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Possibility of LHD Equilibrium with Zero Rotational Transform Surface

KANNO Ryutaro, TOI Kazuo, WATANABE Kiyomasa, HAYASHI Takaya,
MIURA Hideaki, NAKAJIMA Noriyoshi and OKAMOTO Masao
National Institute for Fusion Science, Toki, 509-5292, Japan

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Possibility of a Large Helical Device equilibrium having a zero rotational transform surface is examined by using the three-dimensional MHD equilibrium code, HINT. We find the existence of the equilibrium but with the formation of two or three $n = 0$ islands composing the homoclinic-type structure near the center, where n is a toroidal mode number.

Keywords:
zero rotational transform, LHD equilibrium, HINT computation

In the Large Helical Device (LHD) [1], an MHD equilibrium configuration with both a deep magnetic well and high magnetic shear in the plasma core region has attracted much attention from the point of view of improved MHD stability and plasma confinement. In the LHD, such an equilibrium can be realized by a large Ohkawa current [2] induced by counter neutral beam injection. In a plasma with a net subtractive toroidal current of about –100 kA/T, the rotational transform is expected to be below zero around the magnetic axis.

Previously, a helical equilibrium with a zero rotational transform surface was examined in the Heliotron E experiment [3]. The following results were reported: when a rotational transform at the center was below zero, strong MHD activities were seen to induce relaxation oscillations. These processes were explained by an $m/n = 1/0$ resistive tearing mode, where m is the poloidal mode number and n is the toroidal mode number, based on a numerical analysis employing a low beta resistive MHD model for a straight heliotron-like configuration [4]. The numerical study [4] also showed that when the resonant surface existed near the axis, the $m/n = 1/0$ tearing instability was weak and the magnetic island width saturated at some value. This result suggests the possibility of the existence of the equilibrium with a zero rotational transform surface. From these previous studies, at first we should investigate whether or not an LHD equilibrium with a zero rotational transform surface can be allowed. This article addresses this point.

Numerical analysis of the equilibrium is carried out by using the HINT code [5-8]. The HINT computation starts from the vacuum configuration with $B_0 = 1.5$ T, $R_0 = 3.75$ m, and the initial pressure profile given as $p = p_0(1 - s^4)(1 - s)$, where B_0 is the magnetic field strength at the magnetic axis, R_0 is the major radius of the axis, p_0 is pressure at the axis, and s is the normalized toroidal flux. We find that an LHD equilibrium with a zero rotational transform surface is possible to exist, as shown in Fig. 1. Here an average value of the equilibrium beta β is (a) 0.56 % or (b) 1.7 %, and the total net toroidal current I_t is –100 kA/T. We assume that the profile of the net toroidal current density modeling the Ohkawa current is given as $j \propto -(p/p_0)^2$. Profiles of rotational transforms and pressure are plotted in Fig. 2. In the field line structure of Figure 1 (a), we see two islands. The central island has a negative $\iota/2\pi$, and the other island with the $n = 0$ mode, located around the central one, has a zero rotational transform around an O-point of the central island, as shown in Fig. 2. When the equilibrium beta increases to 1.7 %, the inner region sufficiently away from the separatrix of the latter island is split into two parts, and a doublet-type $n = 0$ island having only one X-point located at $Z = 0$ is formed. Note that the LHD equilibrium maintains a homoclinic-type structure [7,9] composed by the islands near the

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

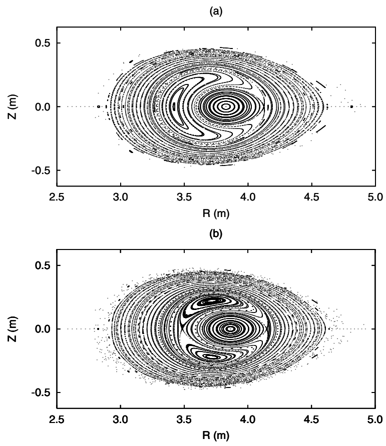

Fig. 1 Poincaré plots of field lines at the horizontally elongated poloidal cross section in the LHD equilibria with (a) $\beta \approx 0.56$ % and (b) $\beta \approx 1.7$ %. The total net toroidal current I_t is −100 kA/T.

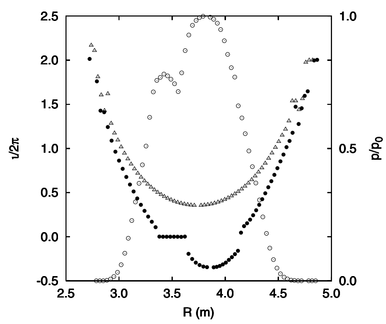

Fig. 2 Profiles of rotational transform $\iota/2\pi$ (solid circle) and pressure (open circle) along $Z = 0$ for $\beta \approx 0.56$ % and $I_t = -100$ kA/T. Open triangles represent $\iota/2\pi$ in the vacuum field.

center, when β increases; see Fig. 1. We can consider that this field line structure is general for both helical and tokamak plasmas, because the toroidal mode number of the islands is zero. The Shafranov shift of the magnetic axis and the radial positions of $Z = 0$ for the last closed flux surface (LCFS) change with a value of the total net toroidal current I_t, as shown in Fig. 3. As I_t increases, the axis shifts to the outside of the torus and the rotational transform around the center decreases to zero. When the $n = 0$ islands appear, however, the shift of the axis is reduced.

Let us consider a comparison to the tokamak plasma with a current hole. Recently, an idea of an axisymmetric tri-magnetic-islands (ATMI) equilibrium has been proposed in Ref. [10], where the ATMI equilibrium is one of candidates of a tokamak equilibrium having a zero rotational transform surface. The ATMI equilibrium has three islands with $n = 0$ near the

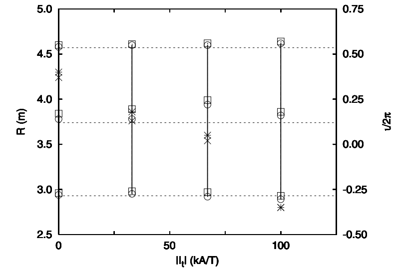

Fig. 3 The Shafranov shift of the axis and the radial positions of the LCFS ($Z = 0$) for 1) open circle: $\beta \approx 0.56$ % and 2) open square: $\beta \approx 1.7$ %. Dotted lines represent the positions of the axis and the LCFS for the vacuum. The central rotational transforms for 1) cross: $\beta \approx 0.56$ % and 2) asterisk: $\beta \approx 1.7$ % are also shown.

center, and they compose the heteroclinic-type structure [7,9]. As contrasted with Ref. [10], in this article we suggest that the homoclinic-type structure is also allowed.

A numerical study of the nonlinear stability of a tokamak-like equilibrium having a negative central current [11] suggests that the equilibria obtained here require to be examined on an MHD stability of $n = 0$ modes. The nonlinear stability of the equilibria will be reported in near future.

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