Preliminary Experiments on the Vertical Stability with Helical Coils in a Small Tokamak, HYBTOK-II

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Introduction

In tokamaks, elongated plasmas for good confinement suffer from vertical instabilities, leading to so-called vertical displacement events (VDEs) during disruptions. The contact of plasma and first wall due to VDEs will lead to the damages of in-vessel structures by high heat flux and induced electromagnetic forces [1]. On the other hand, it has been shown that the plasma position is robustly stable in a current-carrying stellarator, whereas that in an equivalent tokamak is unstable [2]. In order to suppress vertical plasma movement in a tokamak, modular stellarator windings, like saddle coils, were investigated to stabilize plasma position [3]. However, the coil configuration may not have been optimum for the suppression of vertical displacement since the principle of stabilizing effects remains unclear. The aim of our study is to investigate the principle and improve the configuration of the coils for vertical stability experimentally. In this article, we report preliminary results of experiments conducted with a small tokamak, HYBTOK-II.

Experimental Setup

HYBTOK-II is a conventional tokamak with a circular cross-section (the major radius R_0 = 40 cm, the plasma minor radius $a \approx 10$ cm, the limiter radius a_w = 11 cm). In the experiments, the discharge parameters were as follows: the plasma current I_p = 5 kA, the toroidal magnetic field B_t = 0.28 T and the pulse duration was 15 ms.

The saddle shaped stellarator coil system on the HYBTOK-II devices is shown in Fig. 1. This is composed of four coils on the vacuum vessel. The arrows indicate the directions of coil currents which are alternate in the same ways as stellarator windings. The windings have 20 turns, and each maximum coil current $I_{stellarator}$ is around 4kAturns which is comparable to the plasma current. The power supply of the coils can generate the coil current nearly steadily. The plasma position was measured with magnetic probes at 135 degrees in the toroidal direction.

In order to investigate the principle and optimum configuration, two experiments were carried out using different combinations of coil s. In the first experiment, all four coils were used which are symmetrical with respect to the torus axis. In the second experiment, only two coils were selected which are localized at one side of the torus. In fact, HYBTOK-II does not suffer from vertical positional instabilities since it is a circular cross-section tokamak. Therefore we intentionally shifted the plasma slightly upward. In this experiment, we tested the change in the vertical plasma position with saddle shaped stellarator system.

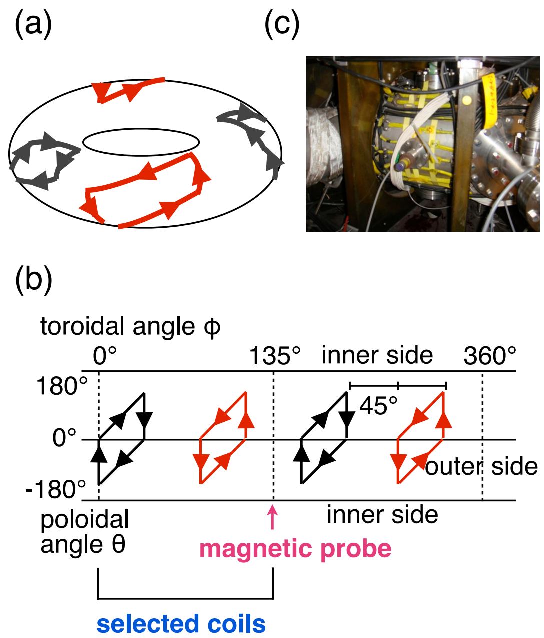

Fig. 1 (a) Schematic illustration of coil configuration (b) Development diagram of coils (c) A picture of the setup of white-colored helical coil on HYBTOK-II

Results & Discussion

Figure 2 shows the plasma position during discharges with and without stellarator coils. Real-time feedback control of the plasma horizontal position was employed (t = 8-15 ms) until the stellarator fields significantly penetrated the plasma (stellarator fields were applied in a period of t = 13-20 ms).

First, we focus on the vertical position of the plasma in the case of using all four coils (Fig. 2 (a)). The blue traces is a case without the stellarator fields. There are some horizontal error fields so that the plasma shifted upward from the beginning. In addition, vertical position shifted slightly downward gradually. When the stellarator fields were applied, the vertical position of the plasma was pushed back to the midplane of the vacuum vessel as shown by the red

