerical simulations, modelling the experiments at "PALS" (in Prague) installation [20]. The model is based on the basic hypothesis that the 3D eddy currents are developed in hot plasma. In order to describe the energy transport in such plasma we have introduced an effective rate of the turbulent pulsations ($\nu_p$) in the transport coefficients, when $\nu_p > \nu_e$ (electron collision frequency). The scale of turbulent pulsation is $l_p=c/\nu_p$, where $c$ is the speed of light ($l_p \sim 1\mu$m).

It is known, that eddy currents induce spontaneous magnetic fields in the conducting matter [21]. The crossed gradients of pressure and density are the sources of curls and magnetic fields generation.

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

Here is $\vec{B}$, $\vec{\omega}$ are magnetic field strength and curl, $\vec{V}$ is plasma velocity vector, $e$ is electron charge, $Z$, $m_i$ are charge and ion mass, $P$, $Pe$ are total and electron pressures ($P \approx \frac{Z+1}{Z} P_e$), $\rho$ is density.

These fields would be able to attain up 10 - 30 MG in turbulent high temperature laser plasma [22]. 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 $\nabla T$ is temperature gradient, $l_p$ is scale of turbulent pulsation ~ $d$ is scale of pore, $u \sim |\vec{V}|$ is plasma flow velocity, $L$ is scale of plasma inhomogeneity. From numerical simulations [19, 22]: $\nabla T \approx 1.6 \cdot 10^{-7}$ 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.

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

## 3. On the Possibility of the Constrained Orientation of Magnetic Moments in Laser Plasma

Figure 2 illustrates the first type of the experiments for the observation of the spontaneous magnetic field in turbulent plasma. The external strong regular magnetic field (~ 0.1 MG) is produced with help of powerful charge in the two special electrodes (see Figure 2a)[1]. The porous target is placed between the electrodes. The laser beam comes through the coil and absorbed in porous target. The hot turbulent plasma is produced. It contains the whirls and magnetic moments with arbitrary vectors of orientation in space (see

1 The results of the experiments of the laser plasma magnetization with help of such device have been presented in [23].

Figure 2b). The external field regularizes the magnetic moments orientations (see Figure 2c). The magnetic fields would be able to observe with help of diagnostic wire probe.

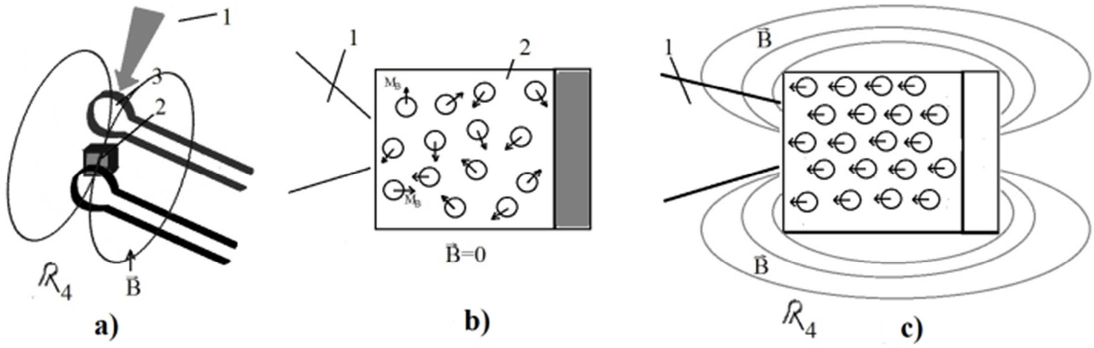



***Figure 2.*** *A scheme of external magnetic field production near laser target (a), porous target on mount and magnetic moments ($M_B$) distribution in turbulent laser plasma without external field (b), magnetic moment reorientation under action of external magnetic field into turbulent plasma (c). 1 – laser beam, 2 – target 3- installation, which has produced the external field, 4 – diagnostic wire 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. The comparison of the results of these experiments would allow to estimate the value of SMF in plasma.

