# EFFECT OF A NON-CIRCULAR SHAPE OF THE TORUS ON THE *l*=2 TORSATRON MAGNETIC SURFACES

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The numerical calculations of magnetic field of the $l$=2 torsatron magnetic system with non-circular poloidal cross-section of the torus is carried out in the work. It is shown that the value $\delta_i \approx 0.2$ of maximal relative deviation of a non-circular poloidal cross-section from basic circular one results in a several-fold contraction of closed magnetic surface existence region. There is some increase in the values of rotational transform angle and the mirror ratio in the central closed magnetic surfaces. An enlarged clearance between the outer boundary of field line stochastic layer, i.e., the boundary of the plasma layer having transient plasma parameters (SOL plasma) and the surface of vacuum chamber can be obtained by the transition from the circular torus to the non-circular torus under consideration.

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## INTRODUCTION

As opposed to an ordinary circular torus poloidal cross-section minor radius of which $a_c$=const. in a noncircular torus the poloidal cross-section minor radius $a_n \neq$const. In the field of fusion research an example of noncircular torus implementation is, in particular, the vacuum chamber of present-day tokamaks, which have a D-shaped poloidal cross-section. For the first time, the stellarator-type magnetic system with a noncircular torus poloidal cross-section highly elongated along the straight $z$-axis of the torus, has been discussed in [1, 2]. The authors reported that the influence of toroidal effects on the plasma diffusion and thermal conductivity can be significantly decreased in the systems. In paper [3] were presented the numerical calculation results for the ideal model of the $l$=2 torsatron magnetic system with non-circular torus, which poloidal cross-section shape differs to a lesser extent from the initial circle. Each helical coil of the ideal model consisted of 1 filament-like conductor turn. The main goal of the investigation was to discover the additional possibility to enlarge the distance between the closed magnetic surface existence region and helical coils, i.e., the first wall-plasma spacing in the stellarator-type fusion reactor [4, 5]. The present study takes into account the model of the $l$=2 torsatron magnetic system with the non-circular torus the helical coils of which have real size cross-section.

## INITIAL CALCULATION MODEL

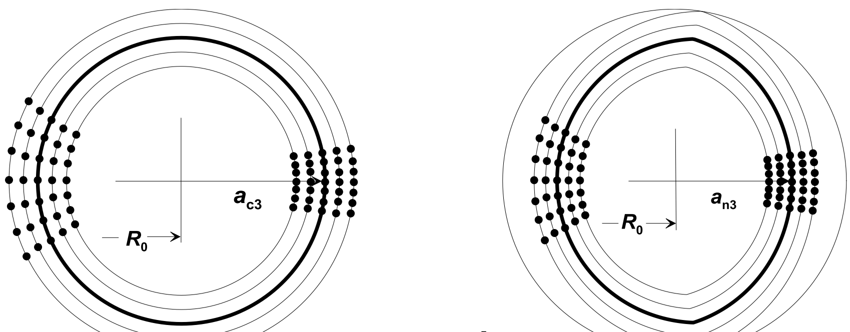
As an initial calculation model with a circular torus, we use an $l$=2 torsatron magnetic system. The main geometrical characteristics of the model are similar to heliotron Large Helical Devise magnetic system characteristics [6]:

- toroidicity $\alpha_{c3}=a_{c3}/R_0=0.25$, $R_0$ is the major radius of the torus, $a_{c3}$ is the average radius of helical coils (see below);
- $l$=2 is the polarity;
- $m$=5 is the number of helical coil pitches along the torus length.

Each helical coil comprises 35 filament-like conductor turns. The turns of each helical coil are placed in 5 layers in 7 turns at the layer. The layers are located on the surfaces of 5 nested coaxial torus with minor radii $a_{ci}/R_0=\alpha_{ci}$=0.2, 0.225, 0.25, 0.275, 0.3 ($i$=1-5, Fig. 1,*a*). The base (central) turn of $i$-layer is marked on $i$-torus according to the combined winding law [7]:

$$\theta_{ci}=\theta_0-k(\theta_{ei}-\theta_0). \qquad (1)$$

Here $\theta_{ci}$ is the poloidal angle, $\theta_0=m\varphi$ is the cylindrical winding law, $\theta_{ei}=2\mathrm{arctg}(((1+\alpha_{ci})/(1-\alpha_{ci}))^{0.5}\mathrm{tg}(\theta_0/2))$ is the equi-inclined winding law, $\varphi$ is the toroidal angle, $k$=0.52. The last 6 conductor turns in $i$-layer are arranged turn by turn along the base turn (packing by method 2 [8]).




