THE INFLUENCE OF THE HELICAL-COIL ANGULAR SIZE ON THE YAMATOR MAGNETIC SURFACE CHARACTERISTICS

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INTRODUCTION

New stellarator-type magnetic systems, called as Yamator, have been considered in papers [1-3]. Numerical calculations were carried out there for the ideal toroidal models of Yamator magnetic systems with filament-like (i.e., vanishing transverse dimensions) helical conductors. The calculations have demonstrated that the closed magnetic surface region with a high magnetic well value $-U$~0.1-0.5 can exist. The practical realization of those magnetic systems will evidently meet the necessity to determine the influence of real finite size of helical conductors/coils on the basic characteristics of the magnetic surfaces, first of all, on the magnetic well value. In this paper the magnetic surface characteristics are numerically studied for the Yamator with helical coils in the form of finite-angular-size thin strip. The main task of the study has been to get a general idea about the tendencies in variations of Yamator magnetic surface characteristics when passing from ideal magnetic systems closer to the real ones.

CALCULATION MODEL

As an initial ideal model, the l=2, m=3 Yamator magnetic system [1] was chosen for calculations. This system consists of two (l=2) 2-wire lines with equal-in-magnitude and opposite-in-direction wire currents. The 2-wire lines are wound round the torus along the helical lines $\theta=m\varphi$ and $\theta=m\varphi+\pi$, θ is the poloidal angle, φ is the toroidal angle, m=3 is the number of helical line pitches on the length of the torus. The wires (helical conductors/coils) of each 2- wire line lie on the coaxial tori of the same major radius R_o and different minor radii a_1=0.3 and a_2=0.45, a_2-a_1=0.15 being the distance between the wires of the 2-wire line. Here and in what follows the lengths are given in R_o units. The amplitude of the circular-axis magnetic field generated by the helical current traversing the torus of the minor radius a_1 is b_o. In the ideal model the magnetic surface configuration forms if the superimposed toroidal circular-axis magnetic field strength is B_o/b_o=2.5. The magnetic surface characteristics are presented in *Table* 1 (System 1, see below).

Fig.1 shows the scheme of the l=2 m=3 Yamator magnetic system with helical coils in the form of thin strips. The strip angular sizes are $\Delta\theta_h=45^o$ (poloidal angle) and $\Delta\varphi_h=15^o$ (toroidal angle). The strip was approximated by 11 filament-like conductors with a toroidal angular distance of $\delta\varphi=1.5^o$ between them. Each of 11 filament-like conductors obeys the winding law $\theta=m\varphi$ (cylindrical law).

For comparison to the ideal model, the regime of the magnetic axis geometry similarity was taken. The Yamator magnetic system belongs to the type of helical magnetic systems, where the undistorted magnetic axis is

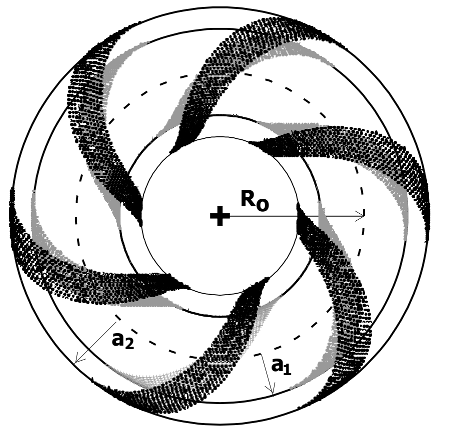

Fig.1. A scheme of l=2, m=3 Yamator (top view) with real-angular-size helical coils: there are 11 filamentary helical conductors spaced 1.5º apart along the toroidal angle in each helical coil. The longitudinal magnetic field coils are not shown.

a helical line, wound round the imaginary torus almost of a circular cross-section and closed on itself after one go-round along the torus. At the upper right of Fig.2a the major radius of this torus is designated as R_{oax} (magnetic axis major radius), the minor radius–as r_{ax} (magnetic axis minor radius, index 1 concerns the ideal magnetic system, index 11- the one with a strip).The magnetic axis geometry similarity means fixing the value of the magnetic-axis major radius, $(R_{oax})_1=(R_{oax})_{11}=R_{oax}$=const. For the ideal Yamator magnetic system under consideration, $(R_{oax})_1$=1.1372 for $(B_o/b_o)_1$=2.5. For the system with a helical strip the calculations give $(R_{oax})_{11}$=1.1372 provided that $(B_o/b_o)_{11}$=1.986. The $(B_o/b_o)_1/(B_o/b_o)_{11}$ ratio for a given magnetic field B_o strength points to the necessity of raising the helical current by a factor of ~1.26 to form the similar (in above-given sense) magnetic surface configuration in the Yamator with a helical strip.

RESULTS

Fig.2 shows three poloidal magnetic-surface cross-sections within ½ magnetic field period (a) φ=0, b) $\varphi=15^o$, c) $\varphi=30^o$) for the Yamator magnetic system with a helical strip (dotted lines) and the cross-section of the last closed magnetic surface (LCMS) for the ideal Yamator model (thin solid line). It is seen from the figures that the magnetic surface existence region has appreciably decreased as compared to that in the ideal model. The LCMSs are not equidistant, i.e., in each cross-section there exists the θ azimuth region, where LCMS contours coincide. At the upper right of Fig. 2a the toroidal projection of the magnetic axis trajectory on an enlarged scale is shown. It can be seen that the magnetic axis minor radius increases, $(r_{ax})_{11}>(r_{ax})_1$, as the helical-coil angular size increases.

