AN l=2 TORSATRON WITH CENTERED PLANAR MAGNETIC AXIS

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The paper is concerned with properties of magnetic surface configurations that have the planar magnetic axis coincident with the circular geometrical axis of the torus. The calculations were performed for the model of an l=2 torsatron comprising additional toroidal magnetic field coils. The magnetic surfaces with a negative shear and a high magnetic well can be realized in the system.

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INTRODUCTION

It is known that transformation of a straight cylindrical l=2 helical magnetic system into the toroidal l=2 helical magnetic system is accompanied by transformation of the straight magnetic axis which coincides with the cylinder axis into a planar circular magnetic axis. The radius of the circular magnetic axis R_{oax} is less than the major radius of the torus R_o, $R_{oax}/R_o<1$ [1, 2]. This is one of the effects that result from the helical symmetry violation of the straight magnetic field, if the latter is bent into the toroidal field, and lead to a change in the integral characteristics of the magnetic surface configuration.

To date, two methods of changing the position of the planar magnetic axis relative to the torus surface are known [3, 4]. Both of them demand an essential deformation of the helical current geometry. One method implies the change in the helical base line winding law, and the other involves the change in the conductor turn packing in the helical coils.

The aim of the present work is to investigate numerically magnetic surface configurations with a centered (R_{oax}/R_o=1) planar magnetic axis which were formed as a result of combined application of the two methods to the l=2 torsatron model with additional toroidal magnetic field coils (ACs) as necessary elements for creating a closed magnetic surface region.

THE CALCULATION MODEL

The calculation model of the l=2 torsatron magnetic system with ACs is based on the design characteristics of the U-2M torsatron [5].

The parameters of the calculation model are as follows:

- toroidicity a/R_o=0.2618, a is the minor radius of the torus (average radius of helical coils);
- l=2 is the polarity;
- m=2 is the number of helical winding pitches along the length of the torus;
- the number of conductor turns in each single-layer helical coil is 20 (40 in total).

Each of the helical coils consists of two equal parts separated by a small diagnostic gap and comprising 10 conductor turns.

The helical base line, i.e., the helical line, along which the load-carrying structure of the helical coil is assembled, serves as the central diagnostic-gap line. The helical base line winding law has the form [3]:

$$\theta(\varphi)=\theta_1(\varphi)-k(\theta_2(\varphi)-\theta_1(\varphi)), \qquad (1)$$

where φ is the toroidal angle, θ is the poloidal angle, $\theta(\varphi)_1$ and $\theta(\varphi)_2$ are the known cylindrical and equi-inclined laws of helical line winding on the torus surface, k is the numerical coefficient.

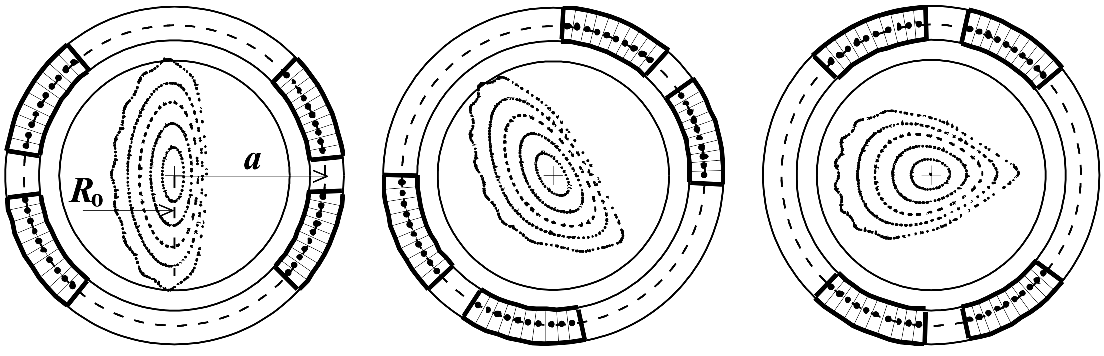
The compensating transverse magnetic field B_z is assumed in the calculations to be a uniform field. The planar magnetic axis regime is realized at a certain value of the compensating magnetic field $B_z=B_{zm}$.

The ACs magnetic field B_φ is axisymmetric ($B_\varphi=B_0R_0/R$, where B_0 is the value of the additional toroidal magnetic field on the circular axis of the torus, R is the observation point radius counted from the main torus axis (z-axis). The parameter $K=1/(1+B_0/b_0)$ also exerts influence on the magnetic surface configuration in the torsatron with ACs. Here b_0 is the amplitude of the toroidal component of the magnetic field generated by helical currents on the circular axis of the torus.

