THE INFLUENCE OF A TRANSVERSE SHIFT OF TORSATRON MAGNETIC SURFACES ON THEIR PARAMETERS

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The paper deals with the influence of the transverse shift (or axial shift along the axis of torus rotation) of magnetic surfaces on their parameters in a calculation model of the l=2 torsatron magnetic system. The shift can be realized by means of a special-purpose controlling coil of a helical type. The coil action combined with the well-known action of common annular controlling coil is considered as an instrument for two-dimensional control of the plasma core position in stellarator-type plasma devices.
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INTRODUCTION

A special-purpose controlling coil (SPC) of the torsatron has been a subject of discussion in paper [1,2]. With the SPC-generated magnetic field, the region of closed magnetic surface existence in the torsatron magnetic system can be shifted perpendicularly to the equatorial plane of the torus (transverse shift or axial shift along the axis of torus rotation). The SPC is an auxiliary helical coil laid in a some special way on the surface of the same torus where the main helical coil of the torsatron resides. Each of l poles of the main helical coil is put into correspondence to 1 pole of the auxiliary helical coil. Any of the points of the auxiliary helical base line, along which the auxiliary helical coil pole is laid, is at a distance S=const from the main helical coil base line, along which the main helical coil pole is laid. The distance S=const. is reckoned along the torus parallel drawn through this point. In Cartesian coordinates, where the z-axis is coincident with the axis of torus rotation, the equation for the auxiliary helical base line can be written in a parametric form convenient for numerical calculations:

$$x=(R_o+a\cos\theta(\varphi))\cos(\varphi\pm S/(R_o+a\cos\theta(\varphi))),$$
$$y=(R_o+a\cos\theta(\varphi))\sin(\varphi\pm S/(R_o+a\cos\theta(\varphi))),$$
$$z=a\sin\theta(\varphi). \qquad (1)$$

Here R_o is the major radius of the torus, a is its minor radius, θ is the poloidal angle, φ is the toroidal angle, $\theta(\phi)$ is the winding law of the main helical coil, the sign in the argument expression depends on the direction of reckoning the S distance. The method of construction an auxiliary helical base line is similar to the method of construction a conchoid of a plane line [3]. So eq. (1) can be considered as an equation of conchoid of a spatial line, i.e., as an equation of conchoid of helical line on the torus.

This papers deals with the influence of a transverse shift of torsatron magnetic surfaces on their parameters.

CALCULATION MODEL

Calculation model of the torsatron magnetic system had the following parameters: R_o=1, a=0.25, polarity l=2, m=5 is the number of helical coil pitches along the length of the torus. The electrical currents in the main filament-like helical coil placed on the torus surface, give rise to a longitudinal component of magnetic field b_o on the torus circular axis. Two SPC poles are displaced from the corresponding poles of the main helical coil by S=0.35<2 $\pi(R_o-a)/ml$ in the direction of toroidal angle φ increase. The transverse magnetic field B_z was usually assumed uniform in the calculations.

If the main helical coil is wounded by the cylindrical winding law $\theta(\varphi)$=5φ (straight line in Fig.1a), the SPC winding law will have the appearance shown in Fig 1a (curve2). Curve 2 in Fig.1b corresponds to the SPC winding law when the main helical coil is laid by the equal-inclined law $\theta(\varphi)$=2arctg(1.291tg(2.5φ)), curve 1. One can see here the significant nonlinear, difficult for analytical description, difference between the "derivative" (conchoid-type) winding law of the SPC and the "original" winding law of the main helical coil.

