

## Drift Reversal Capability in a Quasi-Poloidally Symmetric Stellarator

YOKOYAMA Masayuki

*National Institute for Fusion Science, Toki 509-5292, Japan*

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Maximum- $J$  ( $J$  is the second adiabatic invariant) capability, i.e., drift reversal capability, is examined in a quasi-poloidally symmetric stellarator as a possible mechanism for turbulent transport suppression. The radial variation of the uniform magnetic field component plays a crucial role for the drift reversal in a quasi-poloidally symmetric configuration.

**Keywords:** drift reversal capability, Maximum  $J$  criterion, quasi-poloidally symmetric stellarator, radial variation of the uniform magnetic field.

Improved plasma confinement has been realized in toroidal plasmas by means of the turbulent fluctuation suppression. This has been considered consistent with theoretical predictions for the stabilization of micro-instabilities [1]. Several kinds of micro-instabilities appear when the directions of diamagnetic drift and  $\nabla B$  drift ( $B$  is the magnetic field strength) are in the same direction for trapped particles. The direction of  $\nabla B$  drift precession can be expressed in terms of the radial derivative of the second adiabatic invariant  $J$ . The stability condition for them is derived as  $\nabla P \cdot \nabla J > 0$  ( $\nabla J < 0$  for  $\nabla P < 0$ ) with scalar plasma pressure  $P$  and  $J$ , which is called the maximum- $J$  criterion (drift reversal). Innovative helical systems have been widely studied [2-4] based on quasi-symmetry concepts. It is worthwhile to examine the drift reversal capability in such configurations as the guiding principle of the configuration design for the turbulent suppression [5]. Drift reversal capability in quasi-axisymmetric (QAS) stellarators has been reported [6]. The unique knob for the drift reversal, that is, the residual non-axisymmetric components of magnetic field strength, has been clarified in addition to the well-known magnetic shear contribution in tokamaks.

In this paper, the drift reversal capability in another quasi-symmetry concept, quasi-poloidally symmetric (QPS) stellarator, is described. It should be noted that a particular QPS configuration (being designed at Oak Ridge National Laboratory) [4] has

been obtained through the computational procedure for the close alignment of  $J$  contours with magnetic surfaces for achieving good collisionless particle confinement. The main focus of this paper is to examine  $J$  properties from a different point of view, that is, in terms of the stabilization of micro-instabilities.

The  $J$  is calculated by following the guiding center of low-energy trapped particles whose deviation from a magnetic field line is negligibly small. The guiding center equations [7] are expressed by use of the Boozer coordinates ( $\psi, \theta, \zeta$ ) [8], with  $\psi$  being the normalized toroidal flux and  $\theta$  ( $\zeta$ ) the poloidal (toroidal) angle. The motion of the guiding center is defined by five variables ( $(\psi, \theta, \zeta)$  for the real space,  $v$  and particle energy,  $W$ ). Since the precession direction is the key for the stability condition, the  $W$  dependence is not important here so that particles with fixed  $W = 10$  eV are considered. Also, the integral is performed along the particle trajectory so that one out of  $\theta$  and  $\zeta$  dependence is omitted when the launching points of particles are specified. To obtain the radial profile of  $J$ , tracer particles which are to be reflected at the same  $B$  are launched from the bottom of the dominant magnetic field ripple [eg., the bottom of the bumpy (poloidally symmetric) field-induced ripple ( $\zeta/(2\pi/M) \equiv \zeta_N = 0.5$ )]. Here,  $M$  is the number of the field period. The initial velocity of tracer particles,  $v_{||,st}$ , is defined as  $v_{||,st} = [2W(1 - B_{st}/B_{ref})/m]^{1/2}$ , where  $B_{st}$  ( $B_{ref}$ ) is

author's e-mail: yokoyama@nifs.ac.jp

the magnetic field strength (normalized with the strength averaged on the magnetic axis,  $B_0$ ) at the initial (bounce) point and  $m$  the particle mass. It is noted that the specifying  $B_{\text{ref}}$  corresponds to consider tracer particles with the same magnetic moment ( $\mu$ ), which is the estimate of how deeply these particles are trapped in a magnetic ripple.

A QPS configuration ( $M = 4$ ) (called QBS configuration in Ref. [9]) is used as an example for analysis. The geometrical aspect ratio is about 10. This configuration has been obtained through plasma boundary shaping. A significant variation of area of magnetic surfaces exists in the toroidal direction. This gives the dominant bumpy component of  $B$  through the conservation of a toroidal magnetic flux. The bumpy field is as much as half of the uniform magnetic field. There remain symmetry breaking components such as helicity and toroidicity. However, the amplitudes of these components are less than 1/5 of that of bumpy component, and it should also be noted that the toroidicity is reduced to the level of about the half the geometrical inverse aspect ratio.

Figure 1 shows  $J$  contours (for  $B_{\text{ref}} = 0.65$ , deeply trapped particles) on the  $(r/a, \theta)$  plane for finite beta equilibrium (volume averaged beta value of about 5%). The  $J$  is maximum at the plasma core and it decreases radially, which satisfies the condition  $\nabla J < 0$ . It shows clear drift reversal. It is noted that the drift reversal is not realized in a vacuum case for this particular configuration. The bumpy field component has little radial variation for a vacuum case (cf., Ref. [9]) and it is still the case even for finite beta equilibrium. At vacuum case, the radial difference of the uniform magnetic field amplitude between the core and the edge (providing the vacuum magnetic well) is much smaller compared to the amplitude of the bumpy component. However, its difference is enhanced up to about half of the bumpy component for above mentioned finite beta equilibrium, which establishes the absolute minimum of  $B$  for the core region at the launching plane (cf., Fig. 2). This radial increase of  $B$  towards the plasma edge at a finite beta equilibrium (both for the inner ( $r/a < 0$ ) and outer ( $r/a > 0$ ) regions of a torus) plays an essential role for realizing a radially decreasing  $J$  profile (drift reversal).

This is a unique mechanism for achieving drift reversal in QPS stellarators, differing from that in QAS stellarators [6]. This would also be relevant for the QPS configurations currently being designed [4], which are to be investigated from the viewpoint of the drift reversal capability.

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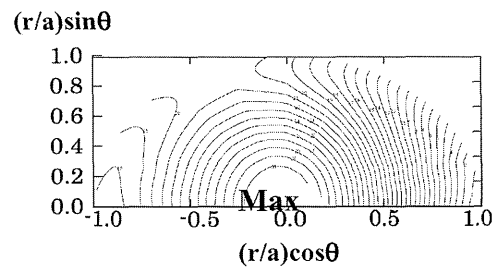


Fig.1 Contours of  $J$  (for  $B_{\text{ref}} = 0.65$ ) on  $(r/a, \theta)$  plane for an example configuration (finite beta case). The "Max" denotes the maximum of  $J$ .

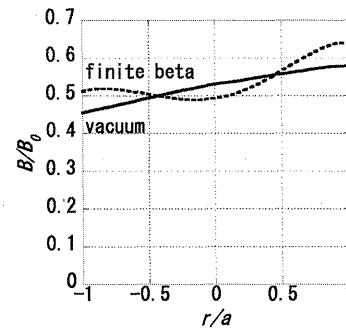


Fig.2 Radial variation of  $B/B_0$  on the equatorial line at  $\zeta_N = 0.5$  for an example configuration (vacuum and finite beta cases).

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