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Design of non-axisymmetric coils for vertical stability of elongated tokamak plasmas by using VMEC
三次元平衡計算コードVMECを用いた垂直位置安定化のための摂動磁場コイルの設計

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A rotationally asymmetrical partial stellarator coils generate averaged vertical fields in combination of toroidal fields which works functionally equivalent to conventional vertical fields in tokamaks. Although this configuration counterbalance horizontal force on current carrying plasma, it can also keep vertical position stably due to averaged horizontal field components. The effect of the partial stellarator fields were studied numerically by using 3-D equilibrium code VMEC. It is shown that partial stellarator coils attain tokamak plasmas equilibrium without axisymmetric poloidal field coils, and generate averaged vertical fields. These characteristics of the configuration have distinct advantages for easy operation of tokamak device.

1. Introductions

It is known that tokamak plasmas vertical position is unstable when the shape of them is highly elongated while the Troyon scaling law for plasma stability implies that high β plasmas can be achieved [1]. Therefore, sophisticated feedback control with axisymmetric poloidal field coils are necessary to stabilize vertical instabilities in such operations.

However, non-axisymmetric coils can passively stabilize the vertical instabilities of elongated tokamak plasmas. From the installation point of view, several concepts of additional stellarator windings, which do not encircle the plasma in the poloidal direction, have been proposed; “semi-setellarator windings” arranged on the outboard side of torus [2] and “parallelogram-shaped saddle (PS) coils” arranged on the top and bottom of torus [3].

This kind of local stellarator windings generates averaged horizontal fields in combination with toroidal field (TF) coils. The averaged fields which is approximately given by Eq. (1), can suppress vertical instabilities.

$$B_{av} = \alpha \frac{I_s^2}{B_t} exp\left[\frac{2(R-R_w)}{d}\right] \qquad (1).$$

where I_s is the current flowing in the stellarator windings, d is the distance between adjacent windings divided by π, and α is a constant determined by the pitch angle and toroidal period of the windings.

2. Condition of computing

Although several coils configuration has been designed based on these principles, one of the results of MHD equilibrium is shown in Fig. 1. It is constitutes of conventional toroidal fields (TF) coils and a pair of PS coils which has opposite current direction each other. The absence of poloidal or vertical field coils is striking point of this configuration.We investigated the impact of PS coils on the position and shape of the tokamak plasma by using 3-D equilibrium code. It is, however, not enough to prove the vertical stability from the MHD equilibrium alone. In this study, the free boundary version of the VMEC code was employed [4]. In calculation, plasma parameters were set as follows: major radius $R_0 \approx$ 40 cm, plasma minor radius a $\approx$ 10 cm, plasma beta $\beta = 0$, toroidal magnetic field B_t = 0.25 T, plasma current I_p = 6 kA, PS coil current I_{PS} = 10 kA, parabolic current profile $j(s) = j_0(1-s^2)$, where s is the normalized toroidal magnetic flux Φ/Φ_{edge}. The B_t was set in the opposite direction to I_p. In addition, the total toroidal magnetic flux in the outermost flux surface was fixed in all cases.It is the objective of this design and study to confirm whether the rotationally asymmetric configuration works as conventional vertical fields coils. Thus, plasmas shape of cross-section was chosen to be nearly circular.

