A MODIFIED *lm*=1 STELLARATOR MAGNETIC SYSTEM

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Numerical studies into the toroidal magnetic field structure of a new modification of the l=1 polarity stellarator with a single (m=1) helical coil pitch along the whole length of the torus have been undertaken. Depending on mutual toroidal and helical magnetic field directions, there may exist two centered magnetic surface/helical divertor configurations in the modified lm=1 stellarator. Similar helical divertor configurations have been realized in the tokamak [9, 10] in order to stabilize large-scale instabilities and to avoid current disruption.

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1. INTRODUCTION

From an engineering viewpoint the magnetic system of the l=1 stellarator with a single (m=1) helical coil pitch along the whole length of the torus is one of the simplest stellarator-type magnetic systems. The stellarator contains only one magnetic field period, lm=1. In comparison with other helical coil systems (lm>1), the system under discussion provides a better access to the working volume and can minimize the helical coil materials consumption, approaching in these characteristics to tokamak magnetic systems that have an extensive magnetic divertor.

However, from the viewpoint of providing, for example, a greater space between the magnetic surface existence region, i.e., the plasma core, and the wall, the classic scheme of the l=1 stellarator magnetic system substantially ranks below more complicated l=2,3,4 polarity helical systems. This is connected with the properties of both a spatial magnetic axis and a single separatrix rib of the magnetic surface configuration in the l=1 stellarator [1-3]. In the case of the lm=1 stellarator with sizable toroidicity, the magnetic surface existence region is localized close to the minor equator of the torus [4]. For this reason, it may appear to be of little use for the stellarator experiment.

This paper reports the results of numerical calculations for the modified lm=1 stellarator magnetic system model that permits one to avoid appreciably the above-mentioned drawbacks.

2. THE ESSENCE OF MODIFICATION

The essence of modification consists in the fact that one of the two helical coils of an ordinary lm=1 stellarator (Fig. 1,a) is fully split into two equal parts [5]. The parts have equivalent currents ($-I$) and are displaced [6] symmetrically relative to the unsplit helical coil (current $2I$) by a certain angle $|\Delta\varphi|<\pi$ in the toroidal direction (see Fig. 1,b).

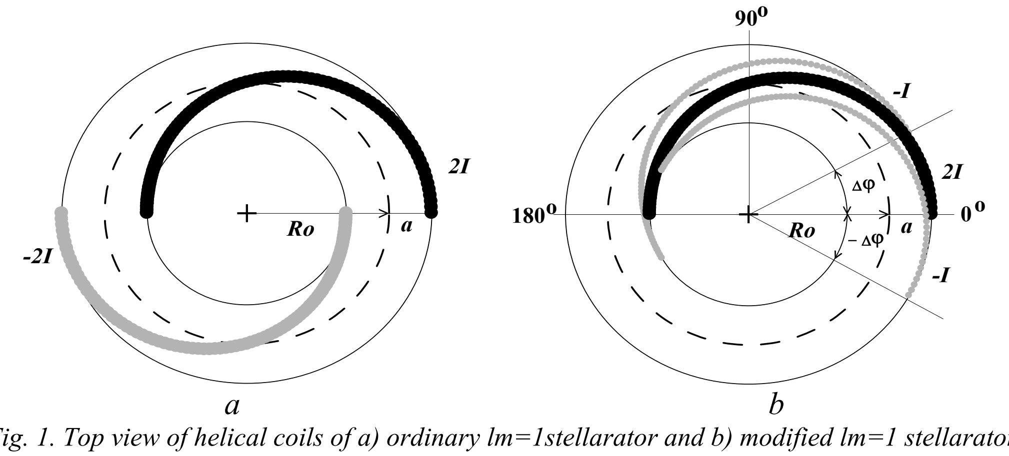

Fig. 1. Top view of helical coils of a) ordinary lm=1stellarator and b) modified lm=1 stellarator. The toroidal azimuths of poloidal cross-sections are shown (see Fig. 2)

3. CALCULATION MODEL

Numerical calculations of the modified lm=1 stellarator magnetic system were carried out for the following ideal model:
- toroidicity $\alpha=a/R_0$=0.3 (a is the minor radius of the torus, R_0 is the major radius of the torus); - polarity l=1;
- number of helical coil pitches along the length of the torus m=1;- the number of magnetic field periods lm=1;
- the number of filament-like helical conductor turns in each of 3 helical coils is 1;
- the helical coils are laid on the torus according to the cylindrical winding law $\theta(\varphi)=m\varphi$, where φ is the toroidal angle and θ is the poloidal angle;
- the toroidal (poloidal) angle of relative displacement of helical coils in the calculation model under consideration is $\Delta\varphi=\Delta\theta=30^{o}$.

