

CALCULATION OF THE MAGNETIC SURFACES OF THE URAGAN-2M TORSATRON WITH ZERO CURRENT IN A SINGLE TOROIDAL MAGNETIC FIELD COIL

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Possibility of existence of closed magnetic surfaces in the Uragan-2M torsatron is analysed in case of zero current in one coil of the set of the toroidal field coils. An influence of the current-feeds and detachable joints of the torsatron helical winding is taken into account. A number of characteristic operating modes of the torsatron work is considered. New computational results are obtained which can be of interest for studies of plasma neutron sources based on stellarator type magnetic configurations with a mirror part of the magnetic configuration at the place where the coil current is zero.

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INTRODUCTION

The Uragan-2M (U-2M) device (Ref. [1]) is an 1=2 torsatron with 4 helical field periods along the torus (big torus radius is $R=170$ cm). The magnetic system of the device consists of the helical winding, the vertical field coils (basic and correcting) and the toroidal field coils (16 by the quantity). Numerical study of magnetic surfaces for this device has been carried out before in a number of works (e.g., Ref. [2]). Magnetic configurations of U-2M considered here are characterized by the magnetic field parameters which are shown in the following table:

Magnetic field parameters in U-2M

| lines | hel | tor | vert | k_ϕ | $\langle B_\perp/B_0 \rangle$ |
|-------|-------|------|------|----------|-------------------------------|
| 1-2 | 9100 | 6100 | 300 | 0.237 | 1.208 % |
| 3 | 13900 | 5400 | 740 | 0.349 | 2.084 % |
| 4 | 9800 | 7000 | 100 | 0.2258 | 0.93 % |
| 5-7 | 13500 | 5500 | 150 | 0.3384 | 1.406 % |
| 8-9 | 13500 | 5500 | 100 | 0.3384 | 1.355 % |

In this table "hel", "tor" and "vert" are currents of the helical winding (as well as of the basic vertical field coils), the toroidal field coils and the correcting vertical field coils, respectively, which have been extracted from the logbook of U-2M. Strings given in the table refer to the corresponding lines in the logbook from 20.02.2015-27.04.2015. Using these values, parameters k_ϕ and $\langle B_\perp/B_0 \rangle$ are calculated with $k_\phi = B_{th}/(B_{th} + B_{tt})$ where B_{th} and B_{tt} are the toroidal components of the magnetic field produced by the helical winding and the toroidal field coils, respectively (see Ref. [1]).

For all configurations the magnetic field is calculated using the Biot-Savart law code [3]), where influence of current feeds and detachable joints of the helical winding is taken into account by the approach analogous to that in Ref. [2]. Along with the above indicated modes calculations also performed for the mode

considered in Ref. [4] for $k_\phi = 0.24$ and practically full compensation of the vertical magnetic field.

Possibility of existence of closed magnetic surfaces in U-2M with switched off one of the coils of a toroidal magnetic field has been shown before by numerical simulation in [5]. The experiments (see in [4]) confirmed the existence of closed magnetic surfaces in such a system.

In the presented here calculations three cases are considered for each mode. In the first case the currents in the toroidal field coils are the same, in the second case the current in the 8-th toroidal field coil is taken to be zero and in the third case the current in the 14-th toroidal field coil is taken to be zero.

COMPUTATION OF MAGNETIC SURFACES

Integration of the magnetic field lines is performed for the intervals corresponding to 250 turns around the major axis of the torus. Cross-sections of the magnetic surfaces obtained as the results of these computations are presented in Figs. 1-8. These cross sections are close to the position of switched off toroidal field coils. Each figure corresponds to three considered cases: for the currents in the toroidal field coils being the same (left), for the current in the 8-th toroidal field coil being zero (middle) and for the current in the 14-th toroidal field coil being zero (right). In the captions under the pictures the toroidal field coil numbers are given between which the cross section is shown, numbers of the corresponding lines of table are also shown. A circle with a radius of 34 shows the inner boundary of the vacuum chamber. One has to bear in mind that for the case with the same current in all toroidal field coils, outer magnetic surfaces are partly beyond the vacuum chamber. Note that the computation results corresponding to lines 8, 9 of the table are very close to those corresponding to the lines 5-7.

