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STELLARATOR FIELDS WITH 2-WIRE LINES WOUND ROUND THE TORUS (*L*=3,4 SYSTEMS)

V. G. Kotenko, G. G. Lesnyakov, S. S. Romanov
Institute of Plasma Physics, National Science Center
"Kharkov Institute of Physics and Technology", 310108, Kharkov, Ukraine

1. Introduction

In this paper calculations are extended to the models of new stellarator-type magnetic systems [1, 2], subsequently referred to as YAMATOR [3, 4], where the poloidal magnetic field components are formed with the help of 2-wire lines wound round the torus.The winding is made in such a manner that the wires of the lines lie on the nested tori of the same major radius R_0 and different minor radii a_1 and $a_2=a_1+h$, h being the distance between the wires of the line. The number of 2-wire lines forming the YAMATOR magnetic system determines its polarity l. Here we outline some the results concerning the l=3,4 YAMATOR systems.

2. Calculation model

Numerical calculations of toroidal systems were carried out for the following basic model [2]: 2-wire lines were wound on the torus along the helical line $\theta=m\varphi$, θ is the poloidal angle, φ is the toroidal angle, m=3 is the number of helical pitches along the torus, h/R_0=0.15 is the distance between the wires of the line, a_1/R_0=0.3, a_2/R_0=0.45 are the aspect ratios of nested tori. The system is plunged into an axisymmetric toroidal magnetic field $B_\varphi=B_0R_0/R$, B_0 is the toroidal magnetic field value on the circular axis of the system, R is the radial position of the observation point, reckoned from the straight axis z. At operating basic conditions the controlling transverse magnetic field is B_z=0. The model allows a simple transition to the torsatron system if B_0 and the inner (or outer) helical current I are put to zero. This circumstance has been used to test the magnetic well value. The present results are in good agreement with the known literature data.

3. The *l*=3 system

This system consists of three 2-wire lines wound round the torus displaced from the other one by angle $\theta=2\pi/3$ in the poloidal direction. Fig.1 presents 3 poloidal magnetic surface cross-sections within one magnetic field period $T=2\pi/ml$ ((a) φ=0, (b) φ=T/4, (c) φ=T/2). Calculations were performed for B_z=0, B_0/b_0=3.33, with b_0 being the amplitude of the circular-axis magnetic field generated by the helical current I traversing the torus of the minor radius a_1. It is seen from the figures that, similarly to l=1,2 systems, there are inner and outer closed magnetic-surface domains. As in l=1,2 systems, the shape and position of the outer-domain magnetic surfaces are almost independent of the toroidal angle φ. The properties peculiar to these surfaces are a very small rotational transform angle, $i\sim10^{-2}$ (from here and on i is given in unit of 2π) and the magnetic hill ($+U$) increasing as the average magnetic-surface radius increases. So, the main parameters of the outer-domain magnetic surfaces are not adequate for the stellarator experiment. The parameters of the inner-domain magnetic surfaces meet the requirements for stellarator experiment. The magnetic surface parameters of inner domain as functions of average magnetic-surface radius r/R_0 are shown in Fig.2. It is seen that in the l=3 system, the magnetic well depth ($-U$)=38%, i=0.25 can be attained.

4. The *l*=4 system

This system consists of four 2-wire lines wound round the torus displaced from the other one by angle $\theta=\pi/2$ in the poloidal direction. Fig.3 presents 3 poloidal magnetic surface cross-sections within one magnetic field period in this system for B_z=0, B_0/b_0=3.75. As in the l=1,2,3 systems, two domains of closed magnetic surfaces exist, and the main parameters of the outer-domain magnetic surfaces are not adequate for the stellarator experiment. In the inner domain (see Fig. 2) the l=4 system provides ($-U$)=45% and i increases from 0.25 to 0.4 at the last closed magnetic surface (LCMS).

5. Effect of the parameter *h*

In the YAMATOR systems there is a parameter h, defining the spacing between the wires of the 2-wire line, which has no analogy in conventional stellarator magnetic systems. Its value determines the ratio of one helical coil minor radius to another a_2/a_1, and thus governs the YAMATOR magnetic system design. Fig. 4 presents the LCMS parameters as functions of the ratio a_2/a_1 (a_1=const.) for l=3,4 systems at B_z=0, B_0/b_0=3.33, 3.75, respectively. As the parameter h decreases, the magnetic well appreciably increases and the LCMS rotational transform angle ι_{lc} decreases; this is accompanied by an increase in the magnetic axis radius R_{ax}/R_0 (φ=0 cross-section), the rotation of field lines slows down mainly at the inner parts of the magnetic surfaces. From Fig.4 it also follows that in the YAMATOR system the magnetic well growth is not accompanied, as it takes place in conventional stellarator systems, by an essential loss of the LCMS volume. If ($-U$) increases (h decreases), the average LCMS radius r_{lc}/R_0 varies only slightly in these systems. If the transverse controlling magnetic field is applied ($B_Z\neq 0$), the behavior of the average LCMS radius relative to the magnetic well value is similar.

