# MAGNETIC SURFACES OF A COMBINED MAGNETIC SYSTEM

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The existence of closed magnetic surfaces in a model of the combined magnetic system is shown by numerical simulations. The numeric model contains a magnetic system of the *l=2* torsatron with the coils of an additional toroidal magnetic field and the mirror-type magnetic system. The mirror-type magnetic system is realized by switching off one of the coils of an additional toroidal magnetic field.

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## INTRODUCTION

In paper [1] as a fusion neutron source for the sub-critical fast hybrid reactor the combined magnetic plasma trap has been proposed. The organic parts of the combined magnetic system are a stellarator-type magnetic system and a common mirror-type magnetic system. In paper [2] the magnetic field in the ideal model of the combined magnetic system has been studied. The model comprises the magnetic system of $l$=2 torsatron with additional axisymmetric toroidal magnetic field and a single current-carrying turn as an element of the mirror-type magnetic system.

In this paper the magnetic field of the combined magnetic system in regard to width of the $l$=2 torsatron helical coils and the coils forming the necessary value of the additional toroidal magnetic field is studied. The mirror-type magnetic system is realized under by switching off one of the coils of the additional toroidal magnetic field.

## CALCULATION MODEL

The main geometrical characteristics of the computational model are similar to the design characteristics of the U-2M torsatron [3]. The model comprises the 16 coils of the additional toroidal magnetic field. The mirror-type magnetic system is realized under by switching off the coil 14 (Fig. 1).

The following technical characteristics of the real helical coils were counted in the calculation:

- toroidicity $a/R_0$=0.2618, $a$ is the minor radius of the torus (average radius of helical coils), $R_0$ is the major radius of the torus;
- $l$=2 is the polarity;
- $m$=2 is the number of helical coil pitches along the length of the torus;
- there are 20 conductor turns in each helical coil;
- counted along the torus parallels the width of each helical coil $S/R_0$=0.782;
- each helical coil is splitted into two equal parts, each part comprises 10 conductor turns;
- the parts are separated by diagnostic gap having the width $\Delta S/R_0$=0.17 along the torus parallels;
- the central line of the diagnostic gap is the helical base line marked on the torus according to the equi-inclined winding law $\theta(\varphi)$=2arctg(1.3074tg$\varphi$), where $\varphi$ is the toroidal angle and $\theta$ is the poloidal angle. The base line is the helical line, along which a supporting structure of the helical coil is assembled;
- the conductor turns are packed turn by turn symmetrically relative to the helical base line on the both side of the diagnostic gap.

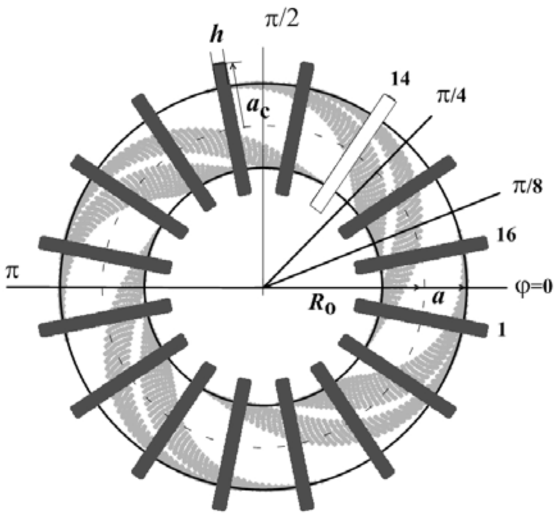

*Fig. 1. Top view of the magnetic system of the l=2 torsatron numeric model. The position of dead coil 14 of the additional toroidal magnetic field is indicated*

The following technical characteristics of the real coils of the additional toroidal magnetic field were counted in the calculation:

- the average radius of the coils is $a_c/R_0$=0.4 (the radial thickness of coil winding 0.113$R_0$ is not taken into consideration);
- the coils have cylindrical form, the cylinder height $h/R_0$ =0.086;
- the calculation model of the coil comprises 3 turns of the thin conductor. The plane of the central turn of the coil model agrees with meridian (poloidal) plane of the torus. The rest 2 turns of the coil lie in the end planes of the coil. The end planes of the coil are parallel the plane of the central turns of the coil.