*a* *b*

*Fig. 1. Poloidal cross-sections of the nested coaxial circular tori (a) and inscribed non-circular tori (b) Helical coil conductor turn traces are marked by large black points*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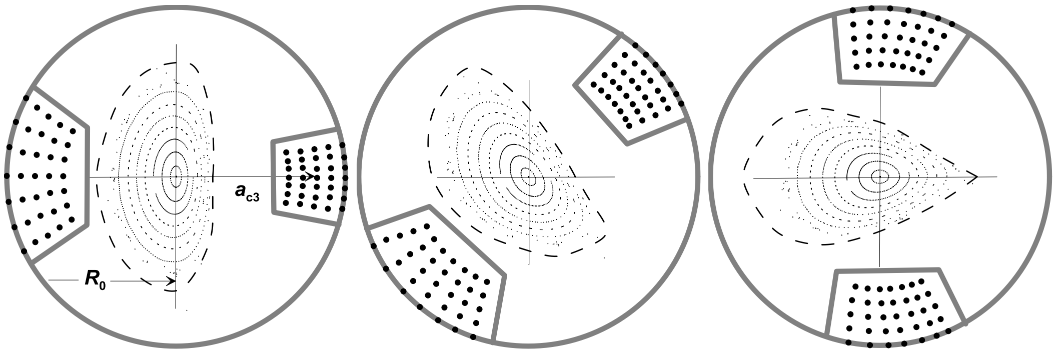



φ=0º φ=9º φ=18º

*Fig. 2. Poloidal cross-sections of the magnetic surfaces in the initial calculation model with circular torus. Cross-sections of the vacuum chamber is pointed out by clarified line*

Fig. 2 shows the calculated poloidal cross-sections for the helical coils and the closed magnetic surface configuration in the magnetic system model under consideration. The cross-sections are spaced apart by the toroidal angle φ within the limits of the magnetic field half-period, φ=0º, 9º, 18º. As is seen from Fig. 2, the chosen combined law for the helical coil winding provides the mode for the closed magnetic surface configuration with a centered planar magnetic axis [7]. In all three cross-sections, the magnetic axis traces are disposed in the torus equatorial plane and its major radius remains invariable, $R_{0ax}/R_0$=1. The mode can be realized at compensating uniform magnetic field $B_z/B_0$=0.35, where $B_0$ is the amplitude of the toroidal component of the magnetic field generated by helical coils on the circular axis of the torus. The average radius of the last closed magnetic surface is $r_{lc}/R_0$=0.14. The magnetic surface parameter values are presented below (in brackets).

Fig. 2 also represents (dashed lines) the calculated cross-sections of the surface of the outer boundary of the field-line stochastic layer [9, 10], i.e., the boundary of the plasma layer having transient plasma parameters (SOL plasma).

## CALCULATION MODEL WITH A NON-CIRCULAR TORUS

Similar to magnetic system with circular torus each helical coil of the magnetic system with non-circular torus comprises 35 filament-like conductor turns. The turns of each helical coil are placed in 5 layers in 7 turns at the layer. The layers are located on the surface of 5 the nested coaxial non-circular torus. By analogy with [3] the running radius of non-circular torus cross-section was determined from the equation:

$$\alpha_{ni}=\alpha_{ci}(1-\delta_i|\cos(\theta_0)|),$$

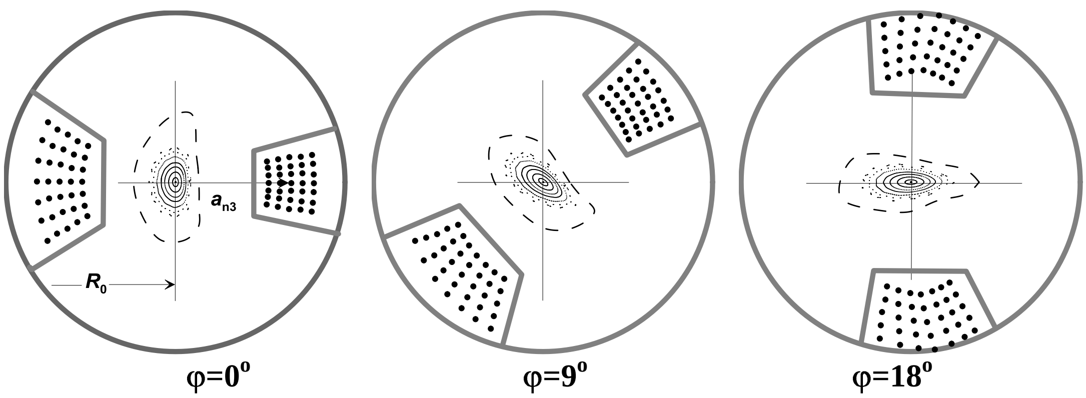
where $\delta_i$=0.175, 0.178, 0.18, 0.182, 0.184 ($i$=1-5, see Fig. 1, *b*). Consequently the base (central) turn of *i*-layer is marked on non-circular *i*-torus according to the combined winding law:

