§23. Consideration on Scale-up of Quasi-axisymmetric Stellarator with Low Aspect Ratio

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Scale-up of quasi-axisymmetric stellarators with low aspect-ratio is discussed to make a survey of the future prospect, which is based on the engineering design of CHS-qa with the major radius of 1.5m.

The stress analysis on modular coils and coil frames was done in the most severe case where the power supply (PS) did not work because of its failure. Here, modular coils are energized with multiple PS. The result under the failure of one PS showed that the maximum stress in the coil frame was within the allowable level of SUS. The stress was larger than 140MPa in supporting legs of modular coil assembly (quadrant). However, the remedy could be easily found by inserting additional supporting bars between 4 quadrants [1].

Next, engineering design of the vacuum vessel of CHS-qa is discussed. To make the control of wall recycling easy the vacuum vessel made of SUS is to be contained inside the modular coils, which inevitably results in a highly deformed shape. In the process of designing the coils the current-carrying surface is located between the inner and outer limiting surfaces that are separated by 19 cm in the radial direction. At the vertically elongated cross-section the modular coil touches the inner limiting surface on the inboard side to make the indentation large for obtaining high beta plasma. The radial distance between the outermost magnetic surface (OMC) and the inner limiting surface is 26 cm as is shown by "d" in Figure 1, and this space is mainly for the vacuum vessel including in-vessel components and for assembling the whole system. The vacuum vessel with the thickness of 10mm is separated from OMC by 8 cm that is utilized for in-vessel components and divertor structure. The process of assembly is as follows; 5 modular coils of the quadrant (total 20 coils as a whole) are to be inserted separately into the quadrant of vacuum vessel. Most difficult coil to insert is, of course, the middle one. Because of non-axisymmetry the movement of the coil must be composed of radial and vertical shifts and rotations in the toroidal and poloidal directions. The middle coil can be set up in the right position within a reasonable number of shifts and rotations. After this process four quadrants of vacuum vessel with 5 modular coils are welded together to make the whole assembly and ports are welded thereafter. The vacuum vessel has one-turn resistance of 1 mΩ in the toroidal direction by using two welded bellows as is in CHS vacuum vessel. The buckling analysis of the vacuum vessel shows that the deformation takes the maximum value of 1.37 mm in the horizontally elongated position and the von Mises's stresses are 47.5 MPa and 42.4 MPa at inner and outer surfaces, respectively. The vessel is robust having the eigen-value of 15.9 for the primary mode although there are a lot of ports.

Scale-up to reactor-grade size is necessary to be discussed for the future prospect. To compare plasma performance in a variety of magnetic configurations helical reactors are designed, as a reference, with the plasma volume of 1000 m^3 (1 GW fusion power output) and the magnetic field strength Bt of 5 Tesla. Here, simple consideration on the size and the magnetic field strength is given. Extrapolation from the plasma volume of CHS-qa of 6.5 m^3 to 1000 m^3 leads to the major radius of 8 m (larger by 5.36 times). The distance between OMC and the inner limiting surface of modular coil, "d" in Figure 1 can be larger than 1 m. Although the details of blanket and maintenance process are out of the scope of this report, the compact reactor design might be possible. The maximum field strength is about two times of that at the magnetic axis, which means the maximum of 10 Tesla when Bt is 5 Tesla. When the coil current density is kept constant, the cross-section is larger by about 18 times (=3.33×5.36). This is less than the square of linear scale ratio (5.36×5.36), which means that design of structures supporting electromagnetic forces gets easier.

References

1) Matsuoka, K., et al., Annual Review (Apr.2004 - March 2005), p.323.

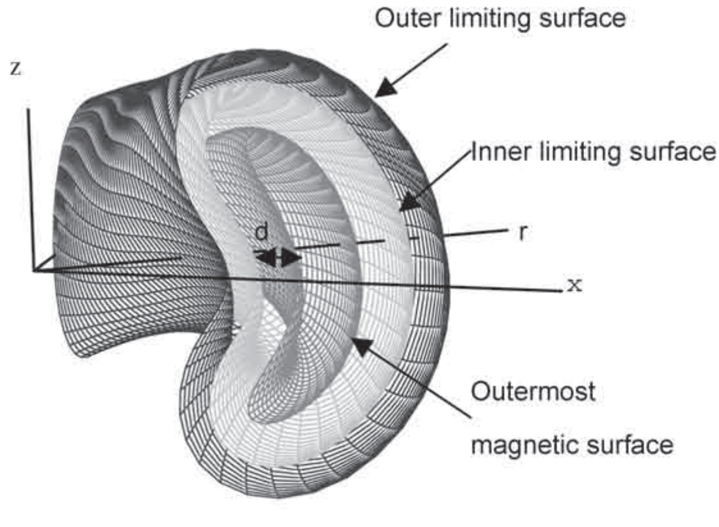

Fig.1. Radial build. "d" in the figure is 26cm in CHS-qa.