ID: 795

Stabilization of vertical plasma position in the PHiX tokamak with saddle coils

S. Naito[1*], M. Murayama[2], S. Hatakeyama[2], D. Kuwahara[3], Y. Suzuki[4], H. Tsutsui[1], S. Tsuji-Iio[1]

[1]Institute of Innovative Research, Tokyo Institute of Technology
[2]National Institutes for Quantum and Radiological Science and Technology (QST)
[3]College of Engineering, Chubu University
[4]National Institute for Fusion Science (NIFS)

*Email: naito.shin@torus.nr.titech.ac.jp

ABSTRACT

- Saddle coils (SCs) were proposed as coils with a stabilizing effect of a vertical plasma position by a non-axisymmetric field, which can generate an averaged magnetic field along the magnetic field line.
- This stabilizing effect of SCs was investigated by the experiments in a small tokamak, PHiX.
- 3D equilibrium calculation using VMEC was also performed to investigate whether elongated cross-sections were obtained in the experiments.

BACKGROUND

- To reduce the cost of a fusion power plant, it is necessary to make a device with high β and high energy confinement time, for that purpose, it is necessary to realize a high elongation ratio κ.
- But there is an upper limit of the κ which can be realized in principle and technically. In addition, considering safety, the κ of the power plant will be smaller than the value that can be realized in existing devices.
- On the other hand, it has been reported that a ***non-axisymmetric magnetic field can stabilize the vertical position of plasma with an elongated cross-section***[1].
- In order to overcome the above limitations, we aimed to realize a vertically stable and elongated tokamak plasma with a non-axisymmetric magnetic field of SCs.

- Merit of SCs: A simple structure → ***Easy to manufacture and install***
  Not passing through the inside of the torus → ***Not increasing the device size***

METHODS

Experiments in a small tokamak, PHiX

- The non-axisymmetric field generated by SCs and TFCs were superposed to vertically unstable tokamak plasmas. Feed-back controls of position were not used in all experiments.

- Each SCs generated a magnetic field in the direction of the arrow in FIG. 1 and the curved magnetic field structure and the averaged magnetic field B^{ave} were obtained as FIG. 3 & 4.

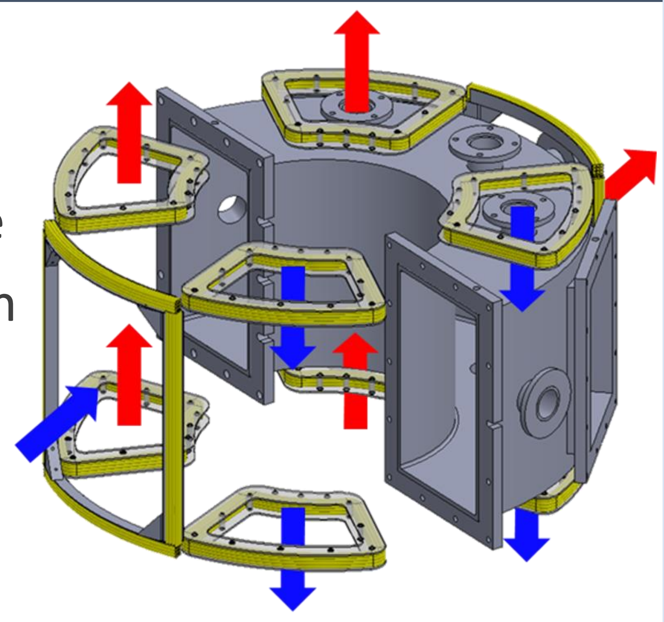

FIG. 1. Arrangement of SCs on PHiX.

