

### § 33. Engineering Design Study of CHS-qa Quasi-axisymmetric Stellarator

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Engineering design of CHS-qa was once described [1] on the basis of the magnetic configuration of 2w39, which was the early version where the optimization priority was put on the realization of magnetic well (w means well). As was mentioned there, the magnetic configuration was under improvement in parallel with the engineering design on 2w39 and the configuration of 2b32 was found [2] at that time that is now the standard one, where the field period is 2, the aspect ratio 3.2, and the optimization effort was made primarily on improving high  $\beta$  characteristics by pursuing ballooning stabilities (b means  $\beta$ ). As physics optimization covers its targets more widely and deeply, the modular coil shape usually gets more complicated, the engineering design being more difficult. However, there is some mitigation to some extent in the process of finding the coil shape from the outermost magnetic surface satisfying physics requirements; in the numerical code there is the function that the shape can be found under optimization with some constraints that mitigate engineering difficulties.

The important point on modular coils is whether the conductor can be manufactured or not under the complicated shape that causes a short curvature radius and large torsion. Modular coil is composed of 160 ( $=10 \times 16$ ) hollow conductors with the size of  $7.4\text{mm} \times 7.4\text{mm}$  and hole of  $4\text{mm}^2$  for water channel. The minimum curvature radius and maximum torsion are 109 mm and 4.90 rad./m in comparison with those of 127 mm and 4.84 rad./m, respectively. There are 10 coils per period with 5 different shapes; The shape changes from the vertically elongated bean-shape of #1 coil to the horizontally elongated shape of #5. The position of minimum curvature moves from #2 (2w39) to #5 coil (2b32). Because the value of 109 mm is larger than the conductor size by more than 10 it should be of no problem to manufacture the modular coil as was done in winding the CHS helical coils. Because of a larger excursion of modular coils in the toroidal direction the supporting frames with the thickness of 30mm embracing the coil interfere each other on the inboard side between #1 and #2, #2 and #3, #3 and #4, and on the upper side between #3 and #4, #4 and #5. However, the extent of interference is a little, less than 20mm and can be solved by making the frame wedge-shaped like TF coils of tokamak.

Electromagnetic forces on modular coils are almost the

same as those of the previous one. The maximum load per unit length along the coil is as follows; The load in the normal curvature direction ranges from  $5.5$  to  $7 \times 10^5$  N/m for #1 to #5, and that in the bi-normal direction from  $2.5$  to  $4.5 \times 10^5$  N/m. These values are almost same as the previous version, the electromagnetic stress being allowable as before. Twenty modular coils are to be energized by 2 power supplies (PS1 and 2) with the voltage of 4.8 kV and the current of 15kA each, which are enough for the coil current of 14.1kA and the coil resistance (10 coils in series) of  $0.29 \Omega$  at  $75^\circ\text{C}$ . One of standard connection of modular coils is as follows; PS1: #19, #20, #1, #2, #3, #9, #10, #11, #12, #13 in series, and PS2: #4, #5, #6, #7, #8, #14, #15, #16, #17, #18 in series. The stress analysis of the coils has been done when one PS does not work by the use of the NASTRAN code. The coil supporting structures are the same as the previous one. The maximum stress in the coil frame is less than 140 MPa, which is within the allowable level of SUS, the maximum stress being 125MPa at #3 and #13 for no PS 2 case, 118 MPa at #4 and #14 for no PS 1 case. However, the stress of rods that support the whole modular coil assembly from the ground exceeds the allowable level, being 187 and 148 MPa for both cases, respectively. The difficulty can be solved by inserting the supporting rods between 4 sectors (#20-#1, #5-#6, #10-#11, #15-#16), the stress level ranging from 50 to 80 MPa. The analysis model is shown in Fig.1. The additional supporting rods also reduce the stress in the coil frame substantially (from about 120 to 80 MPa). For flexibility of experiments an unbalanced coil current from 2 PS is under consideration. The failure analysis of PS in the case of this kind shows no problem in the modular coil structure.

#### References

- 1) Matsuoka, K., et al., Annual Review (Apr.1999 - March 2000), p.307.
- 2) Shimizu, A., et al., Annual Review (Apr.1999 - March 2000), p.306.

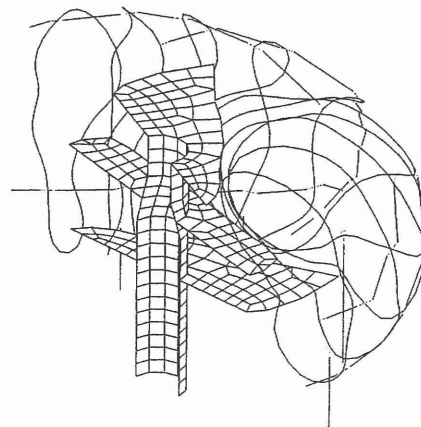


Fig. 1 Analysis model of modular coils.