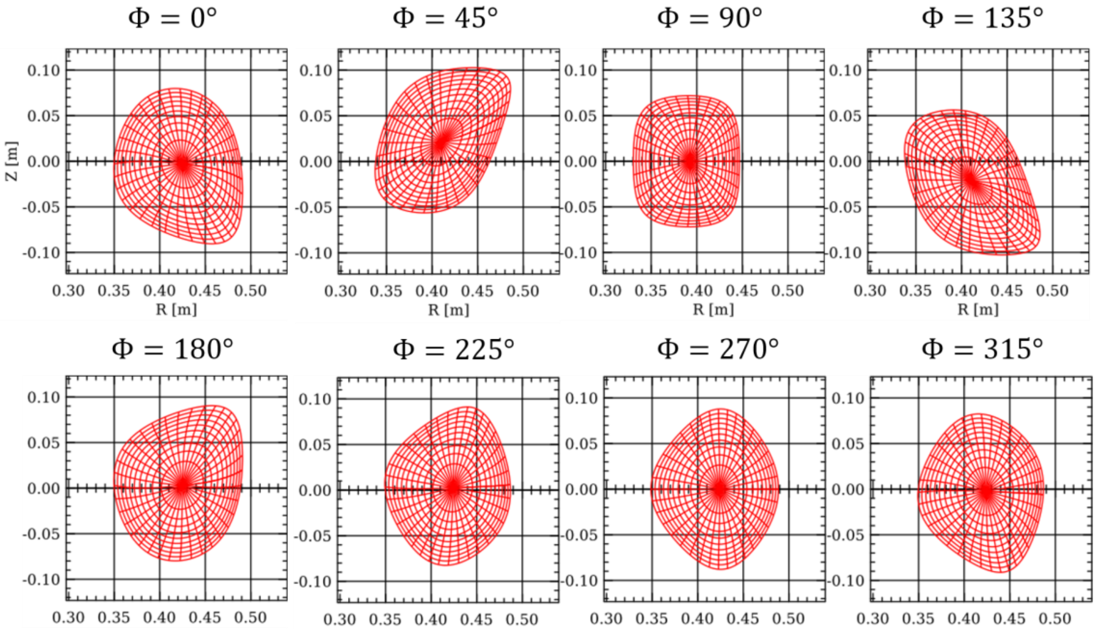

Fig. 1 An example of tokamak plasma equilibrium by use of VMEC.

3. Result and problems

Fig. 1 shows that horizontal positions are kept approximately in the center at toroidal intervals 45°. It is obvious that hoop force of plasma current F_h and averaged forces $F_{av} = I_p \times B_{av}$ generated by PS coils are in equilibrium in the horizontal direction [Fig. 2 (a)]. Compared Φ = 270° to Φ = 90°, the horizontal position of magnetic axis is slightly expanded due to the distance between PS coils and plasma. In addition, it is shown that PS coils can make MHD equilibrium without poroidal or vertical field coils. Surprisingly, the counterbalance force appears in the opposite side of torus.

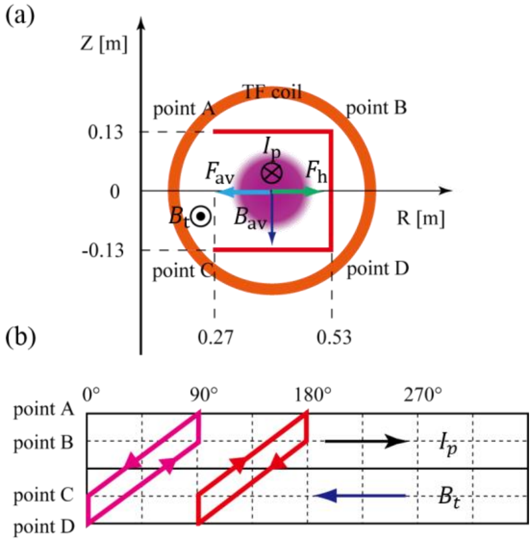

Fig.2 (a) Poloidal cross section calculation model. (b) Development of the PS coils.

The problems we must take into account are very large coil current I_{PS} comparable to the plasma current I_p and the shape of PS coils in proposed systems. As parallelogram is difficult to fix on the vessel, hence, we are constructing a small tokamak device equipped with divided saddle coils (Fig. 3) [5]. We can investigate various shape of PS coils by changing current ratio of each coils. Further numerical study using VMEC of this divided saddle coils should be performed.

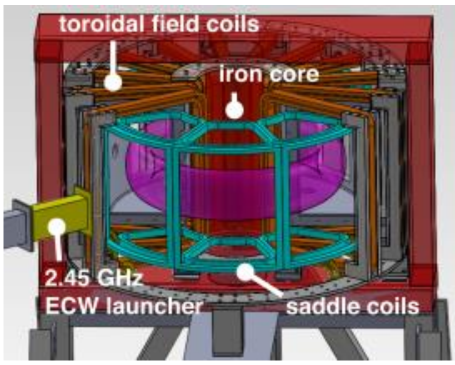

Fig. 3 Small tokamak device equipped with divided saddle coils in place of PS coils under construction.

References

[1] F. Troyon and R. Gruber, Phys. Lett. A 110, **29** (1985).
[2] H. Ikezi and K. F. Schwarzenegger, Phys. Fluids **22**, 2009 (1979).
[3] R. Reiman, Phys. Rev. Lett. **99**, 135007 (2007).
[4] S. P. Hirshman and J. C. Whitson, Phys. Fluids **26**, 3553 (1983).
[5] S. Hatakeyama, et al., Proc. EPS2014, **P4**.012 (2014)