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Development of long-pulse neutral beam injectors for JT-60SA
JT−60SAに向けた長パルス中性粒子入射装置の開発

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A total power of 30~34 MW neutral deuterium beams is required to be injected to JT-60SA plasmas for 100 s by reuse of the JT-60U neutral beam injectors (NBIs) which are composed of 12 positive-ion-based NBI and 1 negative-ion-based NBI. In order to extend the pulse duration from 30 s in JT-60U to 100 s, the cooling capabilities of the ion sources, the beam line components and the power supplies are to be upgraded. In addition, the R&Ds for the long-pulse productions of the negative ions are planned in a new test stand which is under construction and will be operated in 2012.

1. Introduction

In order to realize nuclear fusion by supporting and complementing ITER experiments, JT-60 Super Advanced (JT-60SA) is being constructed as one of large superconducting tokamak [1]. The main target of JT-60SA is sustainment of high beta plasmas for long time by resolving the key physics and engineering issues.

In JT-60SA as well as JT-60U, plasma heating and current drive are mainly achieved by neutral beam injectors (NBIs) where the positive and negative deuterium ion sources are equipped. In JT-60SA, 85 keV, 1.7-2.0 MW beams for 100 s are required for each of the positive-ion-based NBI (P-NBI) and 500 keV 10 MW beams for 100s are required for the negative-ion-based NBI (N-NBI) [2]. The existing NBI systems on JT-60U are reutilized by upgrading the existing hardware to extend the pulse duration to 100 s, where the key issues are the productions of high power beams in the ion sources, the heat removal in the beam line components and the upgrades of power supplies.

In this paper, recent progresses of the development of the long-pulse NBI systems are reported.

2. NBI systems in JT-60SA

The 12 P-NBIs and 1 N-NBI are allocated around JT-60SA to inject the D^0 beams as shown in Fig 1. A total injection power from the P-NBIs is 20-24 MW with the beam energy of 80-85 keV, and delivered from 4 units in a tangential direction toward the plasma current (2 co-direction and 2 counter-direction) and 8 units in the perpendicular direction as shown in Table 1. These various injection directions are one of features in JT-60SA, which contributes a flexibility of the plasma experiments such as plasma rotational torque scans with constant heating power. As for the N-NBI, an injection power is 10 MW with the beam energy of 500 keV in the co-tangential direction. The injection position is changed to 55 cm downward from the equatorial plane in order to obtain weak/negative magnetic shear plasmas by the off-axis current drive.

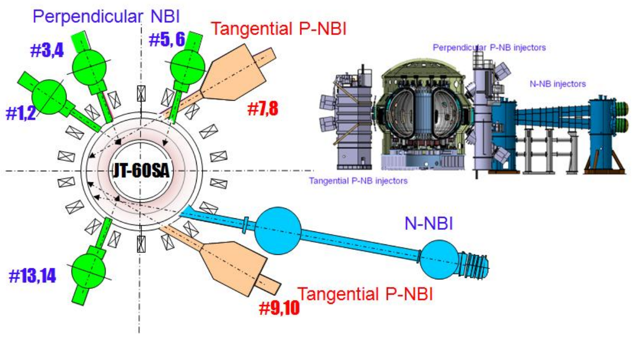

Figure 1. Layout of the NB injectors on JT-60SA

Table 1. Specification of NBI systems for JT-60SA

	P-NBIs	N-NBI
Injection power per injector	1.7-2.0 MW	10 MW
Pulse length	100 s	100 s
Number of units	12	1
Number of ion sources per unit	2	2
Beam energy	80-85 keV	500 keV
Ion beam current per ion source	24.9-27.5 A	22 A
Injection positions	4 units: tangential 8units : perpendicular	Tangential 55 cm off-axis

3. Development of Positive-ion-based NBI for

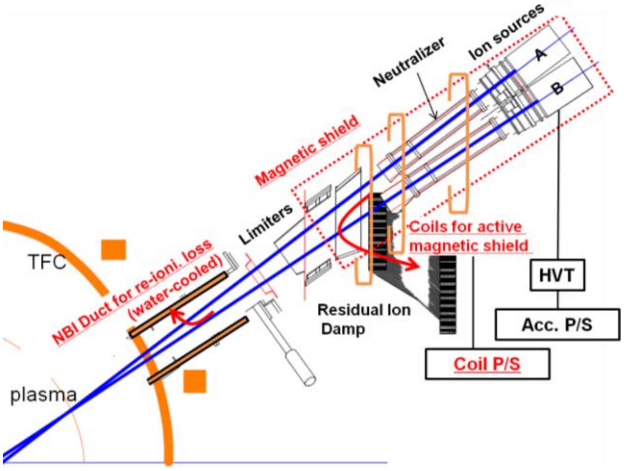

Figure 3. Schematic view of a unit of P-NBI system. The devices with underline are to be upgraded.

