Design and Construction of a Non-circular VDE Free Tokamak

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Introduction

In tokamaks, it is well known that elongated plasmas for high beta and good confinement operation suffer from vertical instabilities, leading to so-called vertical displacement events (VDEs) during disruptions. The contact of plasma and first wall due to VDEs can lead to the damages of in-vessel components 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 than that in equivalently elongated tokamak plasma [2]. The objective of our study is to stabilize vertical instabilities of elongated tokamak plasmas by the use of saddle coils which make helically perturbed fields. Although several studies have been made on the effects, they have been conducted in tokamaks with circular cross-sections [3, 4]. For the next step of this study, we have been constructing a

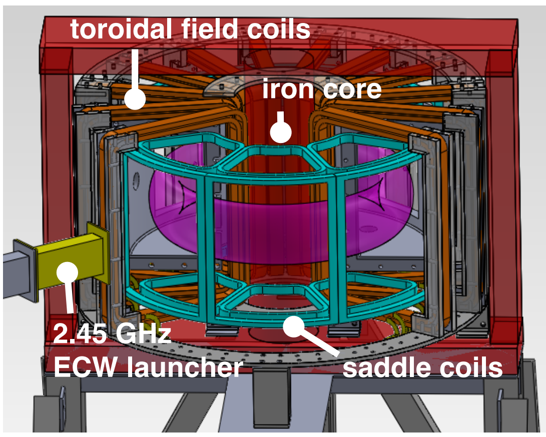

Fig. 1 Illustration of the small tokamak device under construction.

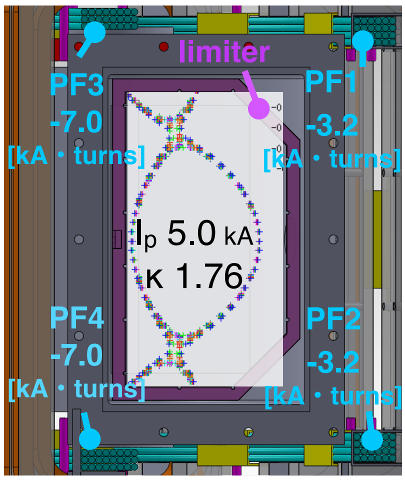

Fig. 2 Cross-section of the device and MHD equilibrium configuration.

small tokamak device (R = 0.33 m, a = 0.09 m, κ = 1.8, Bt = 0.3 T) as shown in Figs. 1 and 2 which has a highly elongated cross-section to demonstrate the stabilizing effect.

Design procudure of the small tokamak

This device is designed on the assumption of the use of an existing iron core for ohmic heating coil that limits the size or shape of the new tokamak device. Firstly, we optimized the shape and arrangement of the toroidal field coils to reduce the toroidal field ripple and enlarging the sectional area of the plasma. To evaluate the disturbance of the magnetic fields form iron core, magnetic field analysis using the finite element method (FEM) was performed. In this device, the major radial position of the plasma and vacuum vessel are set on the area where ripple ratio is less than 2% (Fig. 3). Then, the shape and arrangement of the vacuum vessel with rectangular cross-section were determined under the precondition of κ = 1.8. Figure 4 shows manufactured vacuum vessel.

Secondly, we investigated a configuration of poloidal field coils. As a result of axisymmetric MHD equilibrium calculations, it is feasible to generate highly elongated divertor configuration even with a simple combination of PF coils (Fig. 4). In addition, it was found that a plasma with circular cross-section can be generated which is stable both vertically and horizontally. This result was supported by evaluation of n-index distribution the values of which are positionally stable. To investigate current ramp up scenarios, we are simulating discharge evolutions using tokamak simulation code (TSC).

