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NEOCLASSICAL TRANSPORT IN KOLER TRAP (YAMATOR)

V.N.Kalyuzhnyj, S.V.Kasilov, V.V.Nemov

Institute of Plasma Physics,
National Science Centre " Kharkiv Institute of Physics and Technology",
Akademichna 1, Kharkiv 61108, Ukraine.

The new stellarator type magnetic system having a high magnetic well value was proposed in paper [1]. In the present work neoclassical transport for magnetic configuration of $l = 2$ variant of similar system is investigated by numerical methods. A so-called $1/\nu$ transport regime, in which the transport coefficients are increased with reduction of particle collision frequency ν is considered. For calculating of transport coefficients a technique [2], based on integration along magnetic field lines in given stellarator magnetic field with taking into account particles trapped not only within one magnetic field period but also within several magnetic field periods is used. The obtained transport coefficients are presented in a standard form containing a factor depending on the magnetic field geometry. The dependence of transport coefficients from value of a resulting vertical magnetic field is analysed.

1. Introduction

In Ref. [1] a new stellarator system has been proposed which is characterized by an increased magnetic well value. The magnetic field of such a system is produced by pairs of helical conductors with oppositely directed currents of the same value. The conductors wind with equal pitch values on the nested tori with the same major radii R_0 and different small radii r_1 and $r_2 = r_1 + \Delta r$. High magnetic well values in the proposed stellarator systems suggest a possibility of an MHD stability of plasma in such systems. At the same time the question about transport properties of such a system stays open.

As it is known, one of possible reasons for the increased heat and energy losses in stellarator type systems (together with so-called "anomalous" losses) is the neoclassical transport due to the asymmetry of stellarator magnetic field. According to the theory, different transport regimes are possible in asymmetric system however the most dangerous regime is the so-called $1/\nu$ -regime where transport coefficients increase with decreasing collision frequency ν. Therefore, the reduction of transport coefficients in $1/\nu$ regime is one of important requirements in the optimization of stellarator systems [3]. This transport regime is studied in the present paper for $l = 2$ configuration of the system proposed in Ref. [1].

2. Method and results of numerical investigation

The method of Ref. [2] is used in the present paper for evaluation of transport coefficients. Based on the field line integration technique, this method takes into account particles trapped within one or several magnetic field periods. In accordance with this method transport in $1/\nu$ regime can be described by a standard expression for the magnetic surface averaged particle flux density (or similar formula for the energy flux density),

$$F_n = -\frac{\sqrt{8}}{9\pi^{3/2}} \frac{v_T^2 \rho_L^2}{\nu R^2} \varepsilon_{eff}^{3/2} \int_0^\infty \frac{dz e^{-z} z^{5/2}}{A(z)} \frac{n}{f_0} \frac{\partial f_0}{\partial r}$$

where f_0 is the Maxwellian distribution function which is a function of particle energy and magnetic surfaces, $A(z)$ is a quantity connected with collision operator, v_T and ρ_L are the thermal velocity and the characteristic particle Larmor radius, R is the major torus radius, $\partial f_0 / \partial r$ is the averaged derivative of f_0 over the normal to the magnetic surface, ε_{eff} is the effective amplitude of modulation (non-uniformity) of the magnetic field along the magnetic field line ("effective ripple"). The given formula differs from the corresponding formula for the standard stellarator (see eq. (2.16) of Ref. [4]) by the replacement of the helical modulation amplitude ε_h with the quantity ε_{eff}. ("The standard stellarator" means here a stellarator magnetic field with the circular magnetic axis and magnetic surfaces with circular cross-section.) The value of ε_{eff} is obtained by means of numerical integration over the magnetic field line length for the given magnetic field and over the perpendicular adiabatic invariant (see Ref. [2]). ε_{eff} coincides with ε_h for the standard stellarator. Thus, the parameter ε_{eff} contains all the information about the effect of the magnetic field geometry in the considered transport regime. The transport coefficients in $1/\nu$ regime for any magnetic configuration can be obtained from the corresponding transport coefficients of the standard stellarator by replacement of $\varepsilon_h^{3/2}$ with $\varepsilon_{eff}^{3/2}$. Note that the energy flux density differs from the given formula for the particle flux density by the factor zT in the sub-integrand.