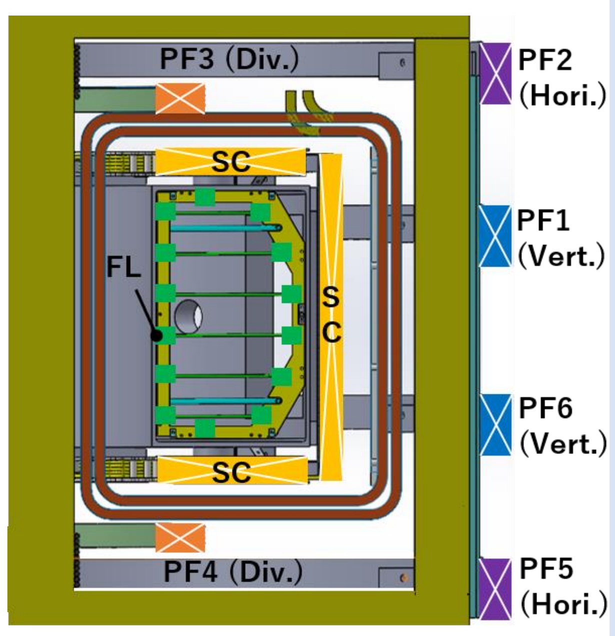

FIG. 2. Poloidal cross-section and coils of PHiX.

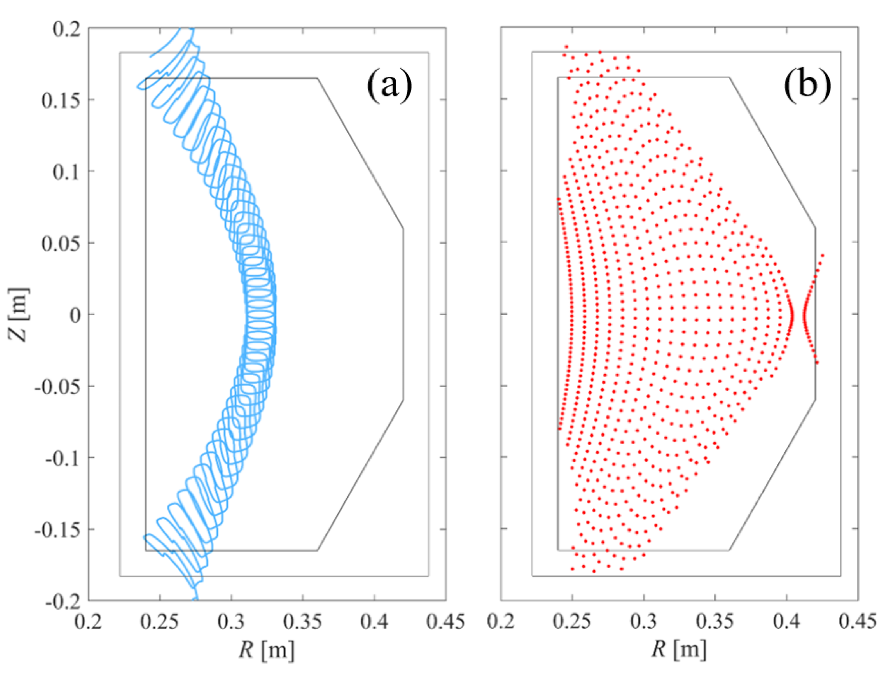

FIG. 3. (a) The magnetic field line projection of the poloidal plane, (b)the Poincaré plot of magnetic field line .

3D equilibrium calculation by VMEC[2]

- Check if an elongated cross-section tokamak plasma can be generated with SCs and calculate the averaged κ in the toroidal direction (κ_{ave}).