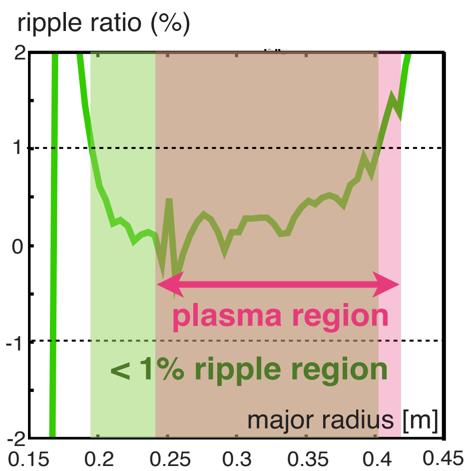

Fig. 3 Radial distribution of ripple ratio on the mid plane.

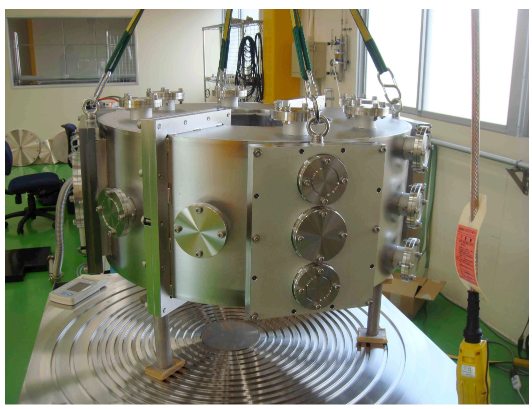

Fig. 4 Picture of the vacuum vessel with rectangular cross section.

Progress of the construction

Among the progress of the construction, we report the following topics: strength tests of a trial toroidal field coil and discharge tests of flywheel power supply for poloidal field coils. Firstly, we designed support structures for the toroidal field coils by stress analysis using the finite element method. After we confirmed soundness of the support structure numerically, we performed strength tests on a trial TF coil as shown in Fig. 5. The maximum electromagnetic force which was estimated to be a centering force of 550 kgf was simulated by the load of a heavy weight of 1000 kg in the tests. It was found from the strain measurements that the deformation of the support structure can be elastic even under overload up to twice of the estimated maximum centering force (Fig. 6). After we got the result, we made all sixteen toroidal field coils and assembled them.

We proposed a new simple flywheel generator system inspired by micro hydro power technology as the power supply for poloidal field coils (Fig. 7). This system uses a self-excited induction generator (SEIG) converted from a commercially available induction motor so that it can be cost effective. The SEIG can maintain nearly constant terminal voltage in combination with rectifier circuit much longer than commonly used capacitor banks. The post stage dc-chopper which was controlled by taking voltage fluctuations in SEIG into account converts the varying voltage to arbitrary voltage to control currents flowing in poloidal field coils. We conducted discharge test of the power supply with a sample coil comparable to poloidal field coils. It was demonstrated that the proposed power supply can main-

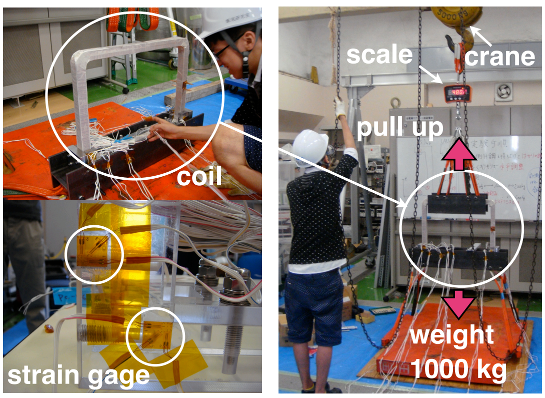

Fig. 5 Picture of strength test of a trial toroidal field coils.

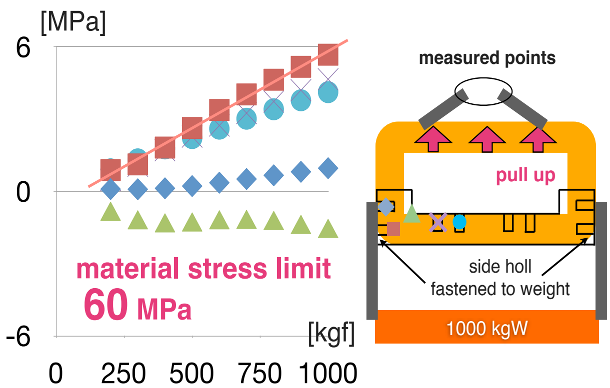

Fig. 6 Measured stress-load relation of the support structure made of polycarbonate resin.