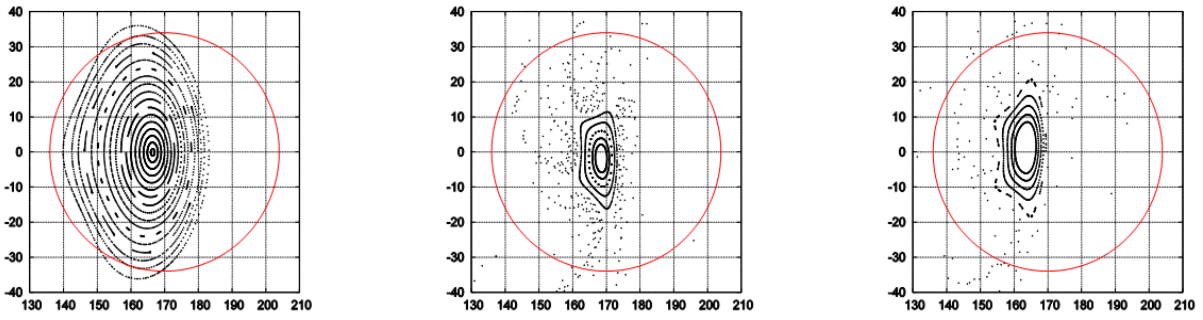


Fig. 1. Cross-sections between 8th and 9th coils for $k\phi=0.237$ (lines 1, 2)

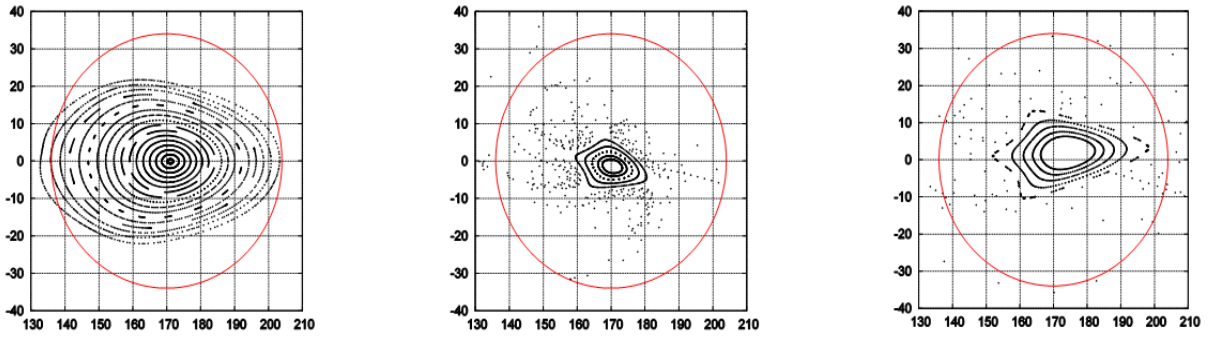


Fig. 2. Cross-sections between 14th and 15th coils for $k\phi=0.237$ (lines 1, 2)

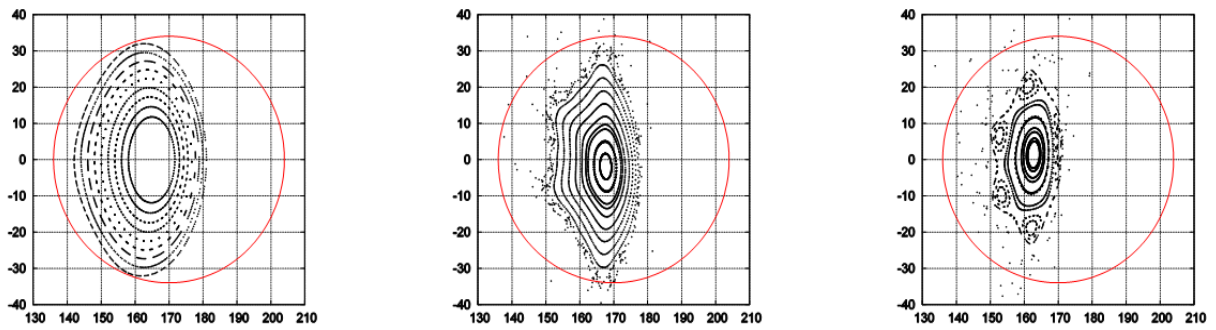


Fig. 3. Cross-sections between 8th and 9th coils for $k\phi=0.226$ (line 4)