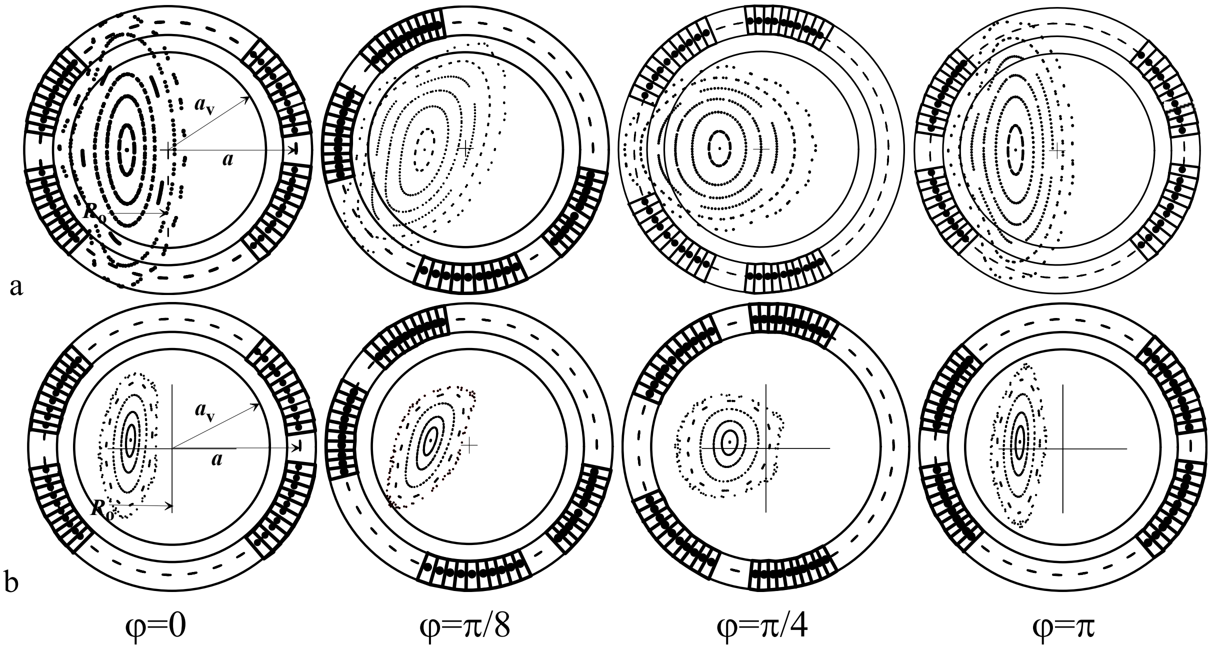

*Fig. 2. Characteristic poloidal cross-sections (see Fig. 1) of the initial configuration of magnetic surfaces in the calculated model of l=2 torsatron (a) and by switching off the coil 14 (b)*

In the present calculations, the transverse compensating magnetic field $B_z$ is considered as uniform. The magnetic surface configuration in the torsatron with an additional magnetic field coils is affected by the parameter $K_\varphi=1/(1+B_o/b_o)$ too ($B_o$ is the value of the additional toroidal magnetic field on the circular axis of the torus, $b_o$ is the amplitude of the longitudinal component of the magnetic field generated by the helical coils on the circular axis of the torus).

## RESULTS OF CALCULATION

Fig. 2,a and b show the poloidal cross-sections of the magnetic surfaces for the calculation model. The cross-sections are spaced round a toroidal angle φ=0, π/8, π/4 and π (see Fig. 1). In the figures, the dashed circle is the cross-section of a torus $a/R_o=0.2618$ with traces of the conductor turns of the helical coils (large black dots). The inner circle shows the cross-section of the vacuum chamber (the minor radius $a_v/R_o=0.2$) in the U-2M torsatron.

