Island bundle diverter configuration for quasi-axisymmetric stellarator

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S. Okamura[1], H. Liu[2], A. Shimizu[1], M. Isobe[1], Y. Xu[2]

[1] *National Institute for Fusion Science, Toki, Japan*

[2] *Institute of Fusion Science, Southwest Jiaotong University, Chengdu, People's Republic of China*

National Institute for Fusion Science, Japan and Southwest Jiaotong University, China are making collaboration in a joint project NSJP for constructing a new stellarator CFQS in China [1, 2, 3]. The device design concept is based on the quasi-axisymmetric advanced stellarator. As well as good performances of confinement properties of core region, the magnetic configuration of the peripheral region is very important because the diverter performance is crucial for the successful achievement of the future reactor design. For the present stellarator experiments, two leading concepts for the divertor are well known. In LHD, the intrinsic helical divertor has divertor magnetic field lines connecting the ergodic boundary layer of the core confinement region and the divertor plates on the wall [4]. In Wendelstein 7-X, the island divertor provides a sophisticated divertor structure combined with small islands created near the boundary of the core confinement region [5]. For the new stellarator CFQS in China, we are designing a new divertor configuration which provides a sufficiently long connection length of magnetic field lines between the plasma boundary and the wall.

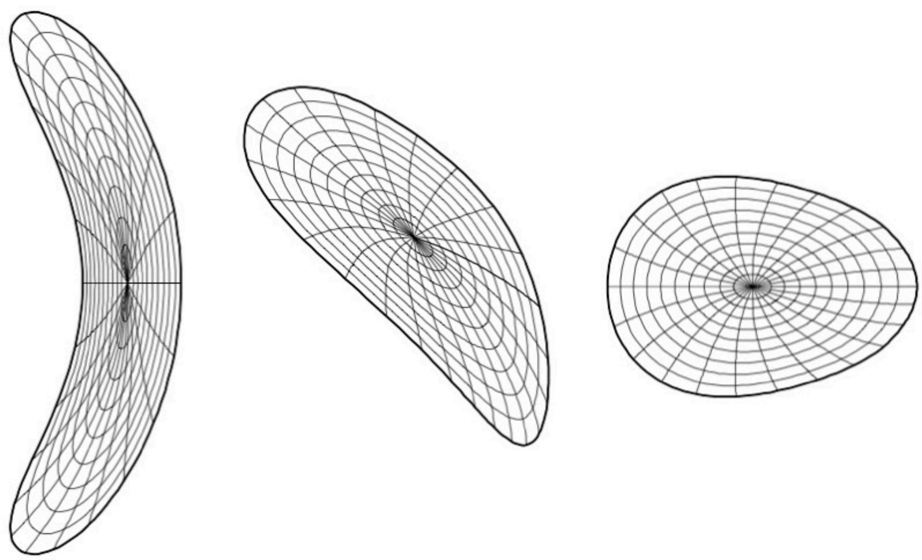

Figure 1 Last closed magnetic surfaces for CFQS advanced stellarator design. Cross sections for three toroidal positions are shown.

Three poloidal cross sections of the last closed magnetic surfaces (LCMS) of CFQS are shown in Fig.1. Modular coils were designed to realize such a magnetic configuration with a choice of the number of coils around the torus as 16 [6, 7]. The success of this coil design was the most important contribution to the finding of a new divertor concept for CFQS. Figure 2 shows the punctual plots of the vacuum magnetic field lines (magnetic surfaces) produced with these modular coils (for the third cross section in Fig.1). Red line shows the LCMS of the target configuration in the modular coil design. The magnetic field produced by the modular coils has many closed magnetic surfaces with a larger area beyond the target LCMS. In usual cases of designing modular coils for the advanced stellarator, it is very difficult to make larger closed magnetic surfaces beyond the target LCMS because the boundary area usually becomes stochastic.

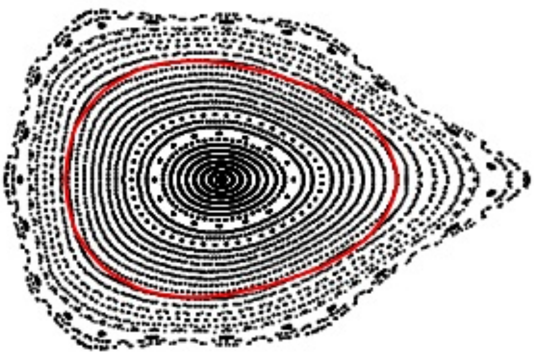

Figure 2 Punctual plots of magnetic surfaces for CFQS configuration produced by 16 modular coils. Red line corresponds to the LCMS of the 3rd plot in Fig. 1

When we introduce the auxiliary toroidal coils to provide additional toroidal field to the stellarator field produced with modular coils, the magnetic configuration is changed to include large islands at the boundary of the core confinement region shown in Fig. 3. The quasi-