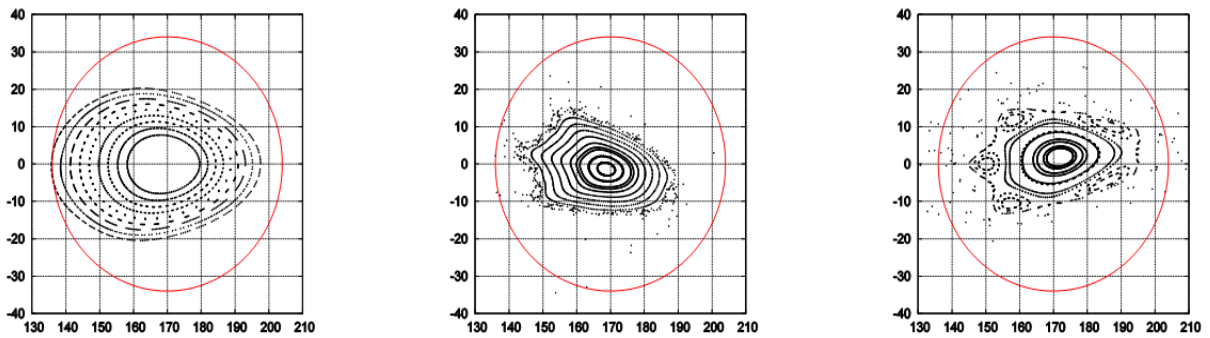


Fig. 4. Cross-sections between 14th and 15th coils for $k\phi=0.226$ (line 4)

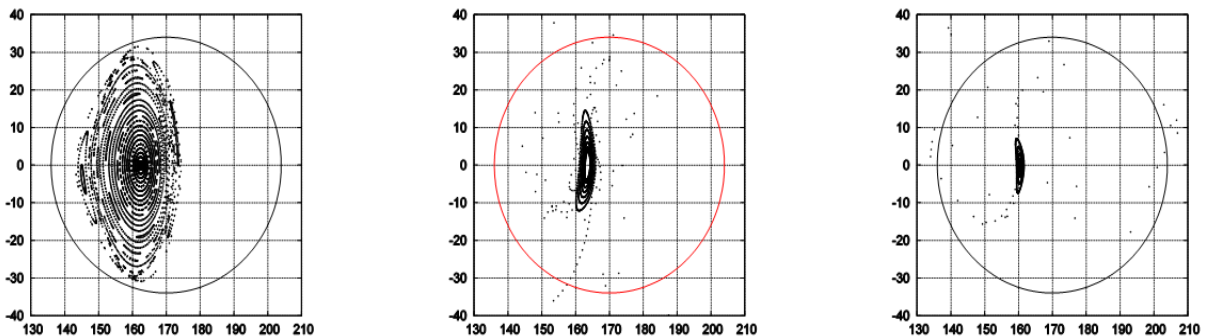


Fig. 5. Cross-sections between 8th and 9th coils for $k\phi=0.338$ (lines 5-7)