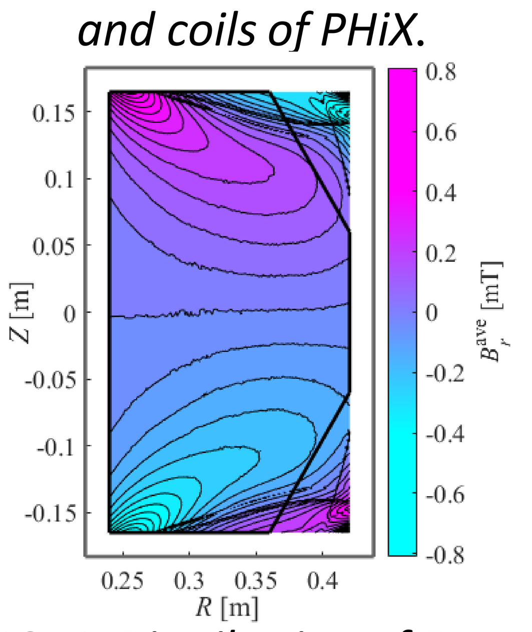

FIG. 4. Distribution of B_r^{ave}.

OUTCOME

Results of tokamak discharges with SCs in PHiX

The stabilization of the vertical positions was confirmed when n-index was from -0.7 to -1.3.

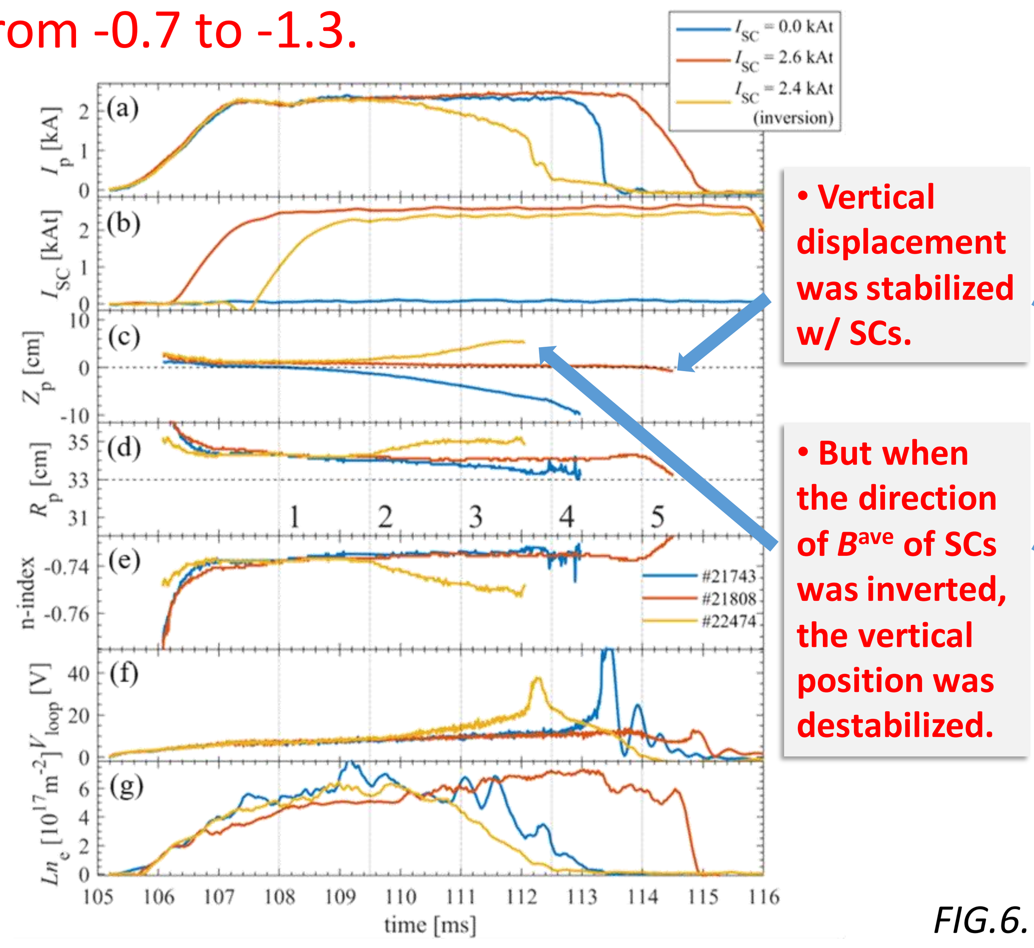

FIG. 5. Time evolution of each parameters in tokamak discharges. (a) plasma current I_p, (b) SCs current I_{SC}, (c) vertical position of the plasmas Z_p, (d) horizontal position of the plasmas R_p, (e)n-index on plasma positions, (f) loop voltage V_{loop}, (g) line electron density Ln_e along the line of $Z = 0$.