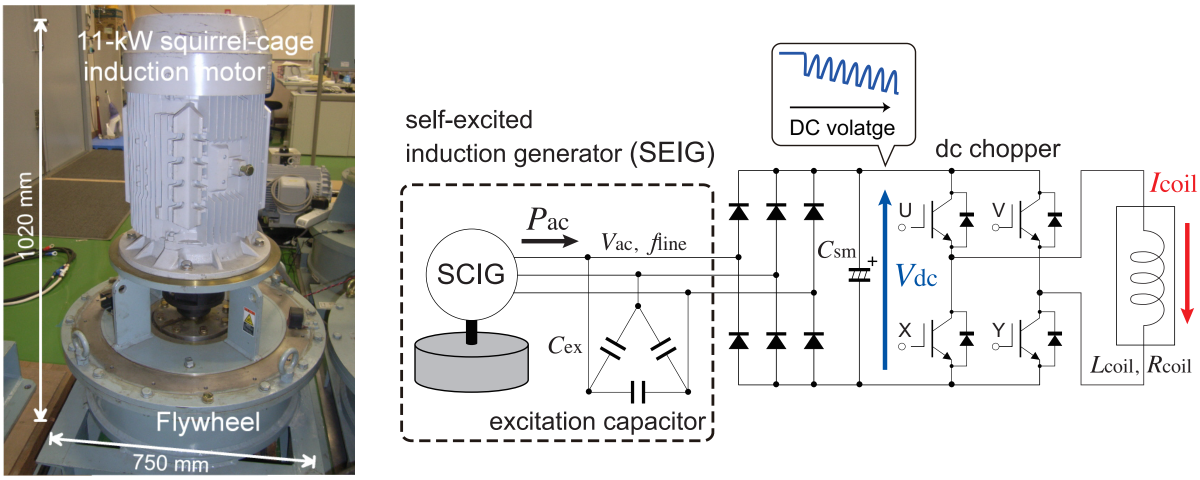

Fig. 7 Picture of the flywheel generator and circuit configuration of the fywheel gennerator system

tain command square-wave current flowing in the test coil for 1 s which is long enough to our small tokamak experiments.

Summary

We designed and are constructing the new non-circular small tokamak to demonstrate the stabilizing effect of plasma position in tokamak due to helical perturbation fields. In this paper, we have reported the following topics: design procedure of shapes and arrangements of the toroidal field coils, poloidal field coils and vacuum vessel, strength tests of the trial toroidal field coil and discharge tests of flywheel power supply for poloidal field coils. The next problem is assembly. We have already assembled all sixteen toroidal field coils. Discharge tests of the coils is under way.

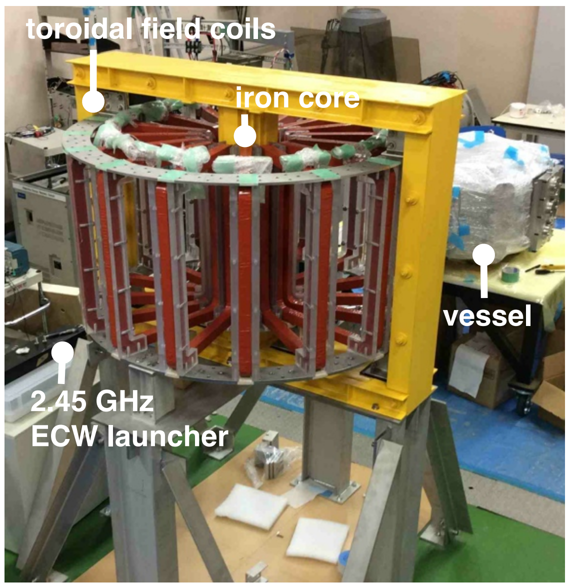

Fig. 8 Assembly of the small tokamak

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