NUMERICAL STUDY OF THE 1/ν NEOCLASSICAL TRANSPORT AND MERCIER PLASMA STABILITY IN AN *l*=2 TORSATRON WITH THE CENTERED PLANAR MAGNETIC AXIS

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The 1/ν neoclassical transport and Mercier plasma stability for a magnetic configuration of *l*=2 torsatron system with the centered planar magnetic axis, which was done by selecting the winding law of the helical coils, formed in the model of the *l*=2 torsatron Uragan-2M type, are investigated numerically. For calculating the transport coefficients and Mercier stability criterion a technique, based on integration along magnetic field lines in a given stellarator magnetic field (NEO code) is used. The magnetic field of helical windings is calculated by the Biot-Savart law. The transport coefficients are presented in a standard form containing a factor depending on the magnetic field geometry. The obtained results are compared with corresponding results for two variants of torsatron Uragan-2M «standard» configuration.

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INTRODUCTION

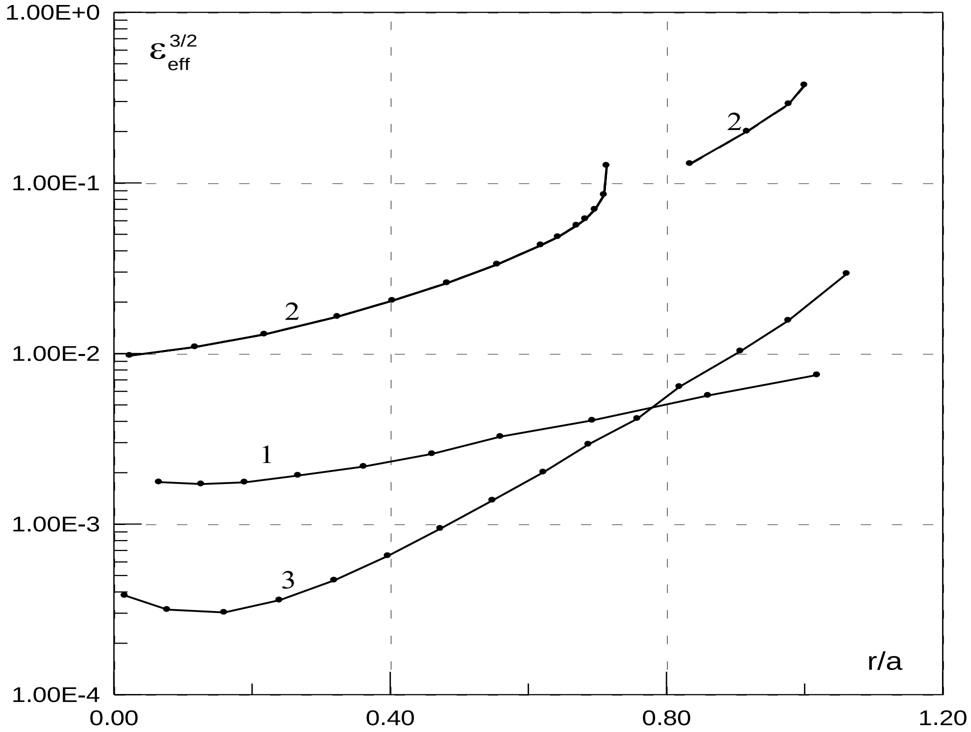
In paper [1] by selecting the winding law of the helical coils, formed in the model of the torsatron Uragan-2M (U-2M) type comprising the additional toroidal magnetic field coils, the *l*=2 torsatron with centered planar axis of magnetic surfaces was proposed. As is shown in paper it is possible to realize the magnetic surfaces with a negative shear and a magnetic well in such system. High magnetic well values and negative shear in the proposed torsatron type system suggest a possibility of an MHD stability of plasma in it. In the present work, numerical calculations have been carried out to investigate the confinement properties of this *l*=2 torsatron configuration that have the planar magnetic axis coincident with the circular geometrical axis of the torus.

Neoclassical transport in so-called 1/ν regime, in which the transport coefficients are increased with reduction of particle collision frequency ν and Mercier plasma stability for a magnetic configuration of *l*=2 torsatron system with the centered planar magnetic axis are analyzed using numerical methods [2, 3] (NEO code) based on the integration along magnetic field lines in a given magnetic field. One of the characteristic features of these methods is that if the magnetic field is originally available in real-space coordinates, calculations can be performed without a field transformation to magnetic coordinates. The obtained results are compared with corresponding results for «standard» magnetic configuration of torsatron Uragan-2M [4].