The helical coil system is plunged into an axisymmetric magnetic field $B_\varphi=B_oR_o/R$ generated by the coils of the toroidal magnetic field (not shown in Fig. 1). Here B_o is the toroidal magnetic field value on the circular axis of the torus, R is the observation point radius counted from the rotation z-axis of the torus. The transverse magnetic field (perpendicular to the equatorial plane of the torus) is assumed to be absent, B_z=0.

4. RESULTS OF CALCULATIONS

As the calculations have shown, the magnetic field structure of the modified *lm*=1 stellarator depends to a great extent not only on the value of the toroidal magnetic field B_o, but also on its direction in relation to the value and direction of the helical-coil magnetic field. The calculations were performed for the both directions of the toroidal magnetic field with the same absolute value of the ratio B_o/b_o=25 (B_o/b_o=-25), b_o being the amplitude of circular-axis magnetic field generated by the helical current 2*I*. Hereafter, the values of magnetic field structure parameters for B_o/b_o=-25 are presented in brackets.

Fig. 2 shows the poloidal cross-sections of the magnetic surface configuration calculated in the modified *ml*=1 stellarator model. The cross-sections are spaced by the toroidal angle φ within the limits of the magnetic field half-period φ=0°, 90°, 180° (see Fig. 1,b). The dark and light circles in Fig. 2 indicate the position of thin current-carrying helical conductors with opposite current directions, which form the helical coils of the calculation model. They are found on the torus surface α =0.3 (thin large circles).

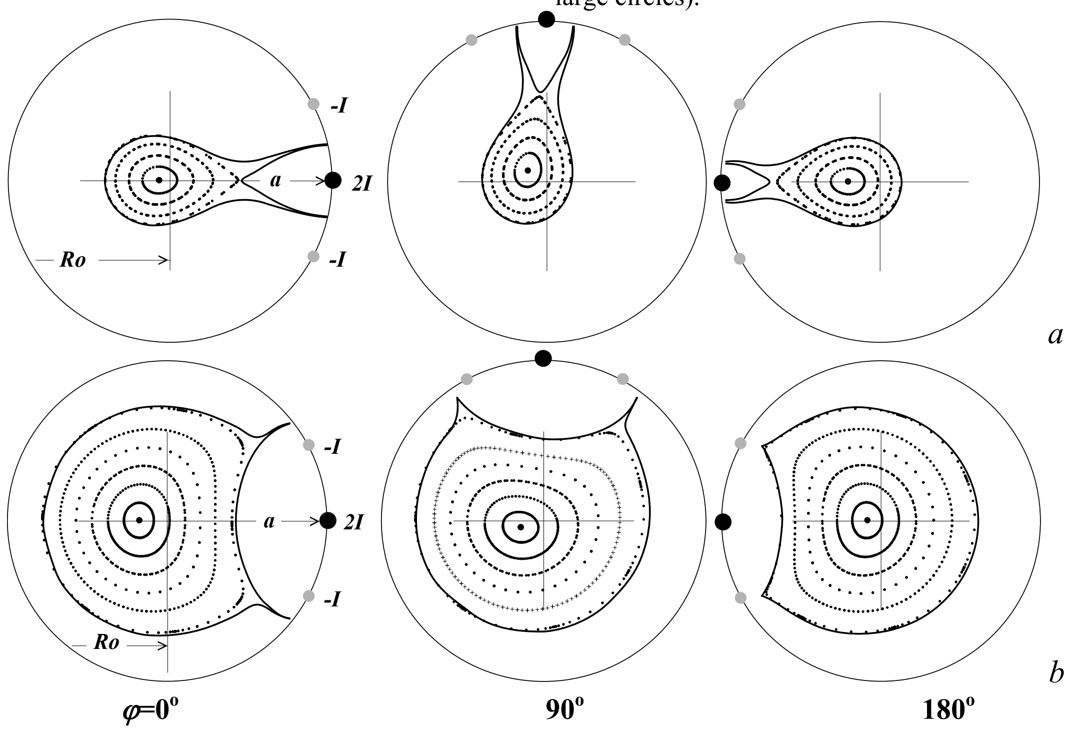

Fig. 2. Cross-sections of magnetic surfaces (dotted lines) and equiconnect [7] *(solid lines) in the modified lm=1 stellarator within the limits of the magnetic field half-period (see Fig. 1,b): a) B_o/b_o=25, b) B_o/b_o=-25*