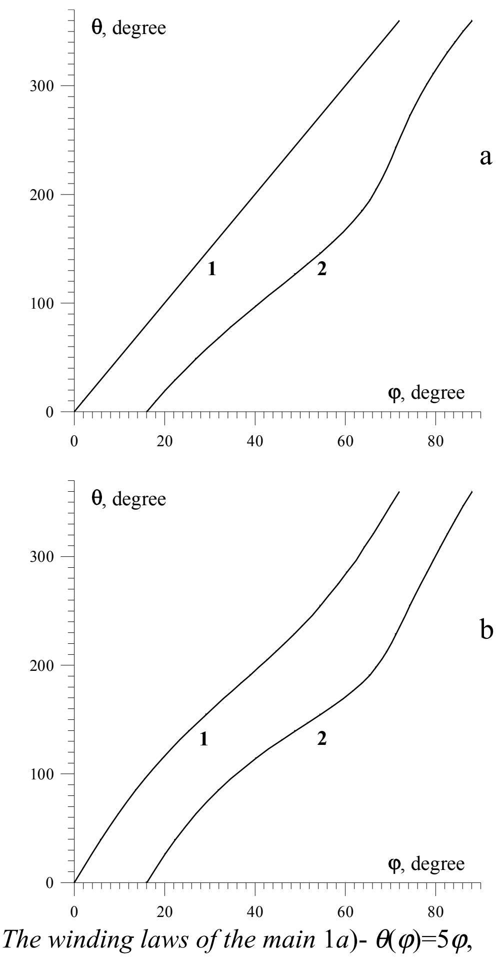

Fig.1 The winding laws of the main 1*a*)- $\theta(\varphi)$=5φ, 1*b*)- $\theta(\varphi)$=2arctg(1.291tg(2.5φ)) *and auxiliary* 2*a*), 2*b*) *helical coils along the length of the helical pitch*

The paper presents the calculation results for the torsatron model with a cylindrical winding law of the main helical coil. Analogous results have been obtained for the torsatron model with the equal-inclined winding law of the main helical coil.

RESULTS OF CALCULATIONS

Fig.2a,b shows the calculated cross-sections of the magnetic surface existence region and the equiconnect, as the surface, on the outside of which the connection length of the diverted field lines does not exceed the length of the torus for two directions of integration [4,5].

Fig. 2a shows the calculated cross-sections for the SPC turned out. The cross-sections are typical for the ordinary torsatron in the regime B_z/b_o=0.297 with minimal field ripple value on the magnetic surfaces [6,7]. In this regime the magnetic-axis major radius is R_{oax}=0.9861, the magnetic-axis minor radius is r_{ax}=0, i.e., the magnetic axis lies in the equatorial plane (z=0) of the torus.

Fig.2b shows the cross-sections for the same regime B_z/b_o=0.297 but with the SPC turned on, when the SPC current value is 0.031 of current value in the main helical coil. It can be seen that all cross-sections are shifted upward relative to the equatorial plane of the torus. The shift value z=0.0203 (z/a<0.1) is estimated from the shift of the magnetic-axis major radius. The value of the magnetic-axis major radius remains the same, R_{oax}=0.9861, while the magnetic-axis minor radius becomes different from zero, r_{ax}=0.0042, i.e., the plane magnetic-axis transforms into a spatial magnetic axis. Similarly to unshifted magnetic surfaces, the shifted surfaces keep their shape, including the last closed magnetic surface (LCMS) slightly decreased in volume. The change in the equiconnect shape and equiconnect position is more significant.

Fig.3 shows the magnetic surface parameters as functions of the average magnetic surface radius. It is seen from the figure that the magnetic surface shift is accompanied by a decrease in both the LCMS average radius and the rotational transform angle on the central magnetic surfaces. The field ripple values and the magnetic hill are increasing.

If the direction of SPC current changes, the cross -sections shift downward relative to the equatorial plane of the torus. Without a change in the current direction the same effect can be attained by the use of the SPC, where the distance S is reckoned in the opposite direction (in the direction of decreasing φ).