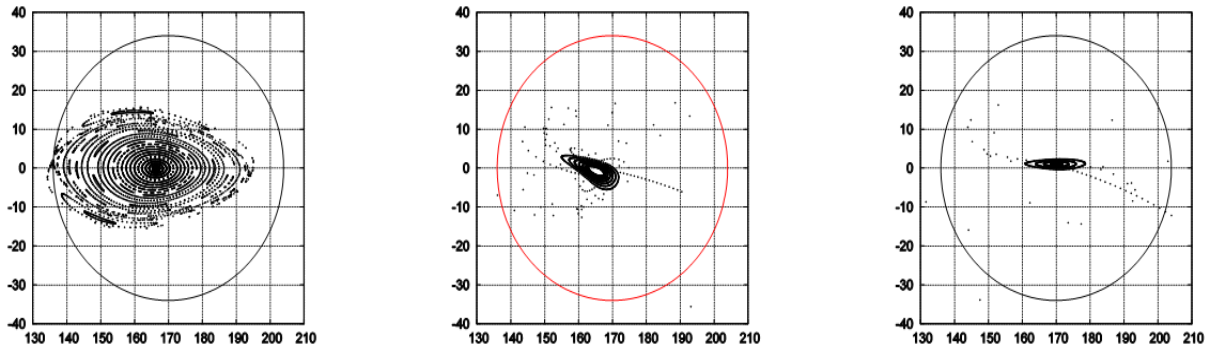


Fig. 6. Cross-sections between 14th and 15th coils for $k\varphi=0.338$ (lines 5-7)

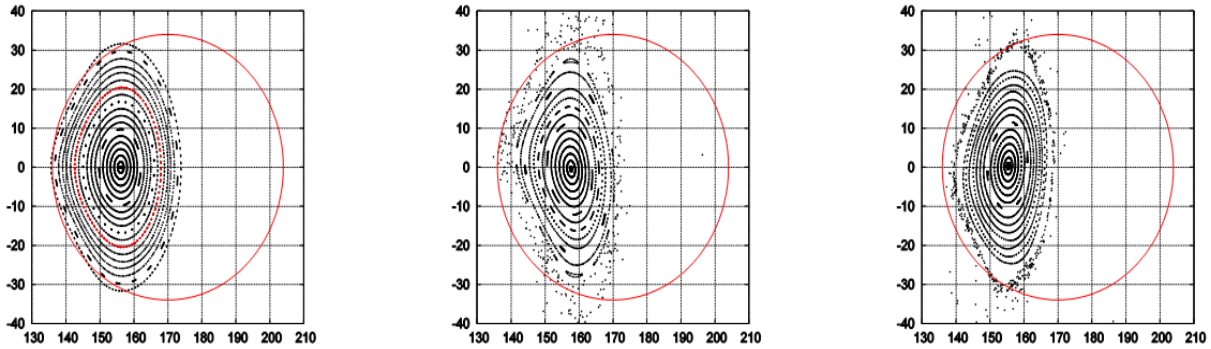


Fig. 7. Cross-sections between 8th and 9th coils for $k\varphi=0.240$ [4]

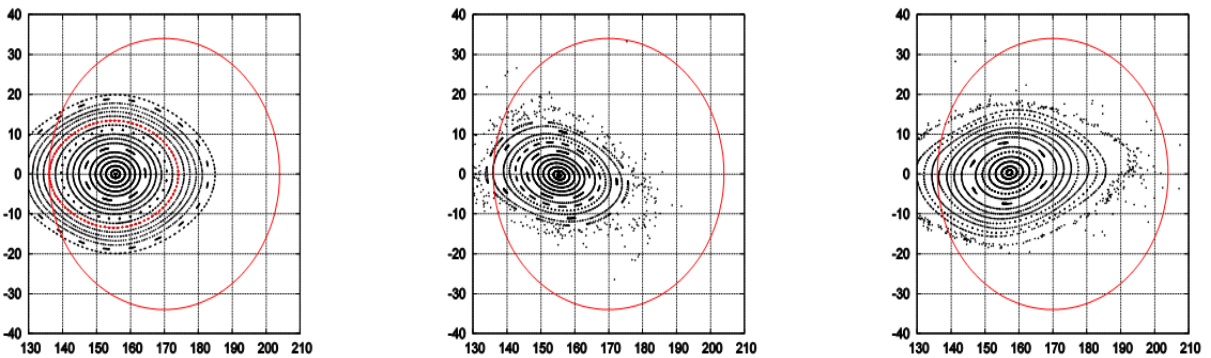


Fig. 8. Cross-sections between 14th and 15th coils for $k\varphi=0.240$ [4]