# 4. 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 [24]. We believe, that it is possible to use a scheme of "laser-plasma diode" [25] for formation of such e-bunches. Figure 3 illustrates the scheme of production of the e-bunch. The first laser beam is diagnostic one (Laser 1). It has intensity $I \sim 10^{16}$-$10^{17}$ W/cm$^2$, the pulse duration is ~ 10-100 ps, the diameter of focal spot is $\underline{d} \sim$ 10-50 μm. The diagnostic e-bunch is created with help of a 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 second intensive laser pulse irradiates the porous target and creates hot plasma. The laser beam intensity (Laser 2) is $I \sim 10^{14}$-$10^{15}$ W/cm$^2$, the pulse duration is ~ 1 ns, and focal spot with diameter $\underline{d} \sim$ 200-500 μm.

This diagnostic e-bunch has normal direction to basic laser beam and comes through laser plasma (see Figure 3).

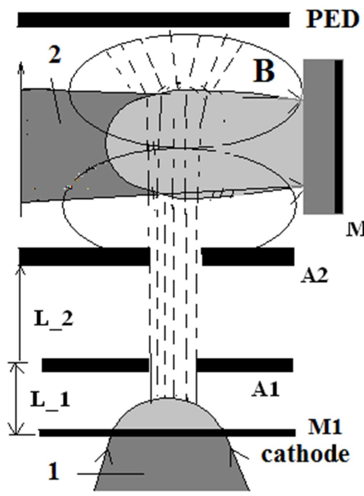



***Figure 3.*** *A design of diagnostic e-bunch formation. 1 – laser beam, which has formed hot plasma for e-bunch formation, M1 – target for hot plasma formation (cathode), A1, A2 – the first and the second anodes. 2 – laser beam, which has formed turbulent plasma. M2 – porous target, which has formed turbulent plasma with internal magnetic fields, PED-Photo-electronic device, L_1, L_2, L3 – interspaces between electrodes.*

# 5. The Observation of Spontaneous Magnetic Field (SMF) with Help of E-Bunch Scattering

The diagnostic e-bunch is scattering in the spontaneous magnetic fields of turbulent laser plasma. In fact, the Larmor radius of electron $R_L \sim \sqrt{\varepsilon_e}$ , but it's collision path is $l_e \sim \varepsilon_e^2$, here $\varepsilon_e$ is electron energy in bunch. So it is possible to choose $\varepsilon_e$ to divert the electron stream only with help of the SMF (see also [26]).

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

$\langle\varphi\rangle = 0.55\cdot\sqrt{\frac{Z}{A}\frac{\langle\rho L\rangle\cdot\Lambda_Q}{\varepsilon_e^2[\text{MeV}]}} \leq 0.005$ [rad]. Here is $Z$, $A$ – average charge end atomic ion number in plasma, $\langle\rho L\rangle = \int_0^L \rho dx$ - "integral" parameter of plasma density along the e-bunch direction [in g/cm$^2$], $\Lambda_Q$ – Coulomb logarithm, $\varepsilon_e$ - electron energy in bunch [in MeV]. If $B$ ~ 10 MG, then the Larmor radius is ~ 1 μm and $\langle\varphi\rangle_B \geq 0.1$ rad (e-deviation in the magnetic fields is much more than 0,005 rad!).

Figure 4 illustrates a scheme of experiments. 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.