$$\theta=\theta_0-k\,(2\mathrm{arctg}(((1+\alpha_{ni})/(1-\alpha_{ni}))^{0.5}\mathrm{tg}(\theta_0/2))-\theta_0),$$

where $k$=0.52.

Fig. 3 shows the poloidal cross-sections calculated for the magnetic surface configuration generated by helical currents, lying on the surfaces of non-circular tori. It is seen from the Fig. 3, the combined law opted for the helical coil windings for the system with non-circular torus provides a mode for the closed magnetic surface configuration with the centered planar magnetic axis too. The mode is realized at a compensating uniform magnetic field value $B_z/B_0$ =0.361. The average radius of the last closed magnetic surface is $r_{lc}/R_0$=0.047. The rotational transformation angle (in 2π units) is $\iota_{axis}\rightarrow\iota_{lc}$=0.98 (0.5)→1.14 (0.75) on the magnetic surfaces, a zero-order magnetic well (hill) $U$=-0.005 (0.002) takes place, and the value of mirror ratio is $\gamma_{axis}\rightarrow\gamma_{lc}$=1.05(1.02)→1.31(1.55). The appropriate parameter values for the initial magnetic surface configuration are indicated in brackets.

Fig. 2 also represents (dashed lines) the calculated cross-sections of the surface of the outer boundary of the field-line stochastic layer.




φ=0º φ=9º φ=18º

*Fig. 3. Poloidal cross-sections of the magnetic surfaces in the calculation model with the non-circular torus*

## CONCLUSIONS

Numerical calculations of magnetic field in the *l*=2 torsatron magnetic system model with the non-circular torus the helical coils of which have real size cross-sections is carried out in the work. Similar to ideal magnetic system model [3] the transition from the circular torus to the non-circular one results in a several-fold contraction of closed magnetic surface existence region. A noticeable increase in the values of the rotational transform angle and the mirror ratio is observed in the central magnetic surfaces. A zero-order magnetic well value takes place. An enlarged clearance can be obtained between the outer boundary of field line stochastic layer and the vacuum chamber surface. The result received can promote the further development the conception of stellarator-type fusion reactor with enlarged the plasma-1$^{st}$ wall spacing.

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### ВЛИЯНИЕ НЕКРУГОВОЙ ФОРМЫ ТОРА НА МАГНИТНЫЕ ПОВЕРХНОСТИ ДВУХЗАХОДНОГО (*l*=2) ТОРСАТРОНА

***В.Г. Котенко***

Проведены численные расчеты модели магнитной системы *l*=2 торсатрона с некруговым полоидальным сечением тора. Показано, что максимальная величина относительного отклонения $\delta_i$≈0,2 полоидального сечения некругового тора от базисного кругового сечения приводит к уменьшению области существования замкнутых магнитных поверхностей и некоторому увеличению величины угла вращательного преобразования и пробочного отношения на центральных магнитных поверхностях. Существенно увеличилось расстояние между слоем стохастических силовых линий, т.е. между плазмой переходных параметров (SOL-плазмы) и поверхностью вакуумной камеры.

### ВПЛИВ НЕКРУГОВОЇ ФОРМИ ТОРУ НА МАГНІТНІ ПОВЕРХНІ ДВОЗАХОДНОГО (*l*=2) ТОРСАТРОНУ

***В.Г. Котенко***

Проведені чисельні розрахунки моделі магнітної системи *l*=2 торсатрона з некруглим полоїдальним перерізом тора. Показано, що максимальна величина відносного відхилення $\delta_i$≈0,2 полоїдального перерізу некруглого тора від базисного круглого перерізу призводить до зменшення області існування замкнутих магнітних поверхонь та до збільшення величини кута обертового перетворення і величини дзеркального відношення на центральних магнітних поверхнях. Суттєво збільшилася відстань між прошарком стохастичних силових ліній, тобто між плазмою перехідних параметрів (SOL-плазмою) і поверхнею вакуумної камери.