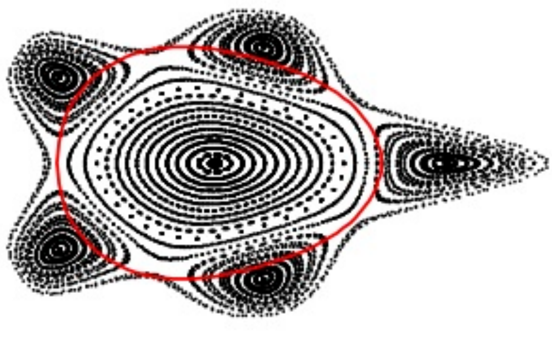

Figure 3 Magnetic configuration of island bundle divertor.

axisymmetry is conserved with the additional toroidal field. The strength of the additional toroidal field is -0.055 times averaged toroidal field produced by modular coils. The rotational transform at the boundary is increased from 0.35 to 0.4. Such a magnetic field structure with islands is a typical magnetic configuration for any type of stellarator that has a rational value of the rotational transform near the boundary. However, essential differences between the configuration shown in Fig. 3 from many other cases are 1) large size of islands and 2) the completeness of the island magnetic surfaces. Old experiment of Wendelstein 7-AS has the similar island strucure at the plasma boundary [8]. However the size of islands are not such big and the separatix structure is dim. It is shown in Fig. 3 that clearly formed island bundle flux surrounds the core confinement region with a clearly defined interface of the magnetic field separatrix. This is the reason why we call such a configuration as 'island bundle divertor (IBD)'. The entire magnetic confinement area is clearly separated into two regions: hot plasma region in the core and cold plasma region in the periphery.

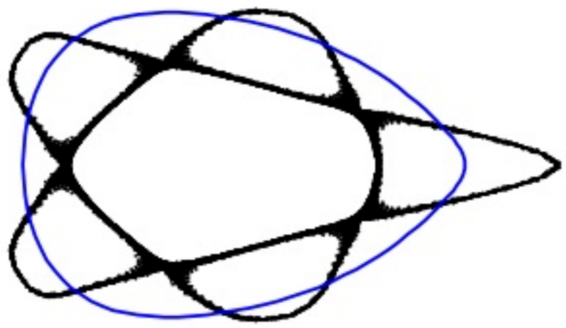

Figure 4 Divertor field line tracing for island bundle divertor. Blue line shows one example of vacuum chamber wall position for locating divertor plates.

Figure 4 shows the divertor field line tracing, which is created in the following calculation procedures. We found first the LCMS of the core confinement region. Then we distributed many field line tracing starting points with a small deviation (5 mm for R=1 m torus) from the LCMS. Because the island magnetic surfaces are complete, there is no escaping field line in such a calculation. Figure 4 shows blue line for one of the possible shapes of the vacuum chamber wall. If we install divertor plates at this wall position, the cold plasma in the island bundle flux can be absorbed at the divertor plates. Figure 5 shows the divertor tracing with the wall target where the field line tracing is stopped. The pattern of the magnetic field line punctual plots is very similar to the tokamak divertor structure. In fact, the transport of the magnetic field lines is exactly the same as tokamak divertor, where the peripheral regions of the divertor are connected to the core confinement region with a clear magnetic separatrix, and divertor magnetic field lines in divertor region have long connection length between the null point and the wall. Because the magnetic field lines go around through all five island bundle fluxes with very small incident angles to the wall, the distribution of the heat load on the divertor plates is determined by the precise geometric design of the shapes and the locations of divertor plates.

The length of the followed field lines between start points near LCMS and the divertor

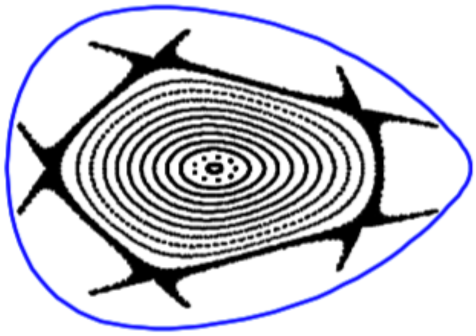

Figure 5 Divertor field line tracing with assumed existence of divertor targets. Magnetic surfaces within divertor separatrix are shown.

plate position is more than 150 m in this calculation and there is no exceptional field line with shorter length. This is because the island magnetic surfaces are very clear and there is no ergodic region between the core confinement region and the divertor bundle flux. This is a very clear difference from the LHD-type divertor structure where there are some field lines with shorter length between the core region and the divertor plate because of the ergodicity of the boundary layer of the core confinement region. In the discussions of connection length, the island bundle divertor is similar to the tokamak divertor situation in the sense that the divertor field lines do not have strong poloidal magnetic field component, which makes the connection length shorter.

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