6. Modular YAMATOR system

It has been indicated earlier [2] that a simple realization of a module version of the YAMATOR system consists in joining the 2-wire line segments 1 on the module ends by means of radial current-carrying jumpers 2 of length *h* (see Fig 5). The jumper currents at the adjacent ends of modules arrainged in series are equal and opposite. So, the magnetic field perturbations caused by these radial currents seem to be compensated very well, at least, for the case of filament-like conductors considered here. Indeed, numerical calculations of a six-module version of the l=3 YAMATOR system [1] at basic operating conditions with the intermodule angular distance $\Delta\varphi=4^{\text{o}}$ have not shown any appreciable disturbances of the magnetic surface configuration or magnetic surface parameters.

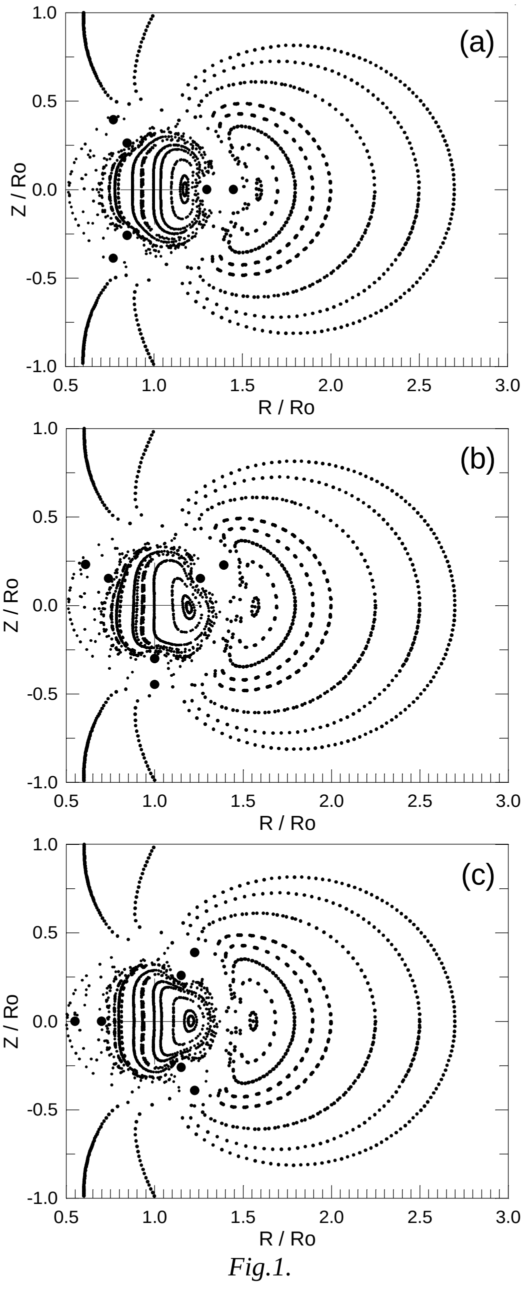

Fig.1.

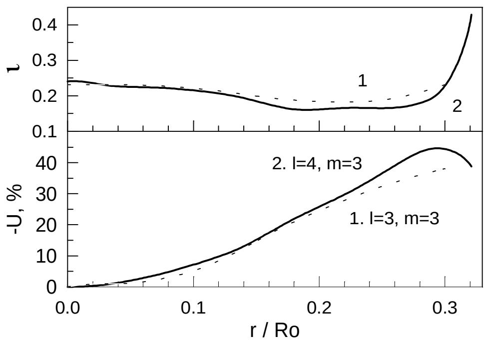

Fig.2.The rotational transform angle ι and the magnetic well (-U) versus the average magnetic-surface radius r/R_O in the l=3, 4 YAMATOR systems