Fig. 2,a shows the cross-sections of the initial (undisturbed by switching off the coil 14) configuration of the magnetic surfaces. It is seen from the figure the initial magnetic surface configuration has the plane magnetic axis (magnetic axis minor radius $r_{ax}=0$) and the last closed magnetic surface transcending of the torus volume. The mode is realized at the compensating magnetic field value $B_z/b_o=0.507$ and additional toroidal magnetic field value $B_o/b_o=3.12$ ($K_\varphi=0.24$). The magnetic axis has the shape of the circle with major radius $R_{ax}/R_o=0.916$ lying in the torus midplane. The average radius of the last closed magnetic surface $r_{lc}/a=0.7$ ($r_{lc}/R_o=0.18$). The shape of the magnetic surfaces in the φ=π cross-section coincides with the shape in φ=0 – cross-section. The rotational transform angle is $i_{ax}\rightarrow i_{lc}=0.1\rightarrow0.33$, and there is a small magnetic hill ($U=0.077$) in the configuration. The mirror ratio ranges within $\gamma_{ax}\rightarrow\gamma_{lc}=1.013\rightarrow1.72$, $\gamma=B_{max}/B_{min}$, where $B_{max}$ and $B_{min}$ are the maximum and minimum magnetic field strengths on the magnetic surfaces.

In the Fig. 2,b the cross-sections of the magnetic surfaces by switching off the coil 14 are presented. It is seen from the Figure that the switching off results in the magnetic surface configuration decrease, so the cross-section size of the last closed magnetic surface doesn't transcend the dimension of the vacuum chamber. The destruction of the periphery layer of the magnetic surfaces of the initial configuration arises from the appearance of a great value of the resultant magnetic field radial component (along the minor radius of the torus) nearby the dead coil 14 locality. The parameter $K_\varphi=0.24\rightarrow0.25$ increase due to coil 14 switching off affects the dimension of the configuration to the lesser extent [3].

It is seen that all the cross-sections, following the magnetic axis displacement, are displaced by ~0.1*a* relative to the equatorial plane. As the magnetic axis displaces, it is gradually changing from a plane one to a spatial one with the minor radius value of $r_{ax}/a<<1$. The magnetic surface shape and the average value of the last closed magnetic surface radius are changing from one cross-section to another. The average value of the last closed magnetic surface radius is $r_{lc}/a=0.38$ ($r_{lc}/R_o=0.1$) in the φ=0 cross-section. The values of rotational transform angle, $i_{ax}\rightarrow i_{lc}=0.09\rightarrow0.18$, and the mirror ratio, $\gamma_{ax}\rightarrow\gamma_{lc}=1.56\rightarrow2.06$, differ substantially from the corresponding parameters of the initial magnetic surface configuration, and being in the initial configuration the magnetic hill vanished, $-U=0.001$.

The magnetic axis displacement value and direction depend on the position of the dead coil within the limits of a magnetic field period. For example, the magnetic surface configuration shifts upward by switching off the coil 16. With that there is not distinct dependence of the magnetic surface parameters on the dead coil position.

## CONCLUSIONS

The numerical calculations have demonstrated the possibility of the closed magnetic surface existence in the combined magnetic system. The system contains a magnetic system of the *l=2* torsatron with the coils of the additional toroidal magnetic field and the mirror-type magnetic system. The mirror-type magnetic system is realized by switching off one of the coils of an additional toroidal magnetic field. Consequently, the cross-section of the initial magnetic surface configuration diminishes and brings to conformity with the dimension of vacuum chamber, and there appear a magnetic field ripple with acceptable value at the context of the proposal [1] on the magnetic axis.

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## МАГНИТНЫЕ ПОВЕРХНОСТИ КОМБИНИРОВАННОЙ МАГНИТНОЙ СИСТЕМЫ

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Численными расчетами показано существование замкнутых магнитных поверхностей в модели комбинированной магнитной системы. В состав модели входит магнитная система двухзаходного торсатрона с катушками дополнительного тороидального магнитного поля и магнитная система типа пробкотрон. Последняя реализуется путем отключения одной из катушек дополнительного тороидального магнитного поля.

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## МАГНІТНІ ПОВЕРХНІ КОМБІНОВАНОЇ МАГНІТНОЇ СИСТЕМИ

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Чисельними розрахунками показано існування замкнутих магнітних поверхонь у моделі комбінованої магнітної системи. До складу моделі входить магнітна система двозаходного торсатрона з котушками додаткового тороїдального магнітного поля та магнітна система типу пробкотрон. Остання реалізується шляхом відключення однієї з котушок додаткового тороїдального магнітного поля.