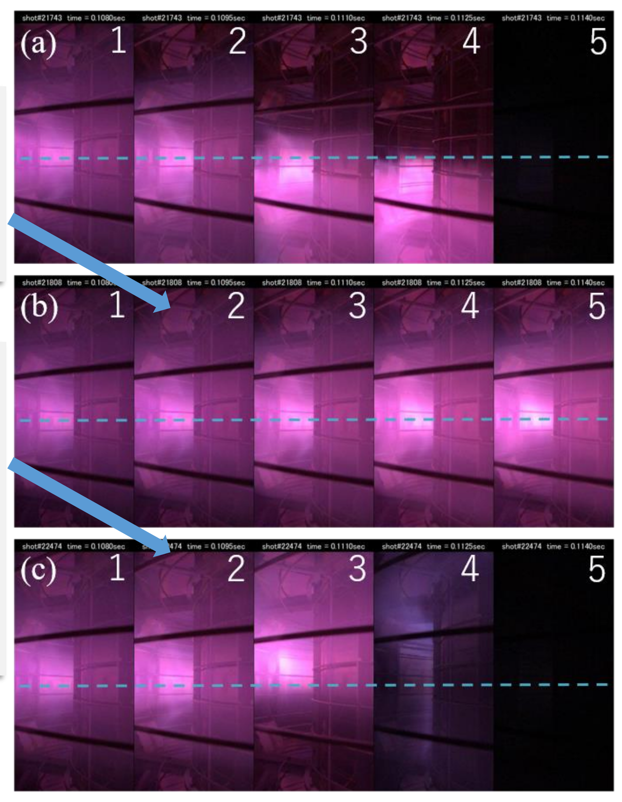

FIG.6. Images of the plasma taken with a high-speed camera. The number displayed on the image means the time corresponding to the numbers in FIG.5 (d). (a) w/o I_{SC}, (b) I_{SC} = 2.6 kAturn, (c) I_{SC} = 2.4 kAturn with inverted current direction in side-installed SCs.