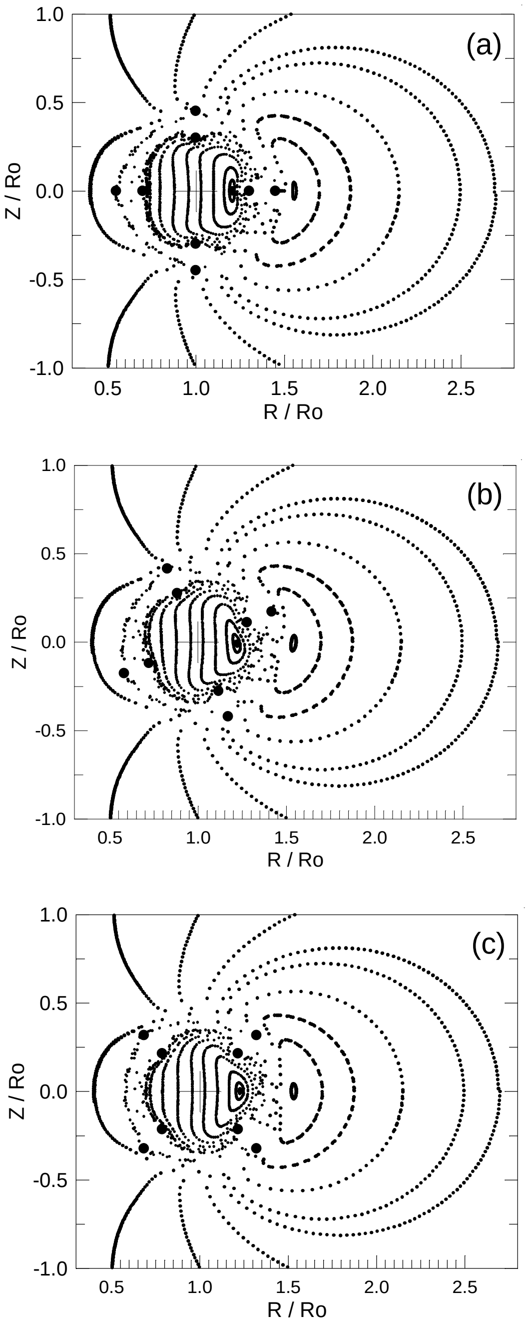

Fig.3.

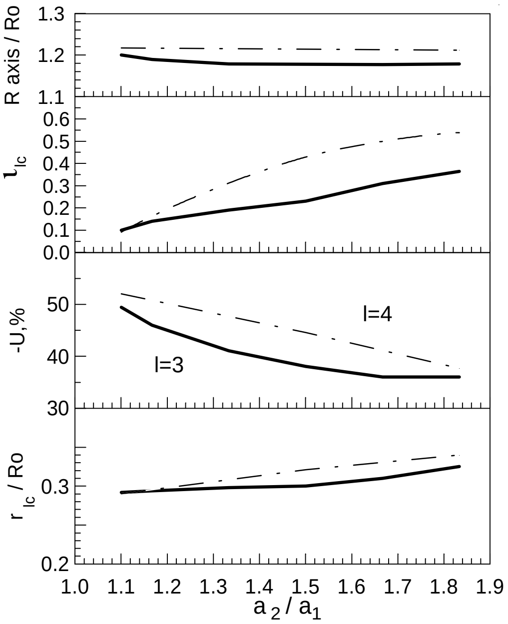

Fig.4 Radius R_{ax}/R_0 of the magnetic axis at $\varphi=0$, LCMS rotational transform angle ι_{lc}, magnetic well (-U) and LCMS average radius r_{lc}/R_0 versus the nested tori minor radii ratio a_2/a_1, where a_1=const

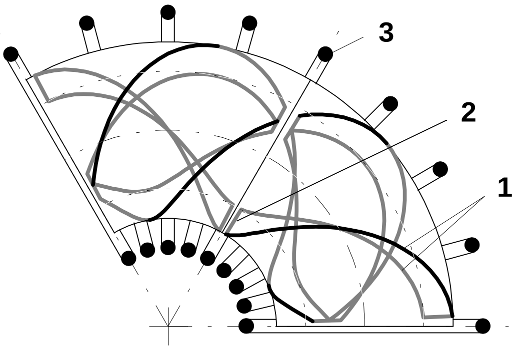

Fig.5 Top view of the six-module version of the l=3, m=3 YAMATOR (third part): the 2-wire line segment, 1; the radial current-carrying jumper, 2; toroidal field coil, 3

7. Summary

The main special feature of the new magnetic systems is the possibility to form on their base a toroidal magnetic field with a large magnetic well ($-U \sim a_1/R_0$). The latter grows as the polarity *l* increases, and for a given *l* it can still be increased if the parameter $h \ll a_1$. In a real YAMATOR these methods to adjust the magnetic well value will have a natural limitation due to the finite size of current-currying conductors, this being aggravated by an increasing toroidicity of the configuration. There is another limitation caused by the rotational transform angle value acceptable for stellarator experiment, since this angle always decreases as the magnetic well grows. The other characteristic feature of the YAMATOR systems is a great volume of the magnetic surfaces, especially in l>1 systems with a low *h* value. Both the features seem to be very attractive for the commercial fusion reactor on condition that the first wall problem is finally solved. However, to support this suggestion, comprehensive theoretical, experimental and engineering investigations must be done. The nearest step includes the study of the influence of finite-size conductors on the magnetic configuration in the real YAMATOR, elucidation of the possibility to construct an effective divertor in it, and the neoclassical transport loss estimation.

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