19pC2-1

Feasibility studies of Negative Triangular Tokamak Configuration for Fusion Reactor
核融合炉の可能性としての負三角度トカマク

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DEMO is an important milestone for fusion research. The power handling becomes a highlight toward DEMO. A tokamak plasma with strongly negative triangularity may offer such an opportunity as an innovative concept. While this configuration is magnetic hill, recent MHD stability calculation shows reasonable beta limit (β_N=3.2) without wall stabilization. In this paper, we discuss favorable and critical issues of such configuration in both physics and technology.

1. Tokamak with Negative Triangularity

Recently, we proposed a tokamak with negative triangularity as an innovative concept for a fusion reactor configuration in order to reduce transient ELM heat load and quasi steady-state heat load [1-3]. Fig.1 shows a comparison of standard D shaped configuration and tokamak with negative triangularity. The power handling area in the divertor plates is essentially wider since the divertor is placed in the large major radius side in this configuration. Since the magnetic field is low, it is possible to use NbTi superconductor for the divertor coils, by which on-site manufacturing is much easier because of the large strain allowance of the NbTi superconductor. Interlinked divertor coils allow the snowflake and flux-expanded divertor [4] with acceptable coil current and provide robust control of divertor configuration.

In addition to the major radius difference of 2-2.5, we can expect flux expansion by 1.5-3. Our target is to enhance power handling area by ~7 [2].

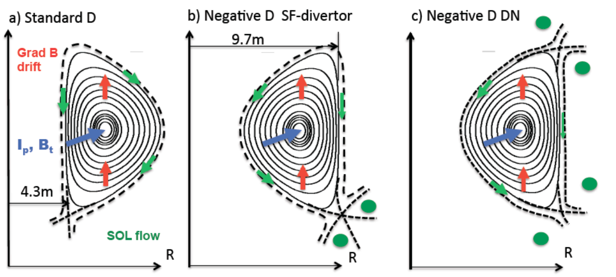

Fig.1. Cross-sectional comparison of standard and tokamak with negative triangularity [2].

2. MHD Stability

Tokamak with negative triangularity is a magnetic hill configuration, which is unfavorable for the plasma confinement, and its MHD stability is not well investigated. Since this configuration has lower edge beta limit, pedestal pressure can be suppressed to lower level compared with the standard D shaped configuration, which is a key merit to reduce ELM heat load.

This is a kind of paradigm shift “If we adopt negative triangularity, lower pedestal pressure leads to lower energy loss/ELM and the erosion of the divertor plate is reduced even if we have ELM in this configuration”. Ultimately, it is preferable to have soft beta limit. But, the shape optimization for MHD stability in general tends to stabilize high n modes and the limiting modes are low n modes resulting in hard collapse.

To compensate magnetic hill, magnetic shear is important for the ideal MHD stability. Medvedev showed that ideal MHD beta limit up to β_N=3.2 is obtained by increasing the edge magnetic shear [5]. The limiting MHD mode is n=1 external kink mode coupled to global internal modes while the Mercier stability criterion is satisfied in the equilibrium with optimized pressure gradient. Further understanding of mode characteristics in the magnetic hill and the optimization of shape and aspect ratio are necessary.

In the single null, the axisymmetric mode is relatively easier to stabilize while double null needs careful design of the configuration and design of resistive shell for n=0 modes [5].

3. Confinement

The original idea of tokamak with the negative triangularity is late T. Ohkawa's proposal in 1988, called the comet configuration to stabilize trapped particle mode with negative triangularity and horizontal elongation [6-7].

The experimental proof of improved confinement in negative triangularity is shown by TCV [8] in the limiter configuration and the gyrokinetic simulation shows strongly tilted TEM eigenmode structure in the negative triangularity. Since we want to have low pedestal pressure, it becomes important to break the profile resilience [9-10] and/or increase critical temperature gradient. Further understanding of mode structure related to profile de-stiffening is necessary. Recent TCV show core turbulence (δT_e) is reduced with edge negative triangularity[11].

4. SOL and divertor

Subsonic SOL flow $u_{//}$~0.5Cs has been a key mystery and plays an essential role in narrow SOL heat channel scaling [12]. Particle simulation by Takizuka [13] clarifies role of neoclassical orbiting effect in explaining this phenomena. SOL flow may be influenced by the strong negative triangular plasma shaping [2]. Experimental and numerical studies of flow characteristics for tokamak with negative triangularity is required.

5. Current Drive

The current drive with ECRF is suitable for the reactor CD method by having high power density and no accessibility issues and also by reducing fast particle population compared with NBCD for TAE stability. However, O-mode ECRF injection low field side is subject to the density limit. The tokamak with negative triangularity allows ECRF lauching from high field side from outboard side to allow ECRF heating and CD with higher density limit [3].

6. Engineering Characteristics

The toroidal field coil design for tokamak with negative triangularity needs some careful analysis since high field region is similar to the circular coil. *Nb3Al* superconductor having lower degradation of *Jc* with strain than those for *Nb3Sn* and the radial plate are preferable. Development of 16T level *Nb3Al* TF conductor is an important research subject.

CS coils may be formed by *Nb3Sn* to have higher flux swing. Interlink PF coils are to be made of *NbTi* conductor with enough thermal insulation from the nuclear heat.

The divertor pumping is much easier by wide and short pumping ducts. The optimization of the arrangement of the resistive shell for *n=0* stability is important, especially for the double null configuration.

The pellet fueling from high field side to increase fuel penetration to form more peaked density profile is also an advantage of this configuration.

The conceptual design of this configuration will clarify the merit and issues as a fusion reactor concept in comparison with standard tokamak fusion reactor such as SSTR [14].

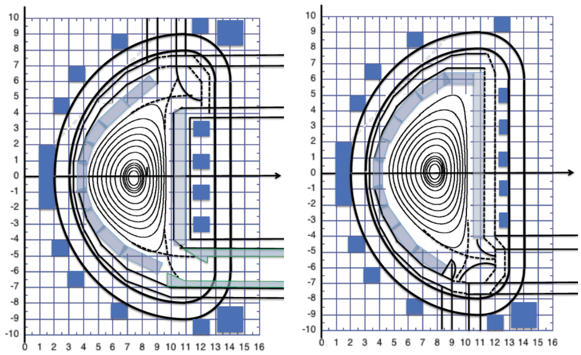

Fig.2. Possible reactor configurations of tokamak with negative triangularity [3].

Acknowledgments

Acknowledgments, if any, should be placed at the end of the text before the references.

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