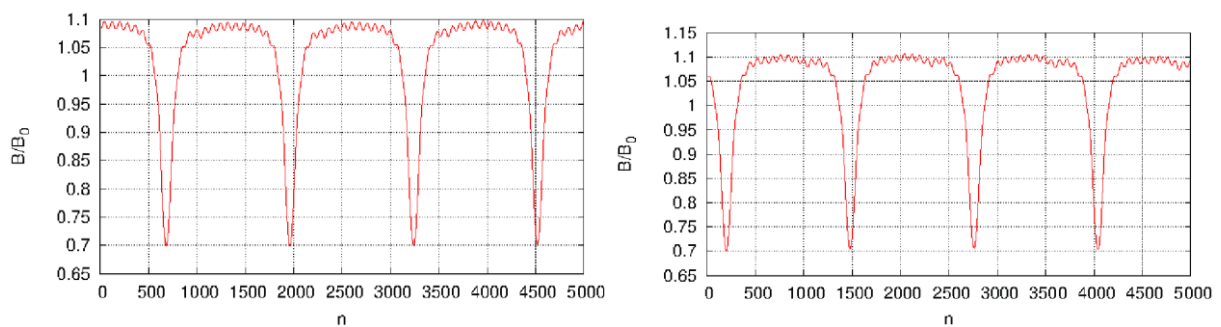


Fig. 9. Distributions of B/B_0 along the magnetic field line for the magnetic surfaces $r/a \approx 0$; n represents the number of integration steps along the field line with 1280 steps per torus length. (left) zero current in the 8th coil, (right) zero current in the 14th coil

For the regime of the line 3 for switched off toroidal coils number 8 or 14 closed magnetic surfaces could not be found although good magnetic surfaces exist for the case when currents in all toroidal field coils are the same.

In Fig. 9 for the second and third cases plots of distribution of B along the magnetic field line are also

presented for the mode $k\varphi=0.24$ [4]. Analogous plots for the rest considered modes are not presented, since these plots are very close to those in Fig. 9

CONCLUSIONS

It follows from the results that a removal of one of the toroidal field coils leads to a significant reduction in

the size of outermost magnetic surfaces, although such a decrease in the U-2M operating modes corresponding to line 4 in the table and Ref. [4], can be acceptable. The results can be of interest for studies of plasma neutron sources based on stellarator type magnetic configurations with a mirror part formed in the vicinity of the toroidal field coil with the switched off current (e.g., [6]).

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РАСЧЁТЫ МАГНИТНЫХ ПОВЕРХНОСТЕЙ ТОРСАТРОНА УРАГАН-2М С РАВНЫМ НУЛЮ ТОКОМ В ОДНОЙ ИЗ КАТУШЕК ТОРОИДАЛЬНОГО МАГНИТНОГО ПОЛЯ

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Анализируется возможность существования замкнутых магнитных поверхностей в торсатроне Ураган-2М в случае равного нулю тока одной из катушек тороидального магнитного поля. Учитывается влияние токоподводов и токоразъёмов винтовой обмотки торсатрона. Рассмотрен ряд характерных режимов работы торсатрона. Получены новые результаты расчётов, которые могут представлять интерес при изучении источников нейтронов, основанных на магнитных конфигурациях стеллараторного типа с пробкотронным участком, в месте катушки с нулевым током.

РОЗРАХУНКИ МАГНІТНИХ ПОВЕРХОНЬ ТОРСАТРОНА УРАГАН-2М З РІВНИМ НУЛЮ СТРУМОМ В ОДНІЙ З КОТУШОК ТОРОЇДАЛЬНОГО МАГНІТНОГО ПОЛЯ

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Аналізується можливість існування замкнутих магнітних поверхонь у торсатроні Ураган-2М у випадку рівного нулю струму однієї з котушок тороїдального магнітного поля. Враховується вплив струмопідводів та струморознімачів гвинтової обмотки торсатрона. Розглянуто ряд характерних режимів роботи торсатрона. Отримано нові результати розрахунків, що можуть становити інтерес при вивченні джерел нейтронів, оснований на магнітних конфігураціях стеллараторного типу із пробкотронною ділянкою, в місці котушки з нульовим струмом.