PLASMA CONFINEMENT BY MEANS OF POLOIDAL-TOROIDAL MAGNETIC SURFACES

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The paper proposes to perform plasma magnetic confinement in the constructions where plasma streams flow by knotted trajectories. It is shown that in this case due to more complicated topology of plasma circulation, a quasi-stationary equilibrium may be carried out without an external magnetic field, and i.e. plasma is self-confined by the self-generation of poloidal-toroidal magnetic surfaces. This phenomenon may serve as a mechanism of a ball-lightning origination and existence.
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1. INTRODUCTION

It is shown that plasma magnetic confinement may be carried out not only in tokamaks and stellarators (see, for example, [1, 2]), but in quite new constructions where plasma streams flow by knotted trajectories. If it aimed at the creation of thermonuclear synthesis reaction, such constructions may be called knotted thermonuclear synthesis reactors (KTSR). Note that first the idea concerning such constructions on heuristic level was expressed in [3, 4].

Thus, let in KTSR the magnetic axis, i.e. the line corresponding to maximum pressure, is written down in the following vector parametric form:

$$\vec{\rho}(\phi)=\left\{\left(R+r\cos\phi_n\right)\cos\phi,\left(R+r\cos\phi_n\right)\sin\phi,\pm r\sin\phi_n\right\}, \quad (1)$$

where $\phi_n=\left(n+1/2\right)\phi$, $-2\pi\le\phi\le 2\pi$, R,r – tore parameters, on the surface of which (Seifert surfaces [5]) one may trace this space curve (here the signs "$\pm$" correspond to right- and left-hand n-foils). In Fig. 1 possible magnetic surfaces with magnetic axis (1) in the case of the meanings of $n=3,5,7,9$ are represented. Besides, in this figure as an example of 5-foils, a current toroidal line is expressed schematically by a dotted line from foil 3 to foil 4 and originated by the poloidal magnetic field (heavy line). This field in concern to foil 1 is also simultaneously toroidal. Thus, an arising magnetic surface may be called poloidal-toroidal. It is generated by a toloidal-poloidal plasma current and vice versa. One may say that in the case of non-dissipative plasma the external field pressure is not in need of its confinement. At the expense of a complicated topology of KTSR, plasma in it, in a stationary regime will be considerably confined by itself. In such constructions some internally distant regions in an external region are neighboring which leads to their magnetodynamic interaction. Maybe just such constructions will be the most optimal for magnetic (correctly, self-confinement) of plasma and at last, the confinement solution of one of the main problems is the realization of the controllable thermonuclear synthesis. Further we will try to substantiate the above mentioned just from the mathematician point of view.

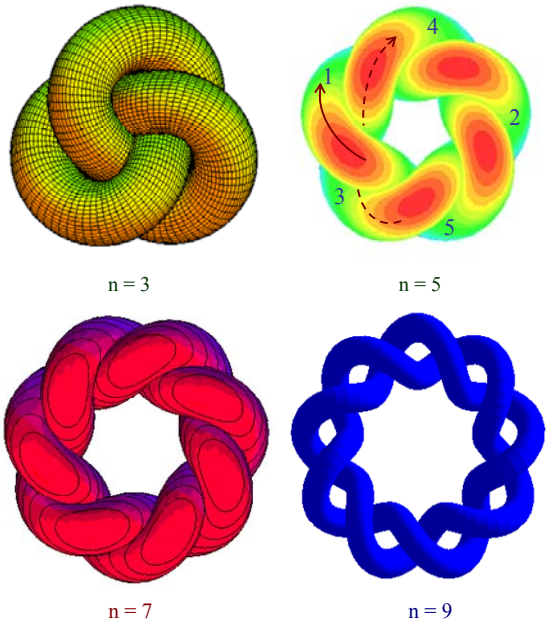

Fig. 1. Schematic representation of knotted poloidal-toroidal-magnetic surfaces at various meanings of the parameter n

2. THE ORIGINATION OF POLOIDAL-TOROIDAL MAGNETIC SURFACES IN KNOTTED PLASMA VOLUMES

As in [6], we will start the investigation of the equilibrium condition of knotted plasma stream from the notes of the magnetic hydrodynamics equations

$$-\nabla p+\frac{1}{c}\left[\vec{j},\vec{H}\right]+\rho\nabla\Phi=0,\quad \mathrm{rot}\,\vec{H}=\frac{4\pi}{c}\vec{j},$$
$$\Delta\Phi=-4\pi G\rho,\quad \mathrm{div}\,\vec{H}=0, \quad (2)$$

where ρ, p – density and pressure of a conducting plasma, $\vec{j}$, $\vec{H}$ – current density and a magnetic field strength, Φ, G – gravitation potential and gravitation constant. However, now besides a local magnetohydrodynamic interaction leading to the generation of poloidal magnetic field plasma by a toroidal current there is a non-local interaction leading to the

generation of poloidal currents by toroidal magnetic fields.

