SPECIAL CORRECTING WINDING FOR *l*=2 TORSATRON WITH INTERNAL SPLITTING OF HELICAL COILS

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A special correcting winding for the l=2 torsatron toroidal magnetic system with non-standard internal split-type helical coils and with the coils of an additional toroidal magnetic field is considered. The numerical calculations have shown that the winding action upon the initial magnetic surface configuration leads mainly to a displacement of the magnetic surface configuration along the straight z axis of the torus.

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INTRODUCTION

In this paper the l=2 torsatron magnetic system with non-standard (internal) splitting of the helical coils into two equal parts is discussed. In this magnetic system unlike the system with standard (external) splitting of the helical coils [1, 2], maximum helical coil splitting is observed on the minor torus equator, and the helical coil splitted parts have the points of contact on the major torus equator [3]. To control the position of the closed magnetic surface configuration in the direction perpendicular to the equatorial plane of the torus [4] a non-standard (internal) split-type special correcting winding (ISCW) is suggested. An idea on ISCW magnetic field structure is obtained by numerical simulations on the effect of this field as a minority magnetic field imposed on the magnetic field of a well-known configuration.

1. CALCULATION MODEL

The general geometrical characteristics of the computation model (Fig. 1,*a*) are close to the design characteristic of the l=2 torsatron U-2M with the additional toroidal magnetic field coils [5]: toroidicity a/R_o=0.2618, a is the minor radius of the torus (average radius of helical coils), R_o 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.

The calculation model consists of two single-layer helical coils, each comprises 12 filament-like conductor turns. The helical coil is splitted into two equal parts, each comprises 5 conductor turns of the helical coil. The currents in the helical coils are similar in direction and strength, the total current in the coil is equal to I_h. The rest of two innermost conductor turns (one in each of the split parts) are the turns of the ISCW. The ISCW scheme is shown separately in Fig. 1,*b*. The ISCW splitting occurs along the base helical lines $\theta(\varphi)=m\varphi$ (dotted lines in Fig. 1,*a*,*b*) by the law $\Delta\varphi_s=\left|\sin(m\varphi/2)\right|\Delta\varphi$, where θ is the poloidal angle, φ is the toroidal angle, $\Delta\varphi_s$ is current value of the toroidal angle of splitting, $\Delta\varphi=20^o$. It is seen that the ISCW currents I_s are equal in value but opposite in direction. Below, it will be shown that $|I_s| << I_h$.

In the present calculations, the transverse compensating magnetic field B_z is considered as uniform, the additional toroidal magnetic field is assumed to be axisymmetric ($B_\varphi=B_oR_o/R$, where B_o is the value of the additional toroidal magnetic field on the circular axis of the torus and R is the radius of the point of observation counted off from the torus rotation axis z). The magnetic surface configuration in the torsatron with additional magnetic field coils is affected by the parameter $K_\varphi=1/(1+B_o/b_o)$ too (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).

2. RESULTS OF CALCULATIONS

Fig. 2 *a*, *b* show the poloidal magnetic surface cross-sections calculated for the initial magnetic surface configuration (I_s=0) and for the case with superposition of the ISCW magnetic field ($I_s\neq0$). The cross-sections are spaced round a toroidal angle φ (see fig. 1a) within the limits of a magnetic field half-period, $\varphi=0^o$, 22.5^o and 45^o. In the figures, the inner circle is the cross-section of a coaxial torus having the minor radius of 0.5a, and the outer circle is the cross-section of a torus with traces of the conductor turns of the helical coils (large black dots) and the ISCW turns (colour dots). All the cross-sections of the last closed magnetic surface are at the distance from the torus surface ~0.5a (B_o/b_o=1.56, K_φ=0.39). For the model under consideration B_z/b_o=0.75.

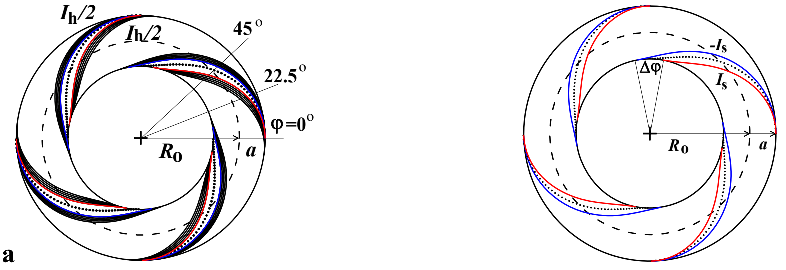

Fig. 1. Top view of split-type helical coils of the computation model (a) with the ISCW indicated by colour lines (b), Δφ is the toroidal angle of splitting. The helical base lines are shown as dotted lines. The toroidal azimuths of poloidal cross-sections are indicated. The additional toroidal magnetic field coils are not shown