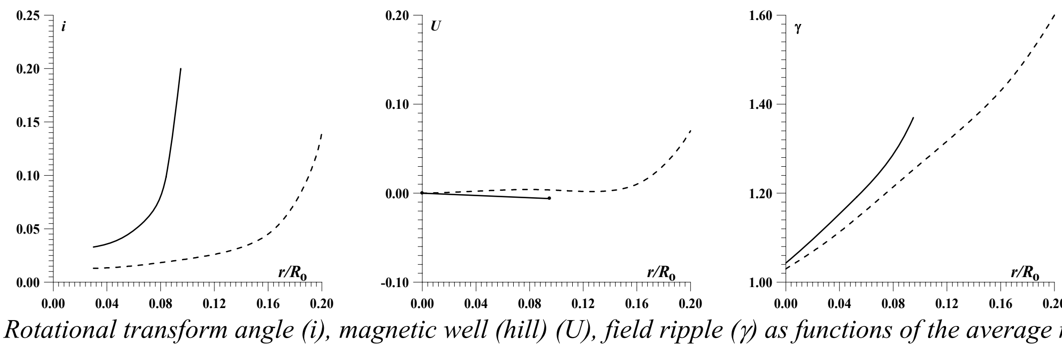

Fig. 3. Rotational transform angle (i), magnetic well (hill) (U), field ripple (γ) as functions of the average magnetic surface radius r/R_o in the modified lm=1 stellarator:B_o/b_o=25 - solid lines, B_o/b_o=-25 - dotted lines

From Fig. 2 it can be seen that the magnetic surface configuration contains a spatial magnetic axis in the form of *m*=1 helical line lying on the surface of the torus $r_{ax}/R_{oax}=\alpha_{ax}$. The calculation gives the major radius of the torus (magnetic-axis major radius) to be R_{oax}/R_o=0.962 (0.962), and the minor radius (magnetic-axis minor radius) to be r_{ax}/R_o=0.02 (0.013). Since $(1-R_{oax}/R_o)<<\alpha$ and $\alpha_{ax}<<\alpha$, the magnetic surface configuration appears slightly shifted inward the torus. In the ordinary *lm*=1 stellarator model, the value of the shift is close to the limiting value, $(1-R_{oax}/R_o)\sim\alpha$ [4].

It is also seen from Fig. 2 that in all the three cross-sections the form of the last closed magnetic surface (average radius r_{lc}/R_o=0.095 (0.2)) keeps well. This is an evidence of a higher helical symmetry stability of the modified *lm*=1 stellarator magnetic field relative to the perturbation caused by bending of the straight magnetic system into the toroidal one.

Fig. 2 illustrates the calculated cross-sections of the equiconnect surface (solid lines) [7, 8], i.e., the surface of the outer boundary of the stochastic layer of field lines. In the vicinity of the layer the plasma of transient parameters, the so-called SOL plasma, is confined. The SOL plasma is a source of diverted plasma fluxes. It follows from Fig. 2 that the considered modification of the *lm*=1 stellarator can provide realization of two different configurations of both the magnetic surfaces and the helical divertor by switching the toroidal magnetic field B_o direction.

The magnetic surface parameters as functions of their average radii are shown in Fig. 3. It can be seen from the figure that the rotational transform angle (in 2π units) is rather small, i~4×10^{-2} (2×10^{-2}) in the central part of the magnetic surface configuration. In the outer region, $r/R_o > 0.05$ (0.15), its value increases steeply up to i~0.2 (0.14) on the last closed magnetic surface. A moderate magnetic well (hill), U=0→-0.006 (0.07), and the field ripple γ=1.1→1.37 (1.6) are observed on the magnetic surfaces.

5. CONCLUSIONS

Consideration has been given to a new modification of one of the simplest stellarator-type magnetic systems, namely, the *l*=1 stellarator with a single (*m*=1) helical coil pitch along the whole length of the torus, i.e., with a single magnetic field period, *lm*=1.

The undertaken numerical studies have shown that the proposed technique of converting the magnetic system of the *lm*=1 stellarator into a modified version makes it possible to form two different, sufficiently well centered magnetic surface configurations. Their parameters meet the requirements for the stellarator experiment. One of the calculated magnetic surface configurations is characterized by an enlarged distance between the last closed magnetic surface and the surface of the support torus.

