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システムコードを用いた原型炉プラズマ設計領域のスコーピング研究

Scoping study of design windows of a tokamak DEMO reactor by using a systems code

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A current status of our scoping study of design windows of a tokamak DEMO conducted under the Broader Approach is reported. One of highlights of the results is evaluation of an ‘inter-linked’ (IL) central solenoid (CS) [1] for inductive plasma current I_p ramp-up in a tokamak reactor [2].

A CS function in a tokamak is inductive I_p ramp-up. If the CS is designed to accomplish this function, the CS size will be large to generate the magnetic flux swing sufficient for the inductive I_p ramp-up. This leads to increase in the reactor size and construction cost. If non-inductive current drive methods are employed, the CS and reactor sizes will be reduced like the compact tokamak DEMO SlimCS [1]. However, such methods have not been demonstrated extensively in a tokamak plasma with the medium or large aspect ratio and moderate plasma performance.

A basic idea of the IL-CS concept is to wind a CS such that it is *linked in* toroidal field coils to achieve a larger amount of the magnetic flux swing than of the conventional (C-) CS by increasing the CS cross section. The two CS configurations are shown in Fig. 1.

We made comparison of the magnetic flux swings generated by the IL-CS and C-CS, $\Phi_{IL\text{-}CS}$ and $\Phi_{C\text{-}CS}$, for the I_p ramp-up. We considered three cases characterized by the different reactor size. We developed sets of design parameters of the C-CS fusion reactors with the fusion power P_{fus} = 2 GW for the three cases by using the systems code TOPPER [3] and the TFC design code SCONE [4]. Sets of design parameters of the IL-CS reactors were developed so that for each case (i) R_p, A, κ and q_{95} are equal to those of the corresponding C-CS reactor and (ii) the IL-CS outer radius is equal to R_{TF} of the corresponding C-CS reactor. The sets of the reactor design parameters calculated are summarized in Table 1. Superconducting strand was Nb_3Al, and the averaged magnetic fields and thicknesses of the C-CS and IL-CS, (B_{CS}, Δ_{CS}), were (12 T, 0.4 m) and (4 T, 0.2 m), respectively. We have found, as shown in Table 1, that,

- $\Phi_{IL\text{-}CS} > \Phi_{C\text{-}CS}$ is expected for $R_p < 8.0$ m, and
- $\Phi_{CS} \cong \Phi_{ramp}$ is expected for the IL-CS configuration for $R_p = 6.5$ m while $\Phi_{CS} < \Phi_{ramp}$ for the C-CS configuration.

These results indicate that use the IL-CS configuration can bring the I_p ramp-up only by the inductive way and the large amount of the flux swing margin that can be used for Ohmic current during the flat-top operation phase, compared to the C-CS.

[1] H. Utoh, et al., to be submitted elsewhere (2012).
[2] M. Nakamura, et al., submitted to Plasma Fusion Res. (2012).
[3] K. Tobita et al., Fusion Eng. Des. 81, 1151 (2006).
[4] H. Utoh, et al., J. Plasma Fusion Res. Ser. 9, 304 (2010).

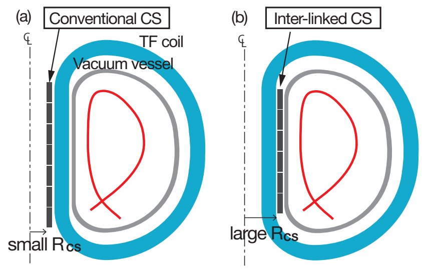

Fig.1 (a) Conventional and (b) inter-linked CS configurations.

Table 1 Design parameters of three cases of C-CS and IL-CS fusion reactors.

Reactor case #	1		2		3	
	C-CS	IL-CS	C-CS	IL-CS	C-CS	IL-CS
Rcs,outer (m)	1.70	2.90	2.20	3.94	2.70	4.32
Rtf (m)	2.90	2.70	3.94	3.74	4.32	4.12
Bmax (T)	13.3	<-	14.0	<-	13.1	<-
Rp (m)	6.50	<-	7.50	<-	8.00	<-
κ	1.83	<-	1.64	<-	1.63	<-
A	2.95	<-	3.47	<-	3.51	<-
βN	3.74	<-	3.35	<-	3.33	<-
q95	4.70	<-	4.46	<-	4.40	<-
Bt (T)	5.94	5.53	7.35	6.98	7.08	6.75
Ip (MA)	14.7	13.7	13.0	12.3	13.1	12.48
HHy2	1.30	1.21	1.30	1.23	1.30	1.24
Pfus (MW)	1888	1418	1921	1560	1881	1556
Φramp (Wb)	203	189	235	223	255	243
Φcs (Wb)	170	197	302	371	471	448
Φcs/Φramp	0.84	1.04	1.28	1.66	1.85	1.84