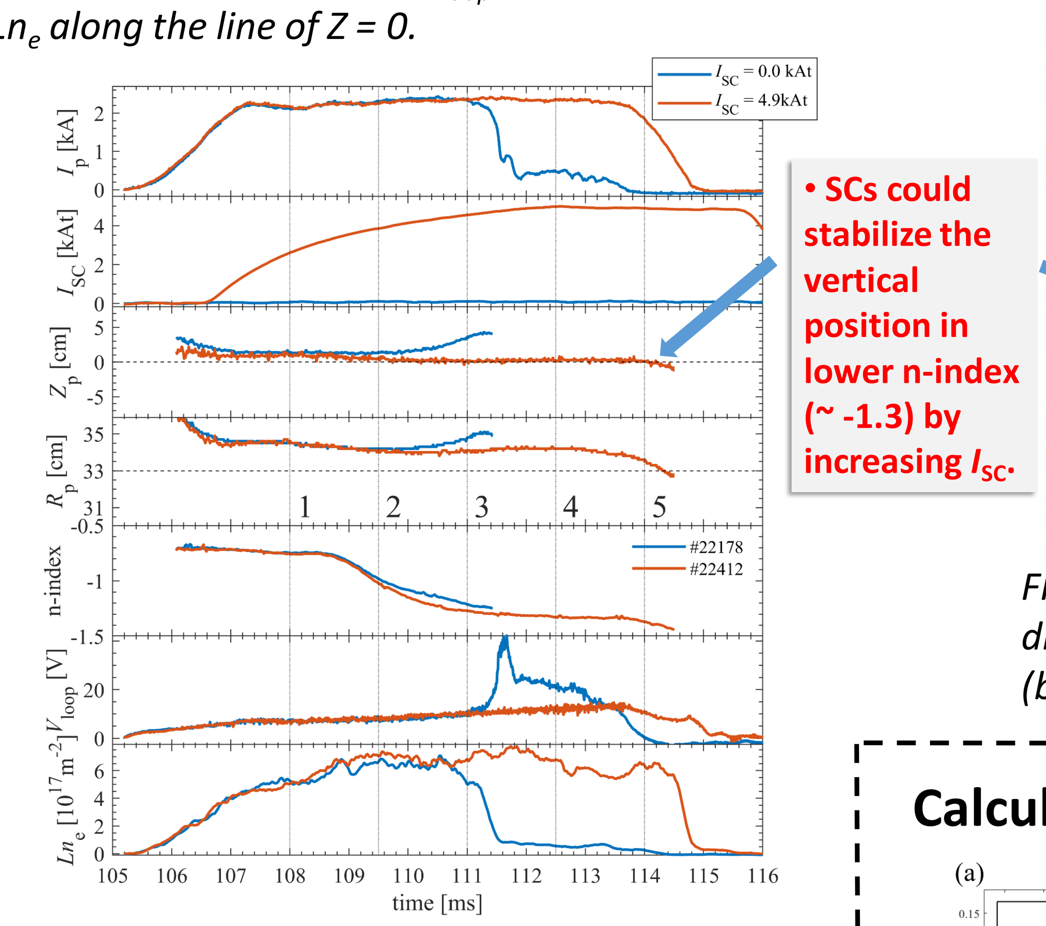

FIG. 7. Time evolution of each parameters in tokamak discharges with divertor coils. The physical quantities shown in (a) ~ (g) are the same as in FIG. 5.

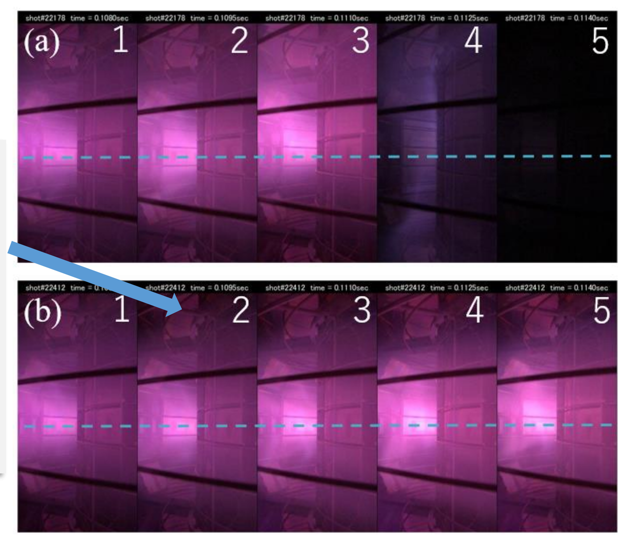

FIG. 8. Images of the plasma of tokamak discharges with divertor coils. (a) w/o I_{SC}, (b) I_{SC} = 4.9 kAturn.