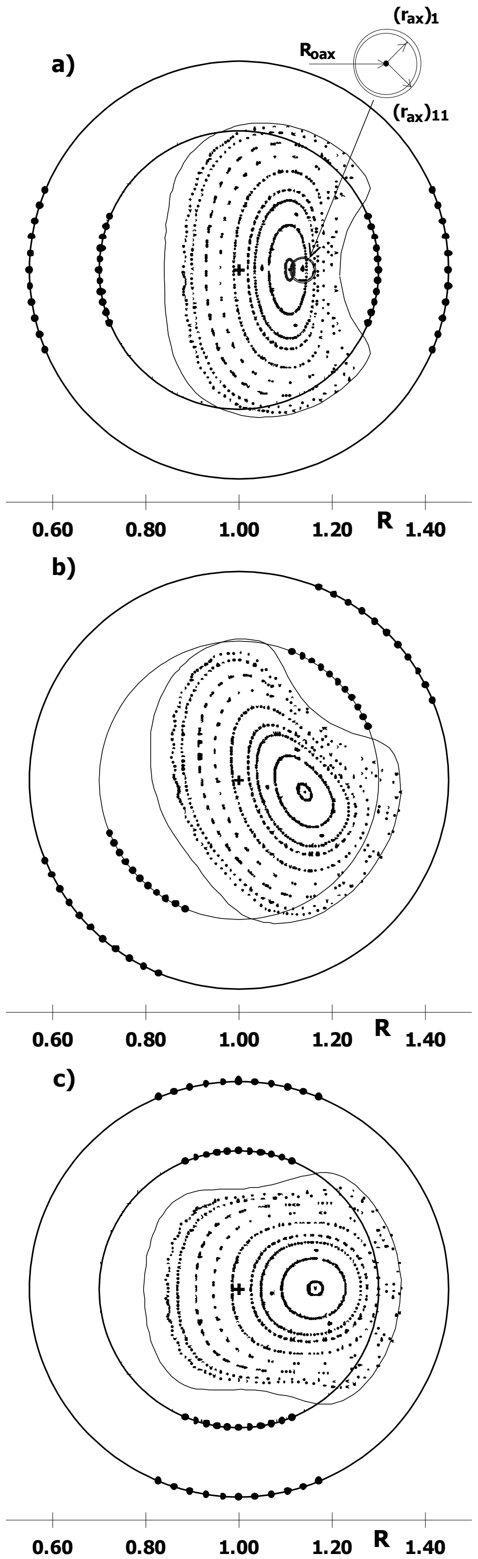

Fig.2. The magnetic surface poloidal cross-sections for Yamator magnetic system with helical strip (dotted lines) and the LCMS for ideal Yamator magnetic system (thin solid line). The poloidal cross-sections of the coaxial tori and the helical strips are shown, the longitudinal magnetic field coils are not shown.

The geometrical parameters of magnetic systems and magnetic axes under comparison, and the magnetic surface characteristics are summarized in *Table* 1. Here, – U_{lc} is the magnetic well value on the LCMS, i_{ax}, i_{lc} are the rotational transform angles (in units of 2π) near the magnetic axis and on the LCMS, γ_{ax}, γ_{lc} are the magnetic field ripples on the magnetic axis and on the LCMS, respectively; r_{lc} is the average LCMS radius.

Table 1

System	1	11
l	2	2
m	3	3
a_1	0.3	0.3
a_2	0.45	0.45
θ	$m\varphi$	$m\varphi$
θ_h	0°	45°
φ_h	0°	15°
B_o/b_o	2.5	1.986
r_k	0.27	0.24
$-U_{lc}$	0.25	0.184
i_{ax}	0.26	0.33
i_{lc}	0.29	0.33
γ_{ax}	1.15	1.17
γ_{lc}	2.28	2.08
B_z/b_o	0.0	0.0

From the analysis of *Table* 1 it becomes clear that in the Yamators with a thin helical strip of the poloidal angular size $\Delta\theta_h \leq 45^o$ the magnetic well is reduced by ≤ 20%, the LCMS average radius is cut down by ≤ 11%, the magnetic field ripple value on the LCMS falls off by ≤ 11%. The magnetic surface configuration still remains shearless, the rotational transform angle increases by ≤ 20%. The calculations were performed for the controlling transverse magnetic field $B_z/b_o=0$, z is the principal (straight) axis of the system

SUMMARY

The calculations performed have demonstrated the possibility of existence of the inner closed magnetic surface region in the Yamator with helical coils in the form of the finite angular size thin strip. In the l=2, m=3 Yamator with $\Delta\theta_h$=45° angular size helical coils, the magnetic surface characteristics, including the magnetic well value, differ by no more than ~10-25% from the ideal level.

A new method of comparison between the magnetic surface characteristics in ideal and real helical magnetic systems is suggested. It is based on searching for the magnetic-axis geometry similarity regime, i.e., equal values of magnetic-axis major radii.

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