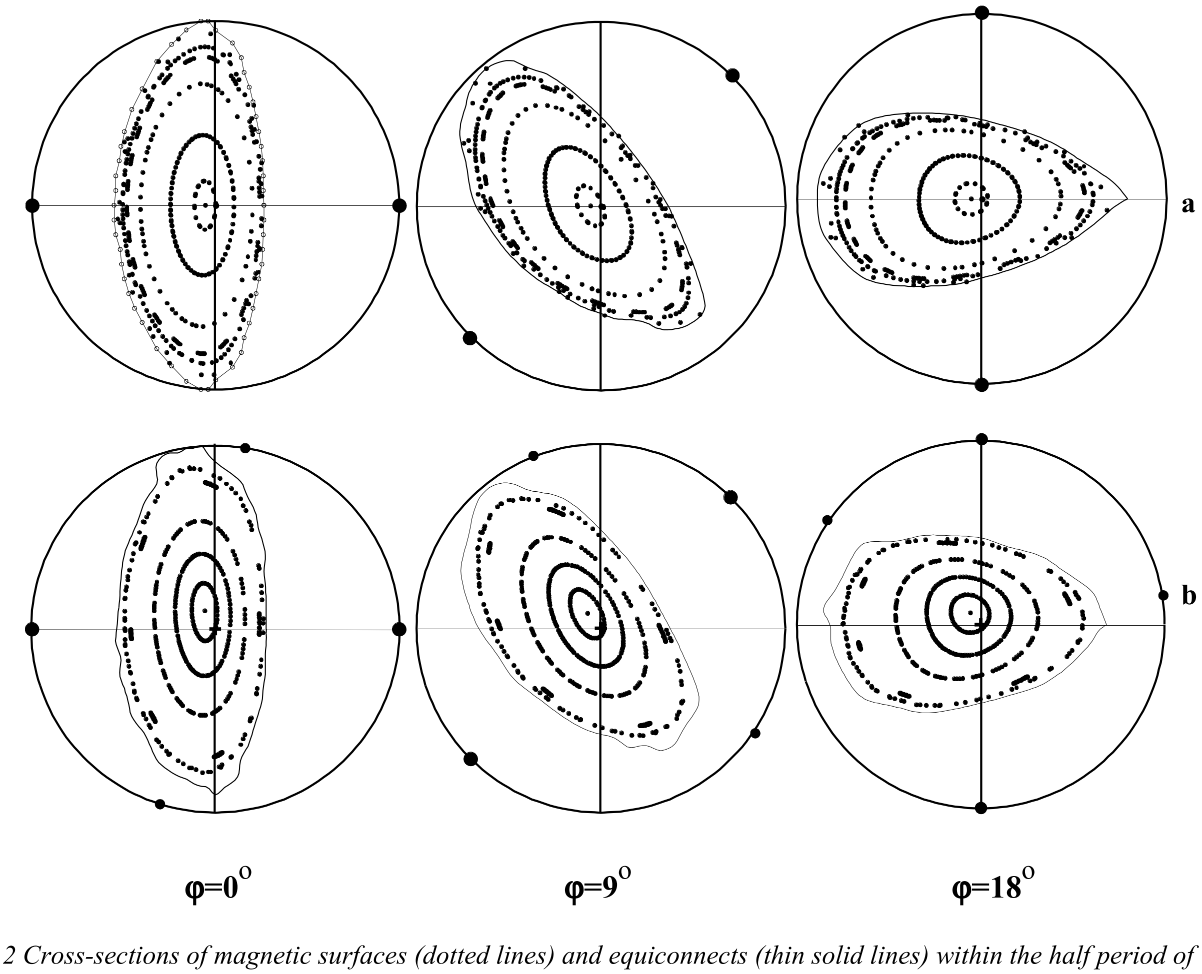

Fig.2 Cross-sections of magnetic surfaces (dotted lines) and equiconnects (thin solid lines) within the half period of magnetic field: a) the SPC is currentless, b) the SPC is turned on. Large solid points are the main helical base line cross-sections, smaller solid points are the auxiliary helical base line cross-sections

