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QUEST Shape Reproduction Based on CCS Method with Two Kinds of Magnetic Sensors
２種類の磁気センサーを用いたCCS法に基づくQUEST断面形状再構成

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Plasma shape control is studied in QUEST divertor configuration. In the shape reconstruction, eddy current in vacuum vessel and plasma current in open magnetic surfaces need to be considered in Ohmic discharge and in RF-driven plasma, respectively. Since magnetic probes have been installed in addition to flux loops, CCS (Cauchy Condition Surface) can be set on the measuring surface and the eddy current effect can be taken into account. And the plasma current effect in the open magnetic surfaces outside of the closed magnetic surfaces could be considered.

1. Introduction

CCS (Cauchy Condition Surface) method is a numerical approach to reproduce plasma shape, which has good precision in conventional tokamaks [1]. The precision was confirmed also in ST and decided to be applied to plasma shape reconstruction and the control in a spherical tokamak QUEST (Q-shu University Experiment of Steady-State Spherical Tokamak) (B_t = 0.25 T, R = 0.68 m, a = 0.40 m) [2].

There are lots of plasma equilibrium reconstruction techniques and they are used in large tokamaks. In NSTX, they use an automated version of EFIT code [3]. In DIII-D, they improve equilibrium reconstruction via Kalman-filter-based vessel current estimation [4]. Here, the CCS method can calculate the plasma boundary shape with no constraint about the basis function set, though it cannot calculate the internal distribution. Therefore, the CCS method may reconstruct the plasma shape precisely using small number of magnetic sensors, if the sensor signals are precise, since it is based on boundary integral equations, which is mathematically precise.

In present stage from the magnetic measurement, it is known that the eddy current effect is large in QUEST experiment, and so some proper model should be selected to evaluate the eddy current, which affect the plasma boundary reconstruction. As the eddy current model, we divided the vacuum vessel into 8 parts, in each part lots of filaments with different current (distributed current density) represent the eddy current [2]. The eddy current density by not only CS (Center Solenoid) coil but also plasma current is calculated using EDDYCAL (JAEA) [5]. The eddy currents are taken as unknown variables and solved together with plasma shape reconstruction by using least square method or singular value decomposition [6].

2. Shape Reconstruction Based on CCS Method

The CCS method is an exact numerical method which is based on the boundary integral equation. The Cauchy condition surface is defined as a hypothetical plasma surface, where both the Dirichlet (ϕ, poloidal flux function) and Neumann (B_t, poloidal magnetic field tangent to the CCS) conditions are unknown. This surface is located inside the real plasma region. It is assumed that CCS encloses all the plasmas and there are no plasmas outside the CCS [1]. After reconstruction, only the flux surfaces outside of the plasma boundary are right including the boundary, which is similar to "image method" in calculation of static field due to a point charge in the presence of semi-infinite ideal conductor.

3. Ohmic Plasma Shape Reconstruction with Two Kinds of Magnetic Sensors

Figure 1 shows waveforms of CS, plasma and vertical field coil currents in ohmic discharge assisted by ECRH (79 kW between 1.19 and 1.32

sec). The CS current was swung in single polarity: This time, after CS coil is excited in negative polarity by power supply, by decreasing the current, plasma current was started. At the same time, the plasma current is driven further by increasing PF26 coil current. Vertical field for horizontal equilibrium was applied by PF17 coil before the plasma initiation and added further by PF26 coil. In divertor coil PF35-12, -1 kA was kept before the plasma initiation and increased to -1.9 kA.

Figure 2 shows magnetic surfaces (t = 1.55 sec) reconstructed by CCS method. In this reconstruction, 20 flux loops were used among 67 loops in (a), and two magnetic probes were used in addition in (b). Uniform eddy currents were assumed in 8 sections. The vertical asymmetry suggests some asymmetry of magnetic fields or eddy currents. In these figures, null points are found, though closed magnetic surface contacts with inner protecting limiter. The detachment could be accomplished by further positive swing of CS coil, but improvement of the power supply is indispensable for circulating current control.

4. Summary

In the ohmic plasma with a lot of high-energy electrons, there may be anisotropic plasma pressure, which makes difficult a usual equilibrium analysis, but the CCS method can reconstruct the plasma shape precisely regardless of the anisotropy. Though eddy current adjustment is necessary, eddy current model must be simple for FB (FeedBack) control. We divided vacuum chamber into 8 sections according to numerical calculation of the eddy current distribution in the vacuum vessel by EDDYCAL (JAEA).

Eddy current model based on several sections is considered to be essentially a projection (the necessary condition is satisfied but the sufficient is not). Eddy current mode expansion is a candidate for higher precision. Inner current mode is higher order and many modes are necessary, which suggests it is difficult for us to adopt in FB control. The number of flux loops is better to be large from the reconstruction precision viewpoint. But some loops cross diagnostic ports and the error is large. In case of CCS, sensor precision is more important than the number, since CCS method is a mathematically exact numerical one.

Since the tangential magnetic field on the flux loop measurement surface must satisfy a boundary integral equation, we can determine more physically consistent eddy current density and shape reproduction by installing tangential magnetic probes inside the vacuum chamber. Two magnetic probes were installed last year, four probes were added last fiscal year, two more probes and 4 partial Rogowski coils will be installed. Increase in reconstruction precision is expected, since CCS can be set also on the measuring surface.

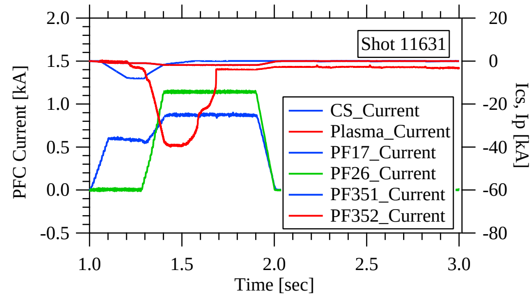

Fig.1. Coil and plasma current waveform in QUEST ohmic discharge.

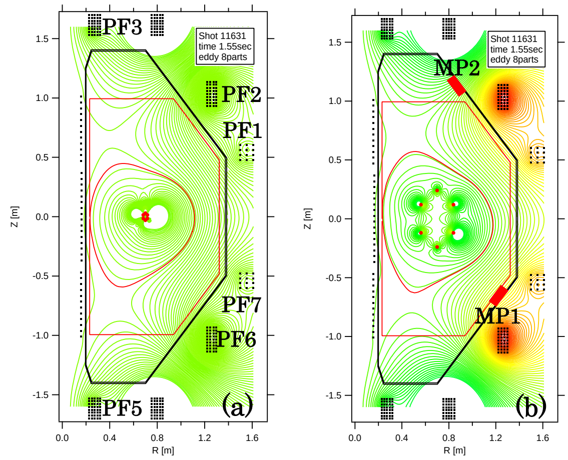

Fig.2. Magnetic surfaces reconstructed by CCS method in ohmic discharge.

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