Analogous to [7] at the calculation of electrostatic potential in non-local polarizable medium, in our case at the calculation of magnetic values instead of conduction current $\vec{j}(\vec{r})$ in the second equation of magnetostatic we substitute the current

$$\vec{j}(\vec{r}) + \frac{c\kappa}{4\pi}\mathrm{rot}\left[\int_{\vec{r}''}\vec{H}(\vec{r}')F(\vec{r}-\vec{r}')d\vec{r}'\right], \qquad (3)$$

which takes into account the reverse effect on the current in point of $\vec{r}$ of magnetic fields of $\vec{H}(\vec{r}')$ in the points $\vec{r}'$. Here κ – a dimensionless coefficient depending on the parameters of medium and the system geometry, $F(\vec{r}-\vec{r}')$ – an averaging nucleus taken as a function of $F(\vec{r}-\vec{r}') = \exp\left[-(\vec{r}-\vec{r}')^2/a^2\right]/\pi^{3/2}a^3$, where a – an averaging length, depending on medium parameters. Further, substituting (3) into the second equation of the system (2), we get integro-differential equation

$$\mathrm{rot}\left\{\vec{H}(\vec{r}) - \kappa\int_{\vec{r}''}\vec{H}(\vec{r}')F(\vec{r}-\vec{r}')d\vec{r}'\right\} = \frac{4\pi}{c}\vec{j}(\vec{r}), \qquad (4)$$

which should be used in the system (2) instead of the second equation. From here it is evident that since magnetic hydrostatics equation remains invariable, magnetic field lines and lines of flux are as usual arranged at the surfaces of the constant pressure of $p = \mathrm{const}$ (see, for example, [8, 9]), in spite of the fact that now these lines must not be self-orthogonal. It allows to take advantage of the results of [6, 9], where by means of Grad-Shafranov equation for axial-symmetric systems it is shown that at some parameters we get limited toroidal configurations nearby magnetic axis with circular cross-sections. One may admit that just in the case of magnetic axis like a space curve (1) there arise nearby limited configurations such as, for example, in Fig. 1. It could be shown strictly mathematical using orthogonal system of Mercier coordinates (see for example, [10]), connecting with the curve (1). Giving a spiral-like lines of flux winding on a knotted limited surface one may by means of equation (4) find magnetic field lines. Using Fourier transformation to the equation (4), we find

$$\vec{H}(\vec{r}) = \frac{4\pi}{c}\int_{\vec{r}'}\left[\vec{j}(\vec{r}'),\vec{G}(\vec{r}-\vec{r}')\right]d\vec{r}', \qquad (5)$$

where

$\vec{G}(\vec{r}-\vec{r}') = (2\pi)^{-3}\int_{\vec{k}}\frac{\vec{k}\sin\left[\vec{k}(\vec{r}-\vec{r}')\right]d\vec{k}}{k^2\left[1+\kappa\exp\left(-k^2a^2/4\right)\right]}$ – vector Green's function, transforming at $\kappa = 0$ into the function of $\vec{G}(\vec{r}-\vec{r}') = (\vec{r}-\vec{r}')/4\pi|\vec{r}-\vec{r}'|^3$, and the formula (5) into the law of the Bio-Savara-Laplasa.

3. THE OBTAINING OF THE CONDITION OF A STEADY BALANCE IN KNOTTED CONFIGURATIONS

It is known [8, 9], that in the case of plasma confinement in tokamaks and stellarators there is so-called virial theorem, leading to a condition of

$$\int_{\vec{r}}\left(3p + \frac{H^2}{8\pi}\right)d\vec{r} = 0, \qquad (6)$$

which fulfills only at the meanings of $p = 0$ and $\vec{H} = 0$, when plasma is absent.