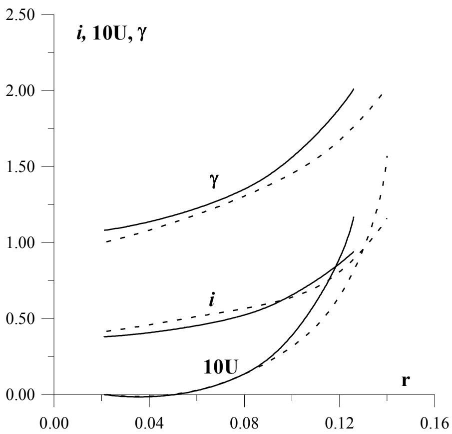

Fig.3. The field ripple γ, rotational transform angle ι (in 2π units), magnetic hill value U versus the average magnetic surface radius r for shifted (solid lines) and unshifted (dotted lines) magnetic surfaces

CONCLUSIONS

Magnetic-surface parameters in the l=2 torsatron magnetic system model with the superimposed SPC magnetic field have been investigated. The calculations have shown that the superposition of the SPC magnetic field exerts no critical effect. For the transverse shift z/a~0.1, the relative changes of magnetic surface parameters are of the same order. A marked change in the shape and position of the equiconnect, i.e., the boundary of the stochastic layer of magnetic field lines (SOL plasma), has been found. This means the standard l=2 torsatron divertor configuration transforms into an excessively localized divertor configuration with a shortened connection length of diverted magnetic field lines [8].

On the whole, it can be assumed that the above-described changes mean the degradation of parameters of the plasma confined on transversely shifted magnetic surfaces. Thus, the SPC is to be considered, first of all, as a tool for suppressing the magnetic-surface transverse shift. An inaccuracy in both the manufacture and the assembly of separate units of the real magnetic system can provoke the transverse shift. Let us conceive that a one-layer winding of the helical pole is laid along the main helical base line on the same side, turn by turn with a constant insulation spacing between them. Then the helical line equation of the last turn in this layer is supposed similar to equation (1) with the parameter S=(n-1)d, where n is the number of turns in the layer, d is the diameter of the conductor, including the insulation thickness. As a result, the magnetic surface position can disagree with the calculated value and equatorial symmetry of different operating signals including the plasma diagnostic signals can be violated. An interference with other possible defects aggravates the problem. Partly it can be settled through a symmetrical winding of the conductor, i.e., turn-by-turn winding on both sides of the main helical base line, or winding of each, taken separately, turn by the winding law of the main helical base line.

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ВЛИЯНИЕ ПОПЕРЕЧНОГО СМЕЩЕНИЯ МАГНИТНЫХ ПОВЕРХНОСТЕЙ ТОРСАТРОНА НА ИХ ПАРАМЕТРЫ

В. Г. Котенко

В работе выяснено влияние поперечного смещения (или осевого смещения вдоль оси вращения тора) магнитных поверхностей на их параметры в расчетной модели l=2 торсатрона. Смещение осуществляется с помощью специальной корректирующей обмотки винтового типа. Действие этой обмотки в сочетании с обычной кольцеобразной корректирующей обмоткой позволяет осуществить 2-мерный контроль положения плазменного шнура в плазменных ловушках стеллараторного типа.

ВПЛИВ ПОПЕРЕЧНОГО ЗМІЩЕННЯ МАГНІТНИХ ПОВЕРХОНЬ ТОРСАТРОНА НА ЇХ ПАРАМЕТРИ

В. Г. Котенко

В роботі з’ясовано вплив поперечного зміщення (або ж осьового зміщення вздовж осі обертання тора) магнітних поверхонь на їх параметри в моделі l=2 торсатрона. Зміщення здійснюється за допомогою спеціальної коректуючої обмотки гвинтового типу. Дія цієї обмотки в поєднанні з дією звичайної кільцеподібної коректуючої обмотки надає можливість 2-вимірного контролю за положенням плазмового шнура в плазмових пастках стелараторного типу.