Confinement Analysis of Compact Magnetic Fusion Configuration Combined with Tokamak and Stellarator Concepts

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Abstract: A compact plasma confinement configuration called TOKASTAR has been proposed combined with spherical tokamak and low-aspect-ratio stellarator systems. By adding helical filed to tokamaks, plasma start-up can be performed easily and the plasma current disruptions might be eliminated. In this TOKASTAR configuration, there is natural built-in divertor. According to the finite beta equilibrium analysis, the higher equilibrium beta value is attained by adding plasma current and increasing average rotational transform.

Keywords: Fusion, Tokamak, Stellarator, Plasma Current, Divertor

1. INTRODUCTION

Tokamak magnetic configuration systems are widely accepted as future attractive toroidal fusion reactors, because of axisymmetric simple coil configurations and good plasma confinement properties. However, to operate in steady state, external power for plasma current drive is required and the risk of plasma current disruptions should be considered.

On the other hand, helical magnetic confinement systems are superior to tokamaks for steady-state operation and possible disruption-free operations, but the non-axisymmetric configuration gives rise to the loss of fast ions.

Here we proposed a compact tokamak-stellarator hybrid system TOKASTAR \cite{1} which is an extension of old crescent-shaped tokamak-stellarator hybrid \cite{2} with outer helical grooves stabilizing ballooning modes.

In the case of fusion power plants, the following several charming points are required: more compact design, better plasma confinement, probability of steady-state operation, rather simple coil system, effective divertor configurations, etc. The similar configurations have been discussed in Ref.\cite{3}

In this paper, we focus on the divertor vacuum magnetic configuration and the finite-pressure magnetic field configurations

2. ANALYSIS CODES

In this paper, we used several computer codes. Figure 1 shows flow-chart of analysis. First, vacuum magnetic configurations are analyzed using field tracing code HSD\cite{4} with multi-filament coil models and Biot-Savart law. The last-closed surfaces obtained by HSD code lead to the Fourier Mode Analysis with DESCUR code. Finally, using this plasma boundary, finite-beta 3-D(dimentional) equilibrium is obtained with VMEC \cite{5} code.

3. MAGNETIC FIELD PROPERTIES

3.1. VACUUM CONFINEMENT FIELD

Figure 2 shows the coil system and vacuum magnetic surfaces of TOKASTAR. Two sets of helically twisted toroidal coil are combined in the center. The shape of this coil is spherical. Additional vertical filed is applied on this configuration to create closed magnetic field.

In this case toroidal periodic number L is 2, and there are enough space for plasma observation and machine maintenance. Typical radius of helical coil is 2.0 meter, and single coil current \( I_h \) is 1.0 MA. At that time the...
applied vertical field $B_y$ is 0.21 T. A typical cross-section of vacuum magnetic surfaces are shown in Fig.3. The plasma cross-section is D-shaped and the averaged plasma aspect ratio $A$ is 1.23. The deformation of plasma shape and the local rotational transform on the outboard side are large. However, the averaged rotational transform is not large. The typical maximum rotational transform $t_{\max}/2\pi$ is 0.39, and the average value $\langle t \rangle/2\pi$ is 0.39.

3.2. DIVERTOR FIELD
The open magnetic field outside last closed surface is shown in Fig.4. In this figure two field lines are extracted to the upper and the lower directions, which suggests the natural built-in divertor functions.

4. FINITE-BETA ANALYSIS
The finite pressure equilibrium is calculated by VMEC code [5] with fixed boundary as shown in Fig.5. By increasing beta value, the strong outward-shift of plasma axis has been observed in the case of TOKASTAR without plasma current (Fig.5 (a)). By adding plasma current, the rotational transform is increased and the radial shift of plasma axis is suppressed (Fig.5 (b)), which denotes that higher equilibrium beta is obtained in the case of current-carrying TOKASTAR.

5. SUMMARY AND DISCUSSIONS
A compact tokamak-stellarator hybrid configuration called TOKASTAR has been proposed, and its vacuum and finite-beta magnetic surfaces are analyzed. Here we conclude as follows;
(1) Using two helically twisted spherical toroidal coils, the clean magnetic surfaces with low aspect ratio are created.
(2) This configuration has natural built-in divertor.
(3) By adding plasma current, the higher equilibrium beta value is obtained.

We are now looking for new TOKASTAR configurations keeping higher rotational transform, and the stability analysis of TOKASTAR is under investigation. The transport analysis by 3-D equilibrium/1-D transport [6] will be also discussed in the future.

REFERENCES