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Autonomous Plasma Position Controls for Tokamak Disruptions with 3D Shaped Coils
３次元形状コイルを用いた自律的プラズマ位置制御

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3D shaped coils are employed to suppress vertical displacement events (VDEs) which occur in elongated shaped tokamak plasma. The coils are simplified helical coils which are placed excluding the inner side of torus. The coils make plasma elongated and stabilize plasma position vertically and holizontally. The two effects were investigated by using VMEC code. The plasma with 3D shaped coils have 3-dimentional geometry and elongated cross-section on average. And it enable us to maintain plasma configuration horizontally even under a drastic change in hoop force. Experimental demonstration of the stabilizing effects on a small tokamak is under study.

1. Introduction

It is well known that a good energy confinement and high β can be achieved in elongated tokamak plasmas. However, elongated plasmas suffer from vertical instabilities conventionally. Usually, we stabilize vertical modes by shell effects and active positional control using a feedback system. At a disruption, however, large eddy currents are generated in thermal and current quench phases and the feedback system fails to keep the plasma at a prescribed position. Then vertical displacement events (VDEs) are triggered. The contact of plasma and first wall will lead to the damages of a reactor by high heat flux and induced electromagnetic forces. This event drops the operating ratio of a reactor which is very important factor of economy for power plants. Since it is difficult to avoid disruptions completely, we must make countermeasure development to ensure the reactor safety.

2. 3D shaped coils for the positional stability and elongation

We proposed a 3D shaped coils system. They have two effects, to make plasma elongated and to stabilize position vertically and horizontally [1,2,3]. Then it avoids an occurrence of VDEs by addition to a tokamak reactor. Figure 1 shows a schematic illustration of the coil configuration. The coils are simplified helical coils which are placed excluding the inner side of torus to give place to existing coils

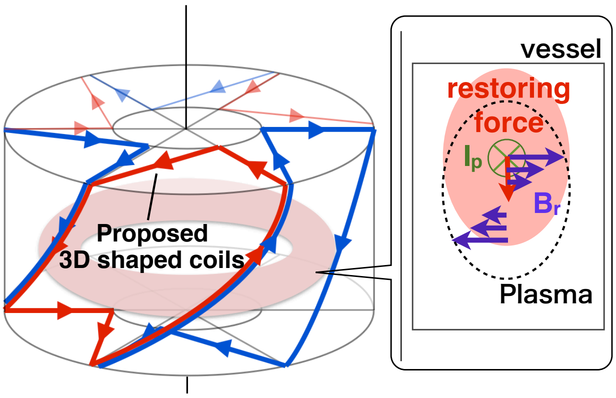

Fig.1. Schematic illustration of the coil configuration. The arrows indicate the direction of coil currents. Here, Ip is plasma current, Br is fields made by coils. Add 3D shaped coils to tokamak. The fields made by coils stabilize vertical mode and make plasma elongated.

of tokamaks. The directions of coil currents are alternate like stellarator windings. 3D shaped coils can autonomously control plasma position without a feedback system. The feature can be advantageous in reactors, since measurements of plasma condition will be limited because of high heat and nutron fluxes.

3. Equilibrium configurations with 3D shaped coils computed with VMEC code

We analyzed magnetic flux surfaces with the VMEC code with free boundary conditions. Figure 2 shows equilibrium configurations with 3D shaped