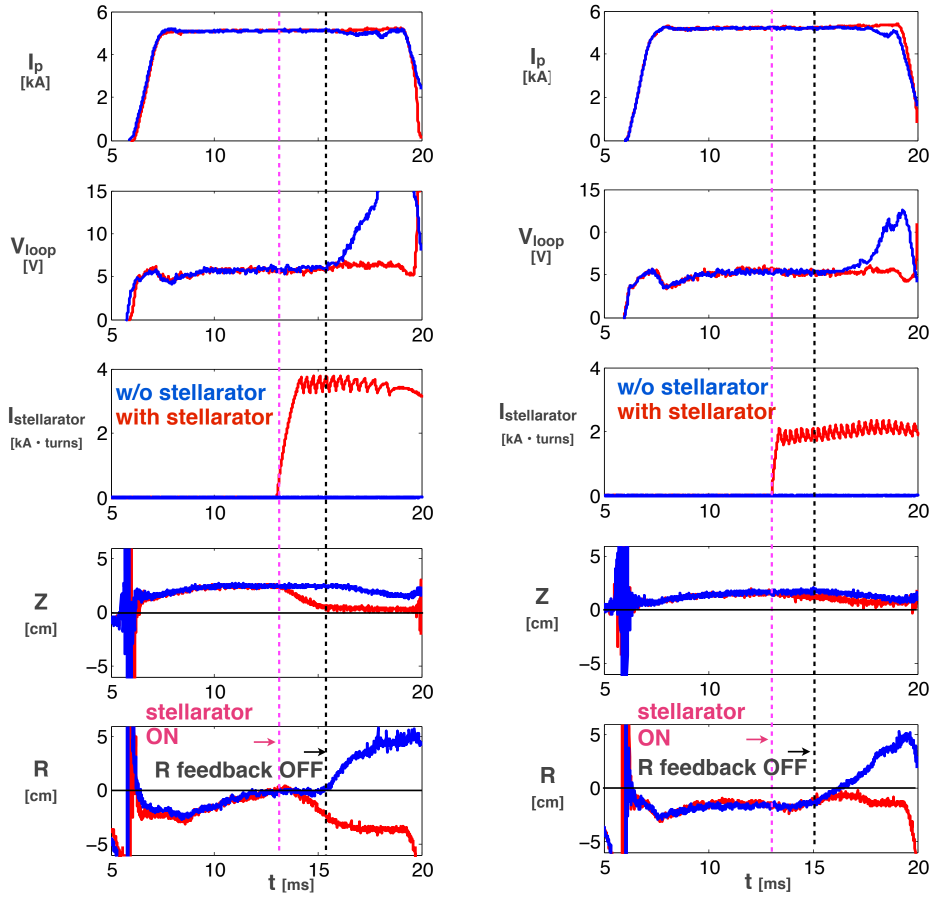

Fig.2 Comparison of discharge waveforms between with and without stellarator coils. (a) in the case of all four coil configuration (b) in a case of selected two coil configuration

traces. Furthermore, the vertical movement of the plasma was significantly suppressed. These preliminary results demonstrated the feasibility of vertical stability with saddle shaped stellarator systems. Next, we focus on the horizontal position of plasma. In the case of without the stellarator system, the plasma shifted largely toward outside and contacted with the limiter after turning off the position feedback control. As a result, high loop voltage was supplied to keep the plasma current constant by an inverter power supply. While in the case that the stellarator fields were applied, the plasma moved toward inside of torus. Finally, the position was fixed at a stable position. It was proved that this localized stellarator fields work as vertical fields which support hoop forces and improve not only the vertical stability but also the horizontal stability of the plasma.

Figure. 2 (b) shows a case that only two coils were selected which are localized at one side of the torus. Even though this case, our system can improve the plasma position. In this experiment, however, the plasma position was measured with magnetic probes at only 135 degrees in the toroidal direction. In order to confirm the stabilizing effect at the opposite side of the torus as well as measured point, we calculated plasma equilibrium with VMEC code. In particular, we focus on horizontal plasma shift by change in hoop force. The hoop force was changed by an increase in plasma current. Figure 3 shows MHD equilibria with and without saddle shaped stellarator coils at one poloidal cross-section. The equilibrium without stellarator coils shifts to outside with increased hoop force. While, equilibrium with the coils remains almost unchanged in the horizontal direction. The improvement in the positional stability may also improve vertical mode.

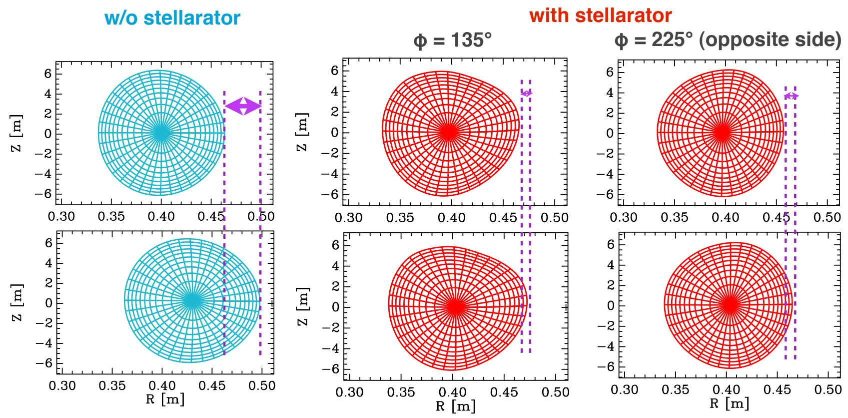

Fig.3. Comparison of equilibrium horizontal shifts between with and w/o saddle shaped stellarator coils calculated with VMEC.

Summary

In summary, we proposed saddle shaped stellarator system for vertical mode in tokamak. These preliminary results demonstrate the feasibility of vertical stability, even if only two selected coils which are localized at one side of the torus. However as noted earlier, the experiment were conducted with the circular cross-section tokamak which is stable vertically. Further work is needed to confirm the improvement in the vertical stability in elongated tokamaks. In addition, very large coil current comparable to the plasma current are needed in our system. In order to reduce the current, future work also should focus on optimal configuration of the coils.

References

[1] T. C. Hender, J. C. Wesley, J. Bialek et al., Nucl. Fusion. **47**, S128 (2007).

[2] G. Y. Fu, L. P. Ku, W. A. Cooper, S. H. Hirshman, D. A. Monticello et al., Phys. Plasmas **7**, 1809 (2000).

[3] H. Ikezi, K. F. Schwarzenegger, Phys. Fluids 22, 2009 (1979).