Special Topic Article
Quasi-Symmetry in Stellarator Research

5. Status of Physics Design of Quasi-Axisymmetric Stellarators

5.3 Comparison of Physics Designs between NCSX and CHS-qa

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(Received 26 December 2001)

Abstract

Physics designs of NCSX and CHS-qa are compared. Although those are basically of similar magnetic configuration the important difference is in the role of the bootstrap current. Different toroidal period numbers make the aspect ratio and the machine design different.

Keywords:
quasi-axisymmetry, high β, bootstrap current, confinement improvement, maximum-J criterion, toroidal period number, aspect ratio

Although the Quasi-Axisymmetric (QA) helical configuration looks quite new, it was discussed at the US-Japan JIFT Workshop on advanced confinement concept and theory held at Columbia University in Oct. 1996 that was in fact the first bilateral meeting with additional participants from Russia and Spain [1]. Physics characteristics on MHH2 (Modular Helias-like Heliac 2 (= N, the toroidal period number)) that had been proposed by Garabedian were discussed and the post-CHS project (later called CHS-qa) was, for the first time, introduced that was the QA machine stimulated by Garabedian's and Nuehrenberg's works. NCSX is motivated by a need to develop an economical compact fusion reactor that overcomes difficulties in tokamaks. So, the target is put on the high β operation with $\langle\beta\rangle$ of 4 – 5% by stressing the merits of stellarator superior to the tokamak : less disruptivity, smaller power for current drive even if necessary, stability against neoclassical tearing mode and no need of the wall for the resistive wall mode stabilization, features of which hold for CHS-qa, too. NCSX is regarded as a proof-of-principle experiment where the high β plasma conditions, including significant amounts of bootstrap current, are to be investigated. An ultimate heating power of about 12 MW is planned by taking full advantage of the NB injectors (6 MW) and radiofrequency sources (6 MW) from PBX-M. The priority of CHS-qa experiment is put on the confinement improvement study under $\langle\beta\rangle$ of 2 – 3% that is discussed in Sec. **5.2**. CHS-qa will take over diagnostics and heatings of CHS; the NBI heating power is about 2 MW.

Tools for designing optimized stellarators are now available, and the magnetic configurations can be examined from the viewpoint of physics requirements by using 3D equilibrium and stability codes, transport codes and so on. These examinations can be feedbacked to the configuration design with reasonable time consumption. Reflecting this situation, the stellarator optimization is inevitably led to basically similar results incorporating robustness of magnetic surface, MHD stability, good neoclassical transport, good high energy particle behavior and so on. Of course there still is some

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trade-off. Big difference among the optimizations is the existence of the currents : PS current and net current (bootstrap, beam driven and OH). In QA configurations the bootstrap current is utilized positively to form the stellarator shear (the reversed shear in tokamak) more strongly for maximum-J criterion in spite of possible current-driven instabilities. The vacuum configuration of CHS-qa satisfies the maximum-J criterion in a wider region than in NCSX. In designing NCSX, a key issue was the quality of magnetic surfaces calculated with the PIES code. This problem has been solved partly by adopting a reference plasma configuration with a deeper magnetic well and partly by the technique of tailoring the modular coil shape for eliminating islands. As was described in Chap. **2** the island formation because of the PS current gets less dangerous as N increases. In respect of the island elimination CHS-qa with N of 2 is also successful by taking account of the residue in the optimization process. In CHS-qa the fragility of the magnetic surface has been studied by HINT code and the robustness is kept up to $\langle\beta\rangle$ of 3 – 4% at present, of which value is sufficient for the purpose of experiment. The N number has some consequence on the aspect ratio A_p and the engineering aspect. NCSX and CHS-qa have A_p's of 4.4 and 3.2, respevtively. In NCSX to get a high modular coil current density the coil is pre-cooled by liquid N_2, which results in the structure where the cryostat contains the whole machine [2], where the diagnostic access has been considered as a top priority by redesigning the coils. CHS-qa, being of a simpler structure, also puts the top priority on the accessibility for diagnostics as an experimental machine [3], referring to the good access in CHS.

References

[1] Papers at the workshop are published in Plasma Physics Reports (1997) Vol.23 No.6–8.

[2] The National Compact Stellarator Team, National Compact Stellarator Experiment Physics Validation Report, March 2001.

[3] CHS-qa Group, CHS-qa Project Design Report, April 2000 (*in Japanese*).