On steep gradients in plasmas confined at convex-concave magnetic field lines near the minimum in the longitudinal adiabatic invariant

M.M. Tsventoukh[1], A.V. Kaziev[2]

[1] Lebedev Physical Institute of Russian Academy of Sciences, Moscow, Russia
[2] National Research Nuclear University MEPhI, Moscow, Russia

The formation of large stable plasma gradients, e.g. in form of internal transport barriers, being of a strong both practical and fundamental interest. Normally the larger the gradient the larger the transport, and any deviation due to collective plasma behavior is of great interest.

We have predicted theoretically that there is a strong stabilizing action against convective (flute-interchange) perturbations when plasma is confined by magnetic field of alternating-sign curvature – i.e. with convex–concave field lines [1]. The calculations that have been done for simple combinations of axisymmetric mirrors and cusps according to the kinetic stability criterion, give strongly centrally peaked stable plasma pressure profiles instead of shallow ones.

Connection of the convex and concave field line parts results in a reduction of the space charge that drives the unstable $\boldsymbol{E} \times \boldsymbol{B}$ motion, as there is an opposite direction of the particle drift in a non-uniform field at convex and concave field lines. The pressure peaking arises at the minimum of the second adiabatic invariant $J = \int v_{\|}\, \mathrm{d}l$ that takes place at the 'middle' of a tandem mirror–cusp transverse cross-section. Recall that there has been proposition by Arsenin [2-3] that there is a plasma interchange stability due to the alternating-sign curvature.

The simple ideal MHD description gives a strong variation in the stable pressure profile due to the strong variation in the specific volume $\int \mathrm{d}l/B$: the critical profile being $p_{MHD} \propto (\int \mathrm{d}l/B)^{-5/3}$. However, we have found that there is a strong variation in the stable pressure profile at regions of almost equal specific volume – near min $\int \mathrm{d}l/B$, with curvature of alternating sign – with appropriate combination of the convex and concave field line parts.

Instead of the well-known max$J$ principle of the plasma stabilization [4], we have proposed that there is an additional stability of the plasmas nearby the field lines layer of the min$J$. Recall that in tokamak max$J$ region nearly corresponds to the region near the axis within min$q$ [5]. As the minimum in the q nearly corresponds to the minimum in the J, one would expect somewhat reduction in the plasma convective transport near min$q$ according to the mechanism proposed.

We have performed an experimental investigation of the plasma confinement at magnetic confinement device of the alternating-sign curvature [6].

For the experimental research of this effect, a compact magnetic confinement device has been modified by adding of the external current coil to fulfil the field-line curvature requirements. The critical convectively-stable plasma pressure profiles calculation in this experimental geometry and the probe measurements of the spatial plasma distribution in the new magnetic configuration of alternating-sign curvature have been performed.

The experimental results give some support for a conclusion that there is an increase in the ion saturation current at the region near the minimum of the specific volume min $\int \mathrm{d}l/B$. This region corresponds to the average minimum in the second adiabatic invariant, and the kinetic description predicts the stable pressure profile peaking here due to reduction of charge separation by particle drift in alternating-sign curvature.

For further experimental investigations, a stationary microwave device has been used. A mirror geometry has been created by axisymmetric coils, Langmuir and magnetic probes have been used for the measurements.

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[1] Tsventoukh 2014 *Nucl. Fusion* **54** 022004
[2] Arsenin V.V. 1983 *JETP Lett* **37** 637
[3] Arsenin V.V. 1986 *JETP Lett* **43** 346
[4] Marshall N. Rosenbluth 1968 *Physics of Fluids* **11** 869
[5] B.B. Kadomtsev 1966 *JETP Lett* **4** (1) 10
[6] Tsventoukh *et al* 2015 *Nucl. Fusion* **55** 062001