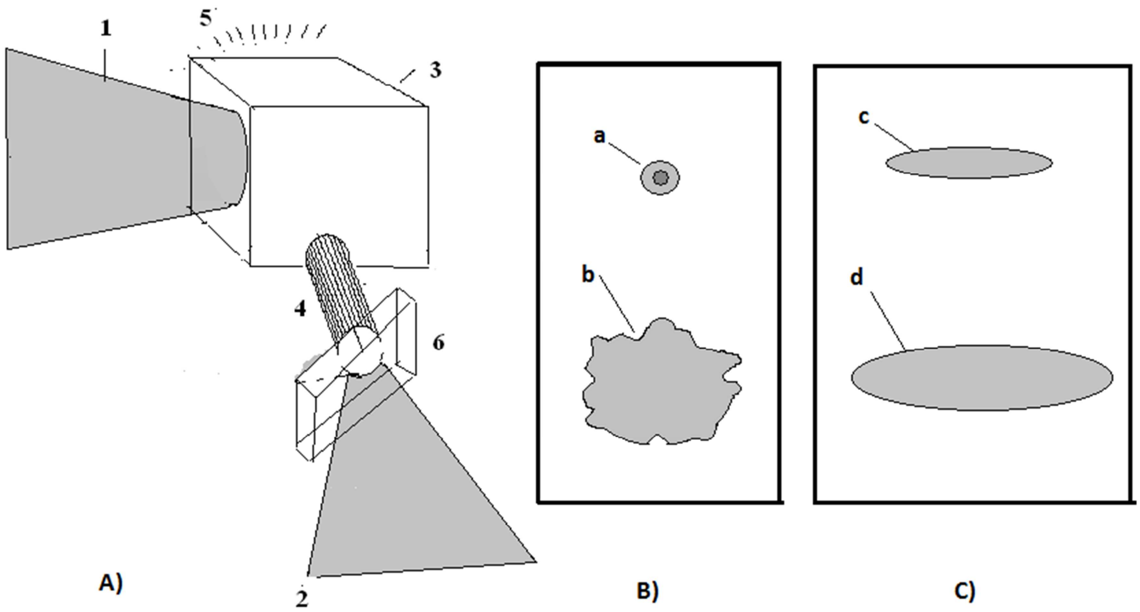



***Figure 4.*** *Scheme of SMF observation in plasma with help of e-beams (A). 1- Main heating laser beam (laser2) of nanosecond duration, 2 – laser beam (laser 1) picosecond duration, which has formed e-bunch, 3 – porous target, 4 – diagnostic e-bunch, 5 – scattering electron bunch, 6 – diagnostic device 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)*

# 6. The Main Results.

1. The external magnetic field would be able to regularize the magnetic moment directions in turbulent plasma.
2. It allows to observe the spontaneous magnetic fields (SMF) with help of the diagnostic probes, which placed near the plasma plume.
3. The other method of SMF study in turbulent laser plasma bases on the scattering of diagnostic e-bunch in magnetic fields. We have considered the design of such diagnostic scheme.
4. The achievement of huge magnetic fields in laser thermonuclear targets can affect to transfer of energy by charged particles in compressed DT fuel [27].

# 7. Conclusion

Earlier the concept of thermonuclear neutron source for laser driven hybrid fusion-fission reactor has been published in [28]. In order to produce "dynamical confinement" of compressed DT fuel at the conic summits it has proposed to use a set of short laser pulses (t ~ 100 ps and a total energy ~ 50-60 kJ). The laser energy has been absorbed in low density aerogel.

The hot low density matter allows to improve the smoothing of the pressure at the compressed DT fuel - wall interface near the conic summit.

The generation of spontaneous magnetic fields of ~100 MGs in low density substance could also suppress the electron heat conductivity from DT-fuel into the wall of cone target.

The experimental study of MGs magnetic fields in turbulent plasma ("turbulent dynamo") under laboratory conditions has important scientific interest for space physics.

# References

[1] Korobkin V. V., Serov R. V. (1966), Pis'ma v Zhurnal Eksp. Teor. Fiziki, 4,103-106 (in Russian).

[2] Askar'yan G. A., Rabinovich M. S., Smirnova A. D., V. B. Studenov V. B.. (1967). Pis'ma v Zhurnal Eksp. Teor. Fiziki. 4, 116-120.

[3] Stamper J. A. et al. (1971). Phys. Fluids, v.26, 1012-1019.

[4] Bol'shov L. A., Dreizin Yu. A., Dyikhne A. M. (1974). Pis'ma v Zhurnal Eksp. Teor. Fiziki, 77, N19, 289-191, (in Russian).