The present numerical calculations have given an idea of the position and form of the cross-sections for the equiconnect being the surface of the outer boundary of the layer of stochastic field lines. It has been demonstrated that the helical coil system of the *lm*=1 stellarator modification under consideration permits realization of two different helical-divertor configurations. Similar helical divertor configurations have been realized in the tokamak [9, 10] in order to stabilize large-scale instabilities and to avoid current disruption.

REFERENCES

1. A.I. Morozov, L.S. Solov'ev. *Problems of Plasma Theory.* M.: "Gosatomizdat", 1963, Is. 2 (In Russian).
2. V.G. Kotenko, S.S. Romanov. *On the possibility of control the ratio of a plasma radii and the first wall in fusion devices.* Kharkov: Preprint: KhFTI 83-8, 1983, p. 1-12 (in Russian).
3. V.G. Kotenko, V.I. Lapshin, G.G. Lesnyakov, S.S. Romanov, E.D. Volkov. A version of advancement towards a commercial fusion reactor // *Plasma Fusion Res.* 2000, v. 3, p. 541.
4. V.G. Kotenko. A modified magnetic system of the *lm*=1 stellarator // *International Conference-School on Pl. Phys. and Contr. Fus* Alushta, Ukraine, September 13-18, 2010, Book of Abstracts, p. 42.
5. V.G. Kotenko, D.V. Kurilo, Ju.F. Sergeyev, E.D. Sorokovoy, Ye.D. Volkov. The influence of helical coil splitting on the magnetic configuration of *l*=2 torsatron with an additional toroidal magnetic field // *Voprosy Atomnoj Nauki i Tekhniki, RSC "Kurchatov Institute". Ser. "Termoyaderny sintez".* 2009, N. 4, p. 30-36 (in Russian).
6. V.M. Zalkind, V.G. Kotenko, S.S. Romanov. Magnetic surface of the *l*=2 stellarator with displaced helical windings. // *Voprosy Atomnoj Nauki i Tekhniki RSC "Kurchatov Institute". Ser. "Termoyaderny sintez".* 2008, N. 4, p. 67-75 (in Russian).
7. V.E. Bykov, Yu.K. Kuznetsov, A.V. Khodyachikh, O.S. Pavlichenko, V.G. Peletminskaya // *A Collection of Papers Presented at the IAEA Technical Committee Meeting on Stellarators and other Helical Confinement Systems.* Garching, Germany, 10-14 May 1993. IAEA, Vienna, Austria, 1993, p. 391-396.
8. V.G. Kotenko. Possible mechanism for onset of vertical asymmetry of diverted plasma fluxes in a torsatron // *Fiz. Plazmy.* 2007, N 3, p. 280 (in Russian). *Plasma Phys. Rep.* 2007, N 3, p. 249 (Engl. transl.).

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МОДИФИЦИРОВАННАЯ МАГНИТНАЯ СИСТЕМА *lm*=1 СТЕЛЛАРАТОРА

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Проведено численное изучение структуры тороидального магнитного поля, создаваемого модифицированной магнитной системой однозаходного (*l*=1) классического стелларатора с одним шагом винтовой обмотки (*m*=1) на длине тора. В зависимости от направления тороидального магнитного поля относительно винтового магнитного поля в *lm*=1 стеллараторе возможно существование двух центрированных конфигураций магнитных поверхностей и винтового дивертора. Аналогичные винтовые диверторные конфигурации были реализованы в токамаке с целью стабилизации крупномасштабных неустойчивостей и подавления больших срывов плазменного омического разряда.

МОДИФІКОВАНА МАГНІТНА СИСТЕМА *lm*=1 СТЕЛЛАРАТОРА

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Проведено чисельні розрахунки тороїдального магнітного поля, створюваного модифікованою магнітною системою однозаходного (*l*=1) класичного стелларатора з одним кроком гвинтової обмотки (*m*=1) на довжині тора. В залежності від напрямку тороїдального магнітного поля відносно гвинтового магнітного поля в *lm*=1 стеллараторі можливе існування двох центрованих конфігурацій магнітних поверхонь та гвинтового дивертора. Аналогічні гвинтові диверторні конфігурації було реалізовано в токамаці з метою стабілізації крупномасштабних нестійкостей та придушення зривів плазмового омічного розряду.