Long-pulse Injection

From each of the P-NBI, 85 keV, 2 MW injections have been obtained for 30 s on JT-60U. In this operation, the beams were stably produced and injected. Moreover, the temperatures of the acceleration grids were saturated in 15 s, which was an allowable level for the long pulse operation. From these results, it is confirmed that the positive ion sources had a capability of 100 s injections.

The magnetic shield is upgraded because the leakage magnetic field on JT-60SA is twice larger than that of JT-60U. Therefore, the passive magnetic shield is additionally installed in JT-60SA. Furthermore, the cooling capabilities of the active magnetic coils for cancelling the stray field from the tokamak are upgraded. However, these modifications can not perfectly shield the magnetic field, which is induced by the discharge with the highest plasma current of 5.5 MA, where some of the residual ions can not reach to the RID. Considering cost effectiveness, this issue is overcome by masking a part of the extraction apertures on the plasma grid of the ion source, which led to the reduction of the injection power from 2 MW to 1.7 MW. The magnetic shield is fully upgraded to inject 2 MW in the extended research phase of the JT-60SA project.

As for the beam line components, it is experimentally confirmed that the cooling capabilities of the existing components are sufficient for 100s injections except for the beam duct, where the maximum heat flux of ~3 MW/m^2 is estimated. The water-cooled beam ducts are designed to have a capability of 100 s injections.

4. Development of Negative-ion-based NBI for Long-pulse Injection

The N-NBI was designed to give 500 keV, 10 MW beams for 10s on JT-60U. As a result of R&D, 500 keV, 3A beams for 0.8 s and 350 keV, 3 MW injections for 30 s were achieved [3]. In addition to these achievements, the R&D on the vacuum insulation of the large multi-aperture grids has been carried out to design the negative ion source for JT-60SA. The scaling of the vacuum insulation to the surface area *S* of the grids and number of the apertures *N* are found to be $S^{-0.125}$ and $N^{-0.15}$, respectively. This is the first scaling of the large multi-aperture grids. By taking this scaling into account, the gap lengths between the acceleration grids are designed as shown in Fig. 4. The whole structure of the accelerator is being designed to have a capability over 500 kV.

The R&D of the negative ion source for JT-60SA is also carried out to produce uniform negative ion beams for long pulse duration. . To produce the beams stably for the long pulse duration, the plasma grids (PG) should be maintained to be high temperature around 200 °C. One of the candidates is the use of actively-cooled PG by high temperature refrigerant fluid having a high boiling point of 270 °C at 0.1 MPa. As for the uniform production, the tent-shaped filter [4] is to be applied in order to suppress the grad B drifts of the primary electrons. These countermeasures will be tested in a new test stand since 2012. In the test, power supplies utilized in N-NBI on JT-60U are utilized.

References

[1] S. Ishida, P. Barabaschi, Y. Kamada and the JT-60SA Team, *Nucl. Fusion* **51** (2011) 094018.

[2] M. Hanada, A.Kojima, T.Inoue et. al., *AIP Conf. Proc*. **1390** (2011) 536.

[3] A. Kojima, et al., *Nucl. Fusion*. **51** (2011) 083049.

[4] M.Hanada et al., *Rev. Sci. Instrum.* **77** (2006) 03A515.

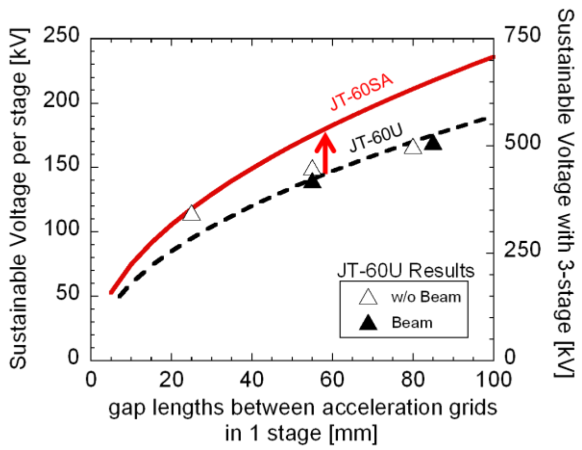

Figure 4. Estimation of the voltage holding capability from the experimentally obtained database for the vacuum insulation. By optimizing the aperture number and the surface area, the voltage holding capability is improved in JT-60SA