Substituting current density from the equation (4) into the first equation of the system (2) (we neglect gravitation potential Φ in this case), after the transformations given in [8], we get an essential condition of a steady equilibrium

$$\int_{\vec{r}}\left(3p + \frac{H^2}{8\pi}\right)d\vec{r} = \\ = \frac{\kappa}{4\pi}\int_{\vec{r}}\left(\vec{r}\cdot\int_{\vec{r}'}\left[\vec{j}(\vec{r}),\left[\nabla_{\vec{r}}F(\vec{r}-\vec{r}'),\vec{H}(\vec{r}')\right]\right]d\vec{r}'\right)d\vec{r}, \qquad (7)$$

which fulfills just at some zero meanings of p and $\vec{H}$, that admits plasma presence. Thus, plasma confinement is possible just at the expense of own magnetic field.

4. ON THE MECHANISM OF BALL-LIGHTNINGS GENERATION FROM THE POINT OF VIEW OF KNOTTED OR BUNCHING PLASMA STREAMS

There are some statements (see, for example, [6, 11]) that ball-lightnings are closed currents. On the basis of above mentioned it is more natural to suppose that currents in ball-lightnings are knotted (or bunching). May be the mechanism of ball-lightnings generation is in that magnetic field lines of the current curved lines at the expense of bunching from the side of positive curvature curve plasma streams more strongly and at last knot them. And maybe only in this case, as it follows from the condition (7), they may be self-confined at the expense of own magnetic fields (in many papers it is also stated that gravitation forces including into the first equation of the system (2) also play an essential role). In this connection the most frequently met ball-lightnings of 20...30 cm [12] in dimension are evidently simple knots (right- or left-hand trifoils). In nature we find some other kinds of ball-lightnings in the form of ellipsoids, strips, cylinders, spindles having tails, etc. [12]. Evidently, they may be as well compared with various knotted structures [5]. Just there may origin ball-lightnings in the form of bunching plasma vortices. For example, such a scenario may be represented by one of the frames of the cinerama in [12, 13], shown in Fig. 2 on the left. It represents the formation of three nearby placed plasmoids associated with Borromean rings (picture in Fig. 2 on the right).

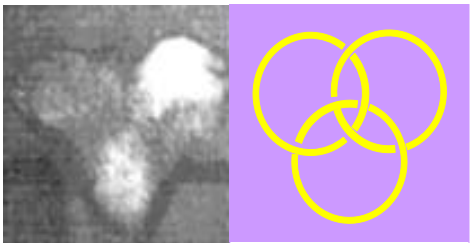

Fig. 2. The comparison of three forming plasmoids with Borromean bunching

At the end of this paragraph it should be mentioned, as it is stated in [13], that sometimes in ball-lightnings we observe an internal structure like, for example, shining layers or moving sparks. It may serve one more argument in favor of the proposed mechanism of ball-lightnings origination.

5. CONCLUSIONS

Thus on the basis of above mentioned we may suppose that in the proposed knotted constructions plasma confinement at the expense of poloidal-toroidal magnetic surfaces will be longer than in tokamaks and stellarators which may lead to the achievement of Lousson criterion in the conditions of self-compensated plasma instabilities. Maybe exotic natural phenomena in the form of long-lived ball-lightnings are just empiric confirmations of the correct geometry choice while constructing thermonuclear synthesis generators in the form of knotted constructions.

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УДЕРЖАНИЕ ПЛАЗМЫ С ПОМОЩЬЮ ПОЛОИДАЛЬНО-ТОРОИДАЛЬНЫХ МАГНИТНЫХ ПОВЕРХНОСТЕЙ

Н.В. Максюта, Г.П. Головач, Е.В. Мартыш

Предлагается магнитное удержание плазмы осуществлять в конструкциях, в которых плазменные потоки движутся зауженными траекториями. Показывается, что в этом случае за счет более сложной топологии циркуляции плазмы квазиустойчивое равновесие может существовать и без внешнего магнитного поля, т.е. плазма удерживает сама себя с помощью порождаемых ею полоидально-тороидальных магнитных поверхностей. Это явление может служить механизмом возникновения и существования шаровой молнии.

УТРИМАННЯ ПЛАЗМИ ЗА ДОПОМОГОЮ ПОЛОЇДАЛЬНО-ТОРОЇДАЛЬНИХ МАГНІТНИХ ПОВЕРХОНЬ

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Пропонується магнітне утримання плазми здійснювати в таких конструкціях, в яких плазмові потоки рухаються завузленими траєкторіями. Показується, що в цьому випадку за рахунок більш складної топології циркуляції плазми квазістійка рівновага може існувати і без зовнішнього магнітного поля, тобто плазма утримує сама себе за допомогою породжуваних нею полоїдально-тороїдальних поверхонь. Це явище може слугувати механізмом виникнення та існування кульової блискавки.