As it is seen from Fig. 2 *a*, in all three cross-sections the magnetic axis traces in the initial configuration are disposed in the torus equatorial plane and the magnetic axis major radius is invariable, R_{oax}/R_o=0.945. Unlike the system with standard splitting of the helical coils, the magnetic surface configuration shifts inward the torus as the angle of internal splitting of the helical coils increases. The value of the average radius of the last closed magnetic surface is r_{lc}/a=0.27 (r_{lc}/R_o=0.07), the rotational transform angle on the magnetic surfaces ι=0.44→0.5 (in 2π units), there is a small magnetic well $-U$=0.023 in the configuration, and the mirror ratio ranges within γ=1.004→1.21.

Fig. 2 *b* shows the magnetic surface cross-sections for the case when the current $|I_s|$ in the ISCW turns is $0.02I_h$. It is seen that all the cross-sections, following the magnetic axis displacement, are displaced down by ~0.1*a* relative to the equatorial plane. When the current direction in ISCW turns changes to opposite one, the magnetic surface configuration displaces up by the same distance. 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 average value of the last closed magnetic surface radius is r_{lc}/a=0.26 (r_{lc}/R_o=0.068), the formation of a magnetic island structure is observed. The values of rotational transform angle, i=0.46→0.57, the magnetic well depth, $-U$=0.02, and the mirror ratio, γ=1.09→1.2, do not differ substantially from the corresponding parameters of the initial magnetic surface configuration.

3. MAGNETIC FIELD OF THE ISCW

Some idea on the ISCW magnetic field structure may be obtained by numerical simulations on the effect of this field as a minority magnetic field imposed on the magnetic field of a well-known configuration. To study the magnetic field of the ISCW (see Fig. 1,b) the axisymmetric toroidal magnetic field configuration was chosen. For this purpose it is sufficient to calculate the model assuming I_h=0 without changing the value and the direction of the additional magnetic field B_o and the ISCW current $|I_s|$. The b_{os}/B_o~0.002 ratio is taken to be a measure of the contribution from the ISCW magnetic field as a minority magnetic field. Here b_{os} is the magnetic field generated on the circular axis of the torus by the ISCW turns with the current I_s. The numerical studies were carried out for the geometry of the initial calculation model of the *l*=2, *m*=2 torsatron, taking $\Delta\varphi$ =35°.

Fig. 2,*c* shows the positions of the traces (dotted lines) calculated for five field lines of the resultant magnetic field at the different poloidal cross-sections of the torus. The starting points in the field line calculations are at R~R_o+a in the poloidal cross-sections φ=0°. The colour points at the torus cross-sections mark the positions of the ISCW turn cross-sections. It is easy to see from the figures that the field lines of the resultant magnetic field look like spirals turning in the direction of major radius *R* decrease. The geometric singularities of spirals allow us to conclude about the properties of the poloidal components B_{sR} and B_{sz} of the ISCW magnetic field.