NUMERICAL METHODS AND RESULTS OF COMPUTATIONS

According to the general concept of stellarator optimization [5], numerical calculations of the 1/ν transport are of big importance for assessing the general confinement properties of the device. Usually, the 1/ν regime is characterized by the so called effective ripple (equivalent helical ripple), $\varepsilon_{eff}^{3/2}$, (see, e.g., in [5]). The quantity $\varepsilon_{eff}^{3/2}$ enters into neoclassical transport coefficients as a geometrical factor representing the influence of the magnetic field geometry. In paper [2] the field line integration technique is proposed for computations of $\varepsilon_{eff}^{3/2}$ in arbitrary stellarator configurations using real space variables. This code is automatically taking into account all kinds of trapped particles. Here, the 1/ν neoclassical transport is studied for *l*=2 torsatron with centered planar axis of magnetic surfaces using the field line following code NEO [2] for computation of transport measures.

The results of $\varepsilon_{eff}^{3/2}$ computation for *l*=2 torsatron configuration that have the planar magnetic axis are shown in Fig. 1 (curve 1). These results are presented as functions of the ratio *r/a* with *r* being the mean radius of the magnetic surface under consideration. The mean radius *a* relates to the outermost magnetic surface of this configuration. For comparison in Fig. 1 the results of our earlier $\varepsilon_{eff}^{3/2}$ computations [4] for "standard" configuration of torsatron Uragan-2M (k_φ=0.375, where $k_\varphi=B_{th}/(B_{th}+B_{tt})$, B_{th} and B_{tt} are the toroidal components of the magnetic field produced by helical and toroidal field coils, respectively) are shown in two cases: $B_\perp/B_0 \approx 2.5\%$ (curve 2) and $B_\perp/B_0 \approx -2.5\%$ (curve 3). The first corresponds to initial "standard" configurations which is well centered with respect to the vacuum chamber and second corresponds inward shift configuration.



Parameters $\varepsilon_{eff}^{3/2}$ as functions of r/a for a magnetic configuration of l=2 torsatron system with the centered planar magnetic axis (curve 1), for «standard» Uragan-2M configuration:

$B_{\perp}/B_0 \approx 2.5\%$ *(curve 2) and* $B_{\perp}/B_0 \approx -2.5\%$ *(curve 3)*

As follows from Figure for the initial «standard» U-2M configuration the 1/ν transport is essentially bigger than that which is desirable from the viewpoint of the stellarator optimization. Markedly smaller 1/ν neoclassical transport can be obtained in «standard» U-2M configuration by changing the resulting vertical magnetic field by a way which lead to an inward-shifted configuration. (see curve 3). This way can be of interest although the inward shifted configuration can posses a magnetic hill (instead of a magnetic well). For the *l*=2 torsatron with centered planar axis of magnetic surfaces having a magnetic well the effective ripple values (curve 1) are some bigger than for inward shifted configuration U-2M in the central region and became smaller than that for outermost magnetic surfaces.

As it is known, the Mercie stability criterion is widely used to study the MHD plasma stability in stellarator magnetic configurations both analytically and numerically [6, 7]. To investigate the plasma stability using the Mercier stability criterion in system with the centered planar magnetic axis, we apply the numerical method based on the calculation of the terms contained in Mercier criterion by tracing the magnetic field lines in the given stellarator magnetic field [3]. The magnetic field of helical windings is calculated by the Biot-Savart law.

For the case of a low-pressure plasma with a finite local pressure gradient this criterion can be presented in the form of the inequality

$$D < 1/4, \qquad (1)$$

where

$$D = p'\frac{X_{GB} - X_{hS}}{(X_S - p'X_{hB})^2}, \qquad (2)$$

with $X_{GB} = \left\langle \nabla\psi \cdot \nabla B^2 / (B^2 |\nabla\psi|^2) \right\rangle / X_B$, $X_{hS} = \langle hS \rangle / X_B$, $X_{hB} = \left\langle hB^2 / (|\nabla\psi|^2) \right\rangle / X_B$, $X_S = \langle S \rangle / X_B$ and $X_B = \left\langle B^2 / (|\nabla\psi|^{2)} \right\rangle$. Here h is related to the equilibrium parallel current density $j_{II} = p'hB$ (the prime denotes the derivation with respect to ψ, ψ is a magnetic surface label), $S = (\vec{B} \times \nabla\psi) \cdot \nabla \times (\vec{B} \times \nabla\psi) / |\nabla\psi|^4$ and $\langle A \rangle$ is determined by integration along the magnetic field line $\langle A \rangle = \int A dl/B \Big/ \int dl/B$.