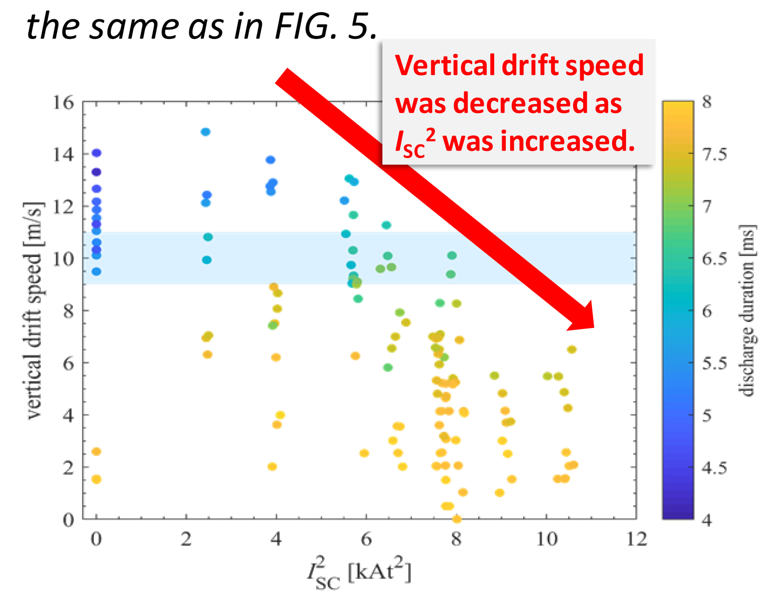

FIG. 9. Ensemble of vertical drift speed versus I_{SC}^2 with discharges whose n-index were ~ -0.7 and initial vertical position Z_p was $1.0 \le Z_p \le 3.5$ cm.

Calculated magnetic flux surfaces

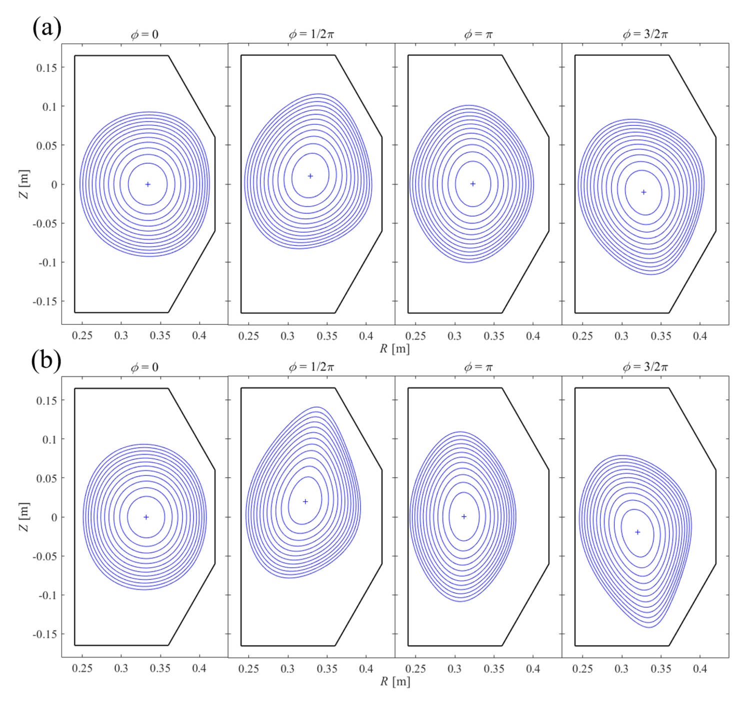

FIG. 10. Magnetic surfaces calculated with the condition of (a) FIG .5, (b) FIG. 8

The calculated value of κ_{ave} was 1.25 in (a) and 1.58 in (b) of FIG. 10.

CONCLUSION

- By the experiments, it was confirmed that the averaged magnetic field generated with SCs and TFCs could ***stabilize the vertically unstable plasmas whose n-index was ≥ -1.3.***
- With SCs, even if the vertical position could not be maintained as constant, the drift speed could be mitigated.
- 3D equilibrium calculations with VMEC have suggested that ***the vertically stabilized plasmas were the plasmas with an elongated cross-section.***

ACKNOWLEDGEMENTS / REFERENCES

This research is performed with the support of the Grant-in-Aid for Scientific Research (17K06990) and NIFS Collaboration Research Program (NIFS18KOAP033).

[1] M. C. ArchMiller et al., Phys. Plasmas **21** (2014) 056113.
[2] S. P. Hirshman et al., Comput. Phys. Commun. **43** (1986) 143.