COMPUTATIONAL RESULTS

In accordance with ref. [4], the calculations were carried out for two methods (1, 2) of conductor turn packing in the helical coils along the base helical line.

Following method 1, each of 40 helical conductors is wound round the torus by the same winding law (1). The numerical calculations have shown that with this way of packing, in order to bring the planar magnetic axis of the magnetic surface configuration into coincidence with the circular geometrical axis of the torus, one must put k=0.3 in Eq. (1).



φ=0° φ=22.5° φ=45°

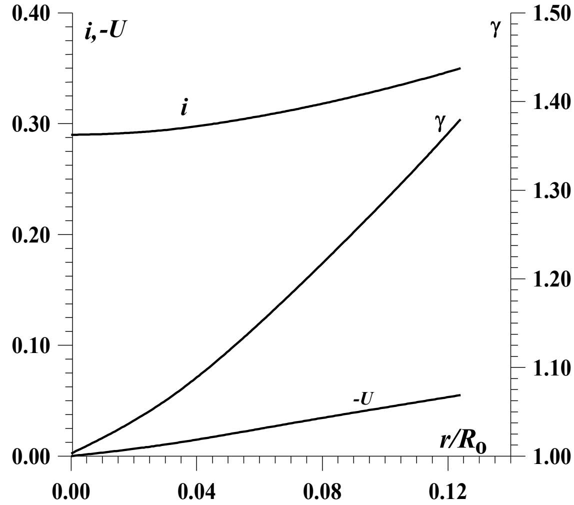
Fig.1. The cross-sections of magnetic surface configuration in l=2 torsatron calculation model (method 1 of conductor turn packing, k=0.3). The parts of each helical coil are spaced by a small (diagnostic) gap

The scaled-down Fig. 1 shows the calculated poloidal cross-sections of magnetic surface configurations for the B_{zm}/b_0=0.8 and K=0.285 (B_0/b_0=2.5) values. The cross-sections are separated by the toroidal angle within the limits of the magnetic field half-period φ=0°, 22.5°, 45°. In the figure, the inner circle shows the cross-section of the vacuum chamber in the U-2M torsatron. The trapezoid-like patterns outline the conductor turn cross-sections. The points inside the patterns mark the position of thin current-carrying conductors of the calculation model. They are located on the torus surface a/R_0=0.2618 (dashed circles). On the same surface, in the middle of the diagnostic gap, there is the base helical line of the calculation model (no trace shown, de-energized). In all three cross-sections the planar magnetic axis trace lies in the equatorial plane of the torus; its major radius being equal to R_{0ax1}/R_0=1.

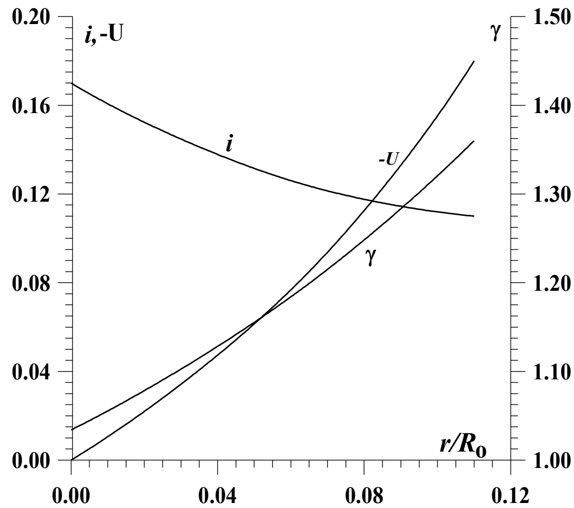
The magnetic surface parameters are shown in Fig.2 as functions of the average magnetic-surface radius. It can be seen from the Fig. 2(a) that the rotational transform angle increases with radius within ι=0.29→0.35 (in 2π units), there is a small magnetic well $-U$=0→0.055 in the configuration, and the mirror ratio on the magnetic surfaces ranges within γ=1.003→1.32.

Following method 2, each helical coil is formed by using the turn-by-turn conductor packing on both sides of the helical base line. The numerical calculations have shown that with this method of packing, in order to make the planar magnetic axis of the magnetic surface configuration coincide with the circular geometrical axis of the torus, in the law of helical base line winding (1) one must put k=1.0 in Eq. (1).