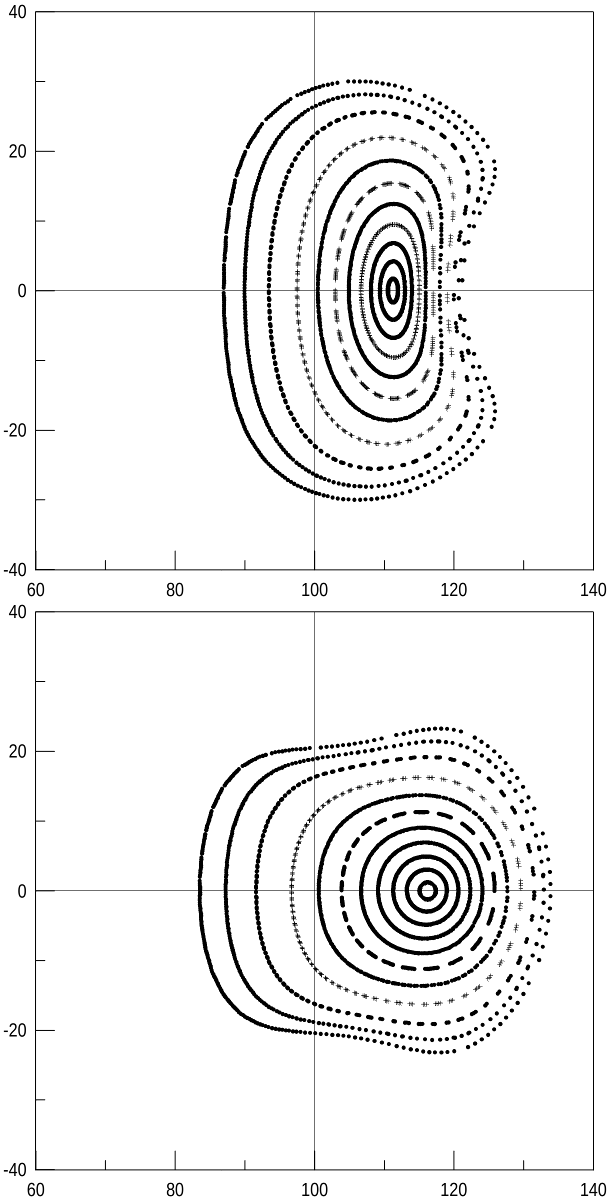

Fig.1. Magnetic surface cross-section for $B_{\perp} = 0$

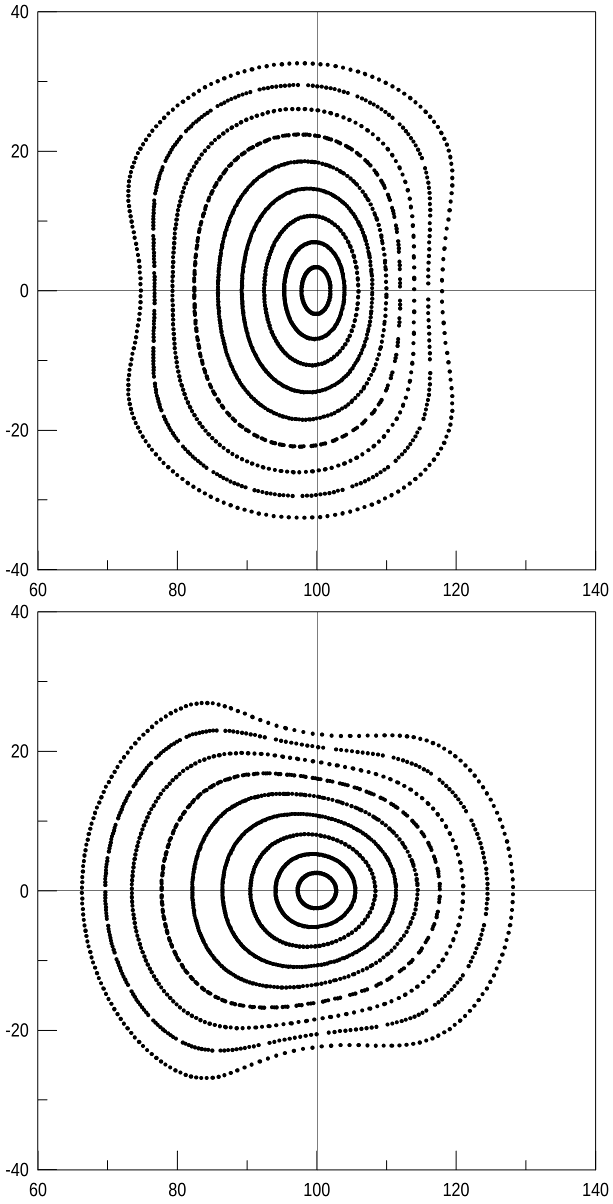

Fig.2. Magnetic surface cross-section for $B_{\perp} \neq 0$

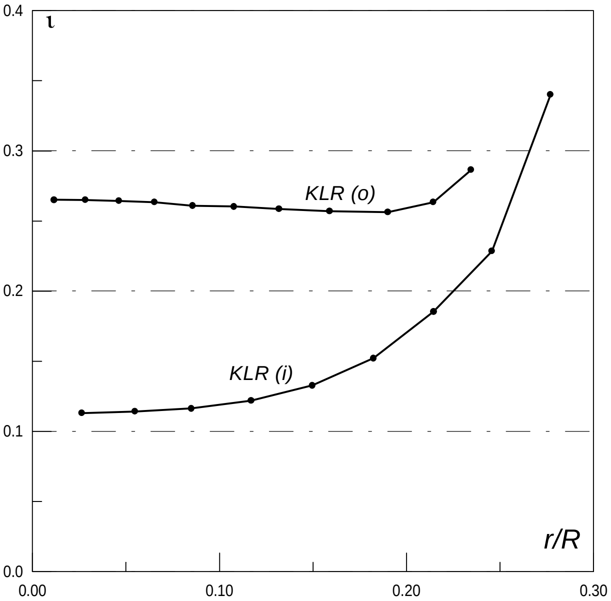

Fig.3. The rotational transform angle ι *versus the average magnetic surface radius* r/R_0

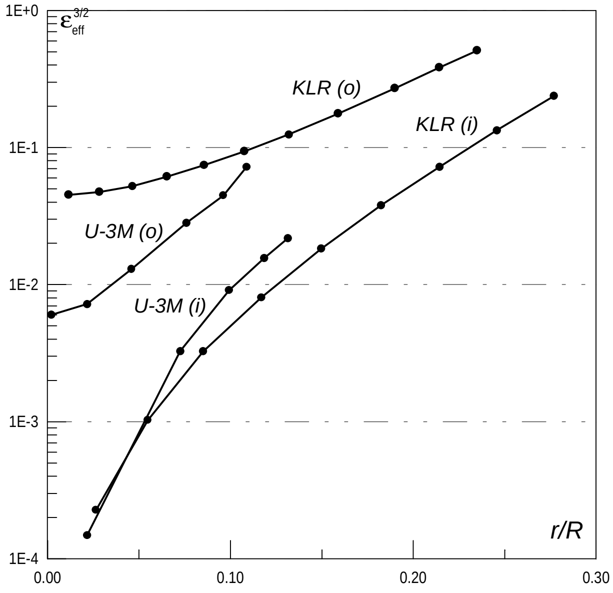

Fig.4. Results of $\varepsilon_{eff}^{3/2}$ *calculation for* $l = 2$ *KOLER trap (KLR) and for Uragan-3M torsatron (U-3M)*

The $l = 2$ variant of the proposed system chosen for the numerical evaluation has the following parameters, $r_1/R_0 = 0.3$, $r_2/R_0 = 0.45$, $\Delta r/R_0 = 0.15$. The evaluation was performed assuming thin conductors placed at the toroidal surfaces along the helical line $\theta = n\varphi$ where θ and φ are poloidal and toroidal angles and n is a number of poloidal turns of the helical line after one toroidal turn ($n = 3$). The initial magnetic field of the system consisted from the field of helical conductors and toridal magnetic field $B_\varphi = B_0 R_0/\rho$ (ρ is the distance from the main axis of torus). The magnetic field of helical conductors has been calculated with the help of Biot-Savart law. In order to study the possibility to change transport coefficients the calculation was performed both for the initial configuration and the analogous configuration with the additional uniform vertical magnetic field. The value of vertical field corresponded to the return of the magnetic axis to the circular axis of torus. The magnetic surface cross-sections for these two cases are shown in Figs. 1 and 2. The corresponding radial dependencies of the rotational transform angle are shown in Fig. 3. The results of the calculation of $\varepsilon_{eff}^{3/2}$ for these two configurations are given in Fig. 4. For the comparison, the values of $\varepsilon_{eff}^{3/2}$ for the torsatron Uragan-3M are shown at the same plot for two opposite values of the total vertical magnetic field. These values correspond to the shift of the magnetic configuration to the inner or outer side of the torus. The absolute value of the vertical field $B_\perp$ was of the order of 1.2% of the toroidal field of the torsatron.

3.Conclusion

It follows from the obtained results that the initial configuration is characterized by increased values of transport coefficients, which exceed approximately by one order of magnitude the corresponding coefficients for U-3M with the shift of magnetic surfaces to the outer side of torus. On the other hand, the later coefficients exceed the corresponding coefficients for the standard stellarator 2-6 times. As it follows from the calculation, the values of transport coefficients can be reduced by order of magnitude or even more with addition of the vertical field that shifts the magnetic configuration to the inner side of torus. For rather large r/R_0 values these coefficients exceed corresponding coefficients for U-3M (shift of the magnetic configuration to the inner side of torus), while for the values of r/R_0 within the limits reached in U-3M they can even be smaller than for U-3M. We should note that such vertical field may cause the decrease of the magnetic well.

Also, we have considered the neoclassical transport in $1/\nu$ regime for $l = 3$ variant of the proposed system [5]. In this case the results for the parameter $\varepsilon_{eff}^{3/2}$ appeared to be similar to the results for $l = 2$ system.

References

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