From (2) follows that for $p' < 0$ (the natural profile of p) and for $X_{GB} - X_{hS} > 0$ the D value is smaller than zero. In this case the Mercier criterion (1) is satisfied. As it follows from the numerical investigation the plasma stability in system with the centered planar magnetic axis this takes place for all magnetic surfaces of this configuration. So, the stability

Mercier criterion is satisfied for all magnetic surfaces of this configuration.

SUMMARY

In the present work, numerical calculations have been carried out to investigate the confinement properties of the U-2M type l=2 torsatron with the centered planar axis. Neoclassical transport in 1/ν regime and Mercier plasma stability for the proposed system are analyzed using NEO code based on the integration along magnetic field lines in a given magnetic field.

As it follows from the numerical investigations, the stability Mercier criterion for this torsatron type system with the centered planar axis is satisfied for all magnetic surfaces of this configuration. Numerical calculations of the neoclassical 1/ν transport for the proposed system show that for the *l*=2 torsatron with centered planar axis the effective ripple values are some bigger than for inward shifted «standard» U-2M configuration in the central region and became smaller than that for outermost magnetic surfaces.

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ЧИСЛЕННОЕ ИССЛЕДОВАНИЕ НЕОКЛАССИЧЕСКОГО ПЕРЕНОСА В РЕЖИМЕ 1/ν И МГД-УСТОЙЧИВОСТИ ПЛАЗМЫ С ИСПОЛЬЗОВАНИЕМ КРИТЕРИЯ МЕРСЬЕ В *l*=2 ТОРСАТРОНЕ С ЦЕНТРИРОВАННОЙ ПЛОСКОЙ МАГНИТНОЙ ОСЬЮ

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Численными методами выполнено исследование неоклассического переноса в режиме 1/ν и МГД-устойчивости плазмы с использованием критерия Мерсье для двухзаходной торсатронной системы с центрированной плоской магнитной осью, что было достигнуто с помощью специального выбора закона навивки винтовой обмотки в модели, близкой по параметрам к параметрам торсатрона Ураган-2М. При вычислении коэффициентов неоклассического переноса в указанном режиме и расчетах величин, входящих в критерий Мерсье, использована техника, основанная на численном интегрировании вдоль силовых магнитных линий в заданном стеллараторном магнитном поле (код NEO). Магнитное поле винтовых проводников вычислялось с использованием закона Био-Савара. Полученные коэффициенты переноса представлены в стандартной форме, содержащей фактор, зависящий от геометрии магнитного поля системы. Выполнено сравнение полученных результатов с соответствующими результатами, полученными ранее для двух вариантов «стандартной» конфигурации торсатрона Ураган-2М.

ЧИСЛОВЕ ДОСЛІДЖЕННЯ НЕОКЛАСИЧНОГО ПЕРЕНОСУ В РЕЖИМІ 1/ν ТА МГД-СТІЙКОСТІ ПЛАЗМИ З ВИКОРИСТАННЯМ КРИТЕРІЯ МЕРС'Є В *l*=2 ТОРСАТРОНІ З ЦЕНТРОВАНОЮ ПЛОСКОЮ МАГНІТНОЮ ВІССЮ

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Числовими методами виконано дослідження неокласичного переносу в режимі 1/ν та МГД-стійкості плазми з використанням критерію Мерс'є для *l*=2 торсатронної системи із центрованою плоскою магнітною віссю, що було досягнуто за допомогою спеціального вибору закону навивки гвинтової обмотки в моделі, близькій за параметрами до параметрів торсатрона Ураган-2М. При обчисленні коефіцієнтів неокласичного переносу в зазначеному режимі та розрахунках величин, що входять у критерій Мерс'є, використана техніка, що базується на числовому інтегруванні уздовж силових магнітних ліній в заданому стелараторному магнітному полі (код NEO). Магнітне поле гвинтових провідників обчислювалося з використанням закону Біо-Савара. Отримані коефіцієнти переносу представлені в стандартній формі, що містить фактор, залежний від геометрії магнітного поля системи. Виконано порівняння отриманих результатів з відповідними результатами, отриманими раніше для двох варіантів «стандартної» конфігурації торсатрона Ураган-2М.