[5] Al'terkop B. A., Mishin E. B., Rukhadze A. A. (1974). Pis'ma v Zh. Eksp. Teor. Fiziki, 77, N19, 292-294, (in Russian).

[6] Craxton R. S., Hains G. (1975), Phys. Rev. Letters, 35, 1336-1346.

[7] Colombant D. G., Winsor N. K., (1977), *Phys. Rev. Letters*, 38, 1278-1285

[8] Afanas'ev Yu. V., Gamaly E. G., Lebo I. G., Rozanov V. B. (1978), Zhurnal Exp, Teor. Fiziki, 74(2), 516-524 (in Russian).

[9] E. G. Gamaly, I. G. Lebo, V. B. Rozanov. (1985). Spontanie magnitnie polya v sfericheskoy lazernoy plazme. Trudi Fizicheskogo Instituta im. P. N. Lebedeva. Academiya nauk SSSR. V.149, 66-96, Moskva, Nauka (in Russian).

[10] Diankov O. V., Glazirin I. V., Koshelev S. V. et al. (2000). Laser and Particle Beams, 18(2), 255-260.

[11] Stamper J. A., McLean E. A., Ripin B. H. (1978). Phys. Rev. Letters, (1978), v.40, 1177-1181.

[12] F. V. Bunkin, Yu. S. Kas'anov, V. V. Korobkin, S. L. Motilev. (1983). Kvantovaya Electronika, 10, 2149-2151.

[13] Dune M., Borghesi M., Ivase A. et al. (1995). Phys. Rev. Letters. 75 (21), 3858-3861.

[14] Koch J. A., Esterbrook K. G., Bauer J. D. et al. (1995). Phys. Plasmas, 2, 3820-3831.

[15] Bugrov A. E., Burdonskiy I. N., I. K. Fasakhov et. al. (2003). *Proc. Of SPIE*, v.5228. Ed. By O. N. Krokhin, S. Yu. Gus'kov, Yu. A. Merkuliev, Bellingham. WA.

[16] Borisenko N. G., Akunets A. A., Khalenkov A. M. et al. (2007). Journal of Russian Laser Research. 28, N.6, 548-566, 2007.

[17] Borisenko N. G., Merkuliev Yu. A. (2010). Jour. of Russian Laser Research. 31, N3, 256-269.

[18] Lebo A. I., Lebo I. G. (2009). Mathematical Models and Simulations, 1(6), 724-738.

[19] Lebo A. I., Lebo I. G. (2010a). A model of the energy transport in turbulent plasma of porous targets. *IOP Publishing. Phys. Scripta*, T142, 014024 (4pp).

[20] Jungwirth K., Cenarova A., Juha L, Kralicova J. et al. (2001). Phys. Plasmas, 8, 2495-3006.

[21] Batchelor G. (1950). On the Spontaneous Magnetic Field in Conducting Liquid in Turbulent Motion. Proceedings of the Royal Society of London, Ser. Math. And Phys. Sciences, 21, London, Cambridge Univ., 23 May.

[22] Lebo A. I., Lebo I. G. (2010). Mathematical Models and Simulations, 2(3), 359-361.

[23] Gotchev O. V., Chang P. Y., Knauer J. P. et al. (2009), Phys. Rev. Letters, 103, 215004(4).

[24] Kotel'nikov S. S., Lebo I. G., Rozanov V. B. (1986). Soviet Physics – Lebedev Institute Reports. Allerton Press. Inc. N12, 95-100.

[25] Korobkin Yu. V., Lebo A. I., Lebo I. G. (2010). Quantum Electronics. 40(9), 811-816.

[26] Konash P. V., Lebo I. G., (2006). Quantum Electronics, 36(8), 767-772.

[27] Konash P. V., Lebo A. I., Lebo I. G. (2013). Mathematical Models and Computer Simulations. 6(1), 9-18

[28] Lebo I. G., Isaev E. A., Lebo A. I. (2017). Quantum Electronics, 47(2), 106-110. Kvantovaya Elektronika and Turpion Ltd.