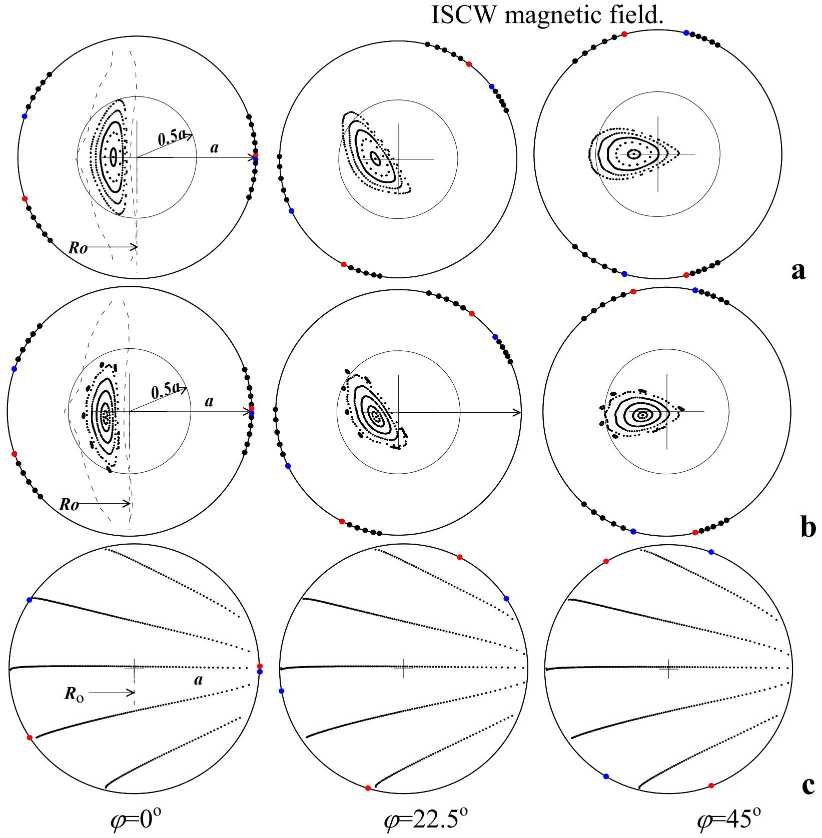

Fig. 2. Characteristic poloidal cross-sections (see Fig. 1a) of the initial configuration of the magnetic surface in the calculation model of l=2 torsatron (a) and in the case of the imposed ISCW magnetic field (b), traces of field lines of the toroidal magnetic field in the poloidal cross-sections of the torus in the case of the minority magnetic field of the ISCW superposition (c). The cross-sections φ=0° of the equiconnect [6] are shown by dashed lines

The spiral pitch is gradually decreases in the direction of major radius R decrease. It means that the values of the components B_{sR} and B_{sz} are proportional to the radius R (B_{sR}, B_{sz}~R). Besides, the observed constancy of the tilt angle of the spiral trace lines to the torus equatorial plane points to the constancy of the B_{sz}/B_{sR} ratio value in these lines. As the trace line shape of a single spiral remains unchangeable in every poloidal cross-section, the observed ISCW magnetic field properties are the same over the full length of the torus.

In the torus equatorial plane the last spiral pitch is by a factor of ~10^2 smaller than the starting pitch. Here, the component B_{sz} is zero and the spiral is the plane curve. The curve is well described by the equation:

$$R=R_0-a(1-2(\tan(\varphi/8N))^{3/2}),$$

where $0\leq\varphi\leq2\pi N$, and N is the number of spiral pitches (N=150). With the colliding beam fusion reactor concept [7] in mind, an interesting possibility arises in the case of practical realization of the spiral magnetic field in the torus. The calculated large initial pitch of the spiral gives a chance for the charged particle injected from the starting point of field line calculation to “miss” the injector and to hit it only after many hundreds of rounds along the torus, being reflected from the region of enhanced magnetic field. It is necessary to make clear the peculiarity of charge particle trajectory in the magnetic field.

CONCLUSIONS

The influence of the magnetic field of the new-type special correcting winding on the centered magnetic surface configuration with a plane magnetic axis and increased clearance between the last closed magnetic surface and the torus surface has been studied. The configuration is realized in the model of the l=2, m=2 torsatron with non-standard internal split-type helical coils and with additional toroidal magnetic field coils.

The calculations have shown that the ISCW action, similar to the split-type SCW action [3], upon the initial magnetic surface configuration leads mainly to a displacement of the magnetic surface configuration along the straight z axis of the torus. The displacements of ~$0.1a$ are not critical for the magnetic surface parameters. In the torus equatorial plane the ISCW magnetic field is directed, predominantly along the major radius of the torus within torus volume.

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СПЕЦИАЛЬНАЯ КОРРЕКТИРУЮЩАЯ ОБМОТКА ДЛЯ *l* = 2 ТОРСАТРОНА С ВНУТРЕННИМ РАСЩЕПЛЕНИЕМ ВИНТОВЫХ ОБМОТОК

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Рассмотрена специальная корректирующая обмотка для магнитной системы двухзаходного торсатрона с нестандартным (внутренним) расщеплением винтовых обмоток и с катушками дополнительного тороидального магнитного поля. Численные расчеты показали, что действие обмотки на исходную конфигурацию магнитных поверхностей приводит преимущественно к смещению конфигурации магнитных поверхностей вдоль прямой z оси тора.

СПЕЦІАЛЬНА КОРИГУЮЧА ОБМОТКА ДЛЯ *l* = 2 ТОРСАТРОНА З ВНУТРІШНІМ РОЗЩЕПЛЕННЯМ ГВИНТОВИХ ОБМОТОК

В.Г. Котенко

Розглянута спеціальна коригуюча обмотка для магнітної системи двозаходного торсатрону з нестандартним (внутрішнім) розщепленням гвинтових обмоток та з котушками додаткового тороїдального магнітного поля. Чисельні розрахунки показали, що дія обмотки на вихідну конфігурацію магнітних поверхонь зводиться переважно до зміщення конфігурації магнітних поверхонь уздовж прямої z осі тора.