Fig. 3 shows the calculated poloidal cross-sections of the magnetic surface configuration. The cross-sections are separated by the toroidal angle within the limits of the magnetic field half-period φ=0°, 22.5°, 45°. There are noticeable variations in the dimensions of poloidal cross-sections of the helical coils. The regime with the centered planar magnetic axis R_{0ax2}/R_0=1 occurs at B_{zm}/b_0=0.98. In certain poloidal cross-sections, if K=0.25, the last closed magnetic surface size approximately equals the dimensions of the vacuum chamber.



a



b

Fig.2. Rotational transform angle (i), magnetic well (-U), mirror ratio (γ) as functions of the average magnetic surface radius (r) for methods 1(a) and 2 (b) of conductor turn packing

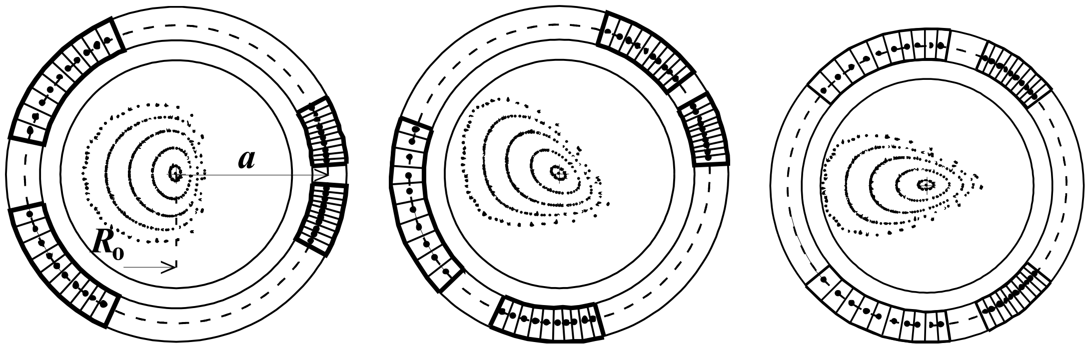


Fig.3. Cross-sections of magnetic surface configuration in l=2 torsatron calculation model (method 2 of conductor turn packing, k=1.0)

The magnetic surface parameters are shown in Fig.2b as functions of the average magnetic-surface radius. It can be seen from the figure that the rotational transform angle decreases with radius, ι=0.17→0.11 (in 2π units), there is a great magnetic well -U=0→0.18, and the mirror ratio on the magnetic surfaces makes γ=1.034→1.36.

SUMMARY

In the present work, numerical calculations have been carried out to investigate the properties of magnetic surface configurations with the centered planar magnetic axis, which were formed in the model of the U-2M type l=2 torsatron comprising additional toroidal magnetic field coils. Two methods of conductor turn packing in the helical coils along the base helical line have been examined.

The calculations have demonstrated that with an appropriate choice of the method of conductor turn packing in the helical coils it is possible to realize the magnetic surface configuration with a negative shear and a high magnetic well. In some designs of fusion reactors (tokamaks) a similar magnetic field mode is considered to be the basic one [6].

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ДВУХЗАХОДНЫЙ ТОРСАТРОН С ЦЕНТРИРОВАННОЙ ПЛОСКОЙ МАГНИТНОЙ ОСЬЮ

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Изучаются численным методом свойства конфигураций магнитных поверхностей, которые имеют плоскую магнитную ось, совмещенную с круговой геометрической осью тора. Расчеты проводились для модели двухзаходного торсатрона с катушками дополнительного тороидального магнитного поля. В системе могут быть реализованы магнитные поверхности с отрицательным широм и большой магнитной ямой.

ДВОЗАХОДНИЙ ТОРСАТРОН З ЦЕНТРОВАНОЮ ПЛОСКОЮ МАГНІТНОЮ ВІССЮ

В.Г. Котенко

Вивчаються чисельним методом властивості конфігурацій магнітних поверхонь, які мають плоску магнітну вісь зуміщену з круговою геометричною віссю тора. Розрахунки проводились для моделі двозаходного торсатрону з катушками додаткового тороїдального магнітного поля. В системі можуть бути зреалізовані магнітні поверхні з від’ємним широм та великою магнітною ямою.