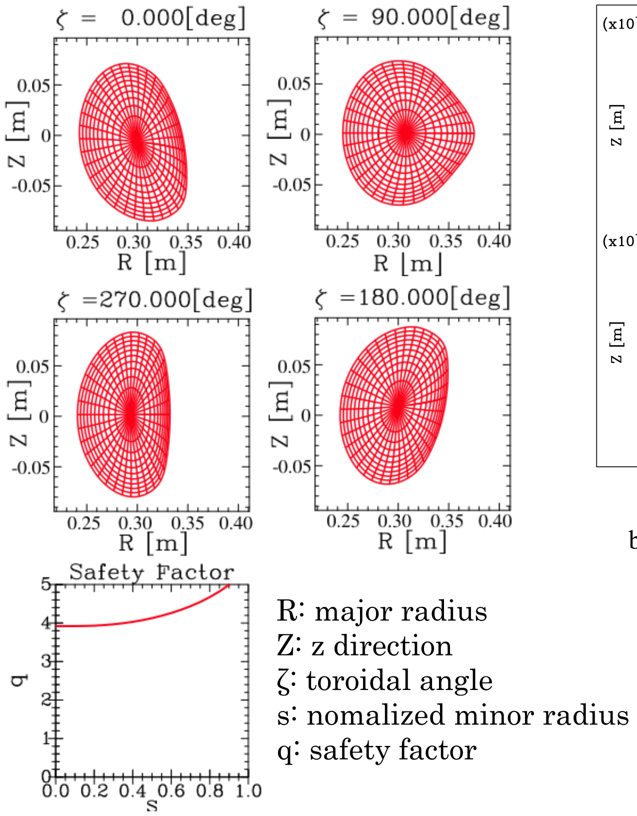

Fig.2. Equilibrium configurations with 3D shaped coils computed with VMEC

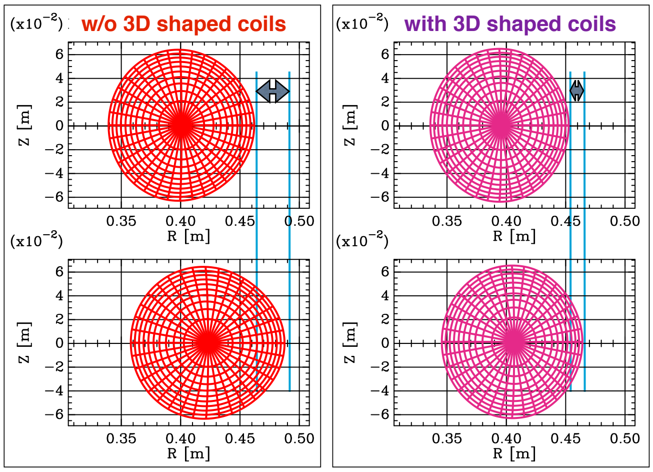

Fig.3. Comparison of equilibrium horizontal shift between with and w/o 3D shaped coils

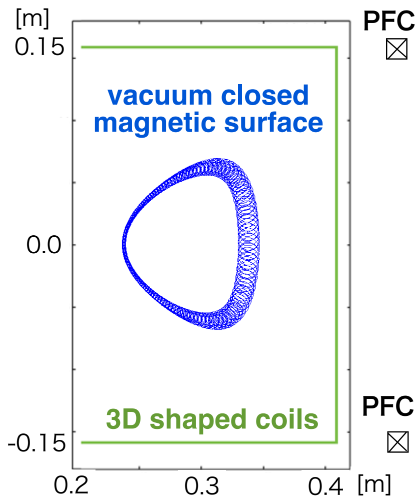

Fig.4. Vacuum closed magnetic surface made with 3D shaped coils in combination with poloidal magnetic field coils

coils. Six 3D shaped coils are located around the torus except the inner side. The plasma parameters are R = 0.3 [m], a = 0.08 [m], B_T = 0.5 [T], I_p = 5 [kA], β = 0%. We confirmed that the cross-section is elongated, whose averaged ellipticity is 1.6. The q-profile increases with normalized small radius in the same way as conventional tokamaks.

4. Horizontal plasma shift under a drastic change in hoop force

We analyzed stabilizing effect of plasma position. In particular, we focus horizontal plasma shift by change in hoop force. The hoop force was changed by an increase in plasma current. Figure 3 shows equilibrium with and without 3D shaped coils at one poloidal cross-section. The equilibrium without 3D shaped coils shifts to outside with increased hoop force. On the other hand, equilibrium with 3D shaped coils remains almost unchanged in the horizontal direction. Furthermore, if we use 3D shaped coils, equilibrium can be obtained without poloidal field coils which tokamaks have normally. We assumed that the coils stabilize plasma position vertically in the same way as the horizontal result.

5. Vacuum closed magnetic surface made with 3D shaped coils and poloidal field coils

Furthermore, the proposed coils have another advantage. It can make closed vacuum magnetic surfaces in combination with poloidal magnetic field coils. Then it makes plasma breakdown and current drive easy in application of spherical tokamaks.

6. Summary and future work

We proposed 3D shaped coils for the position control and plasma elongation. And we analyzed these effects with VMEC code. We confirmed that the coils produces elongated plasma and it has a capability of maintaining plasma configuration horizontally even under a drastic change in hoop force. We are investigating the stabilizing effects experimentally on a small tokamak.

References

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