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Present Status of the Development and Procurement on Neutral Beam Injectors for JT-60 SA

JT-60SAに向けた中性粒子入射装置の開発及び調達の進展

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This paper reports the present status of the R&Ds to realize the neutral beam (NB) injectors for JT-60 SA where a total injection power and pulse duration time are 34 MW and 100 s, respectively. The R&Ds for the positive-ion-based NB injector has been well in progress, which ensures to inject 24 MW, 85 keV for 100 s from twelve injectors. As for the negative-ion-based NB (N-NB) injector, the performance of the negative ion beam has been energetically improved by modifying the JT-60 negative ion source to realize a 10 MW, 500 keV for 100 s. The achievements of the beam performance fulfills the beam current of 22A, the beam energy of 500 keV, pulse duration time of 100 s required for JT-60 SA independently. In addition, the long pulse production of the high-current beam is being tested, where 15 A of the high-current beam is produced for 100 s.

1. General

Neutral beam (NB) injector is a main plasma heating and current drive system on JT-60 SA, where existing NB injectors are required to be upgraded and re-used. Twelve positive-ion-based NB (P-NB) and one negative-ion-based NB (N-NB) injectors are required to produce 24 MW, 85 keV and 10 MW, 500 keV D^0 beams for 100 s, respectively [1]. In order to realize the NB injectors in JT-60 SA, the positive and negative ion sources are being developed. In particular, the JT-60 negative ion source of the largest negative ion source in the world is modified to fulfill the requirement, 22 A, 500 keV, 100s for JT-60 SA. In addition, the NB components such as the control system and power supplies have been also upgraded to extend the nominal operation time from 10 s to 100 s while the injection power is kept to be the same as that in JT-60. In this paper, we report the present status of the development of the P-NB and N-NB injectors for JT-60 SA.

2. P-NB injector development

Out of 14 P-NB injectors in JT-60, 12 P-NB injectors are planned to be re-used in JT-60 SA after upgrading (Fig.1). In the previous operation, the P-NB injector has already achieved 2 MW, 85keV during 30 s. The achievement except for the pulse duration time fulfills the requirements for JT-60 SA.

The critical NB components to extend the pulse duration time to 100 s are a positive ion source and a residual ion dump (RID) that is exposed to the highest heat and particle loads in the NB components. The longer pulse production of the high current beam has been experimentally tested to realize the 85 keV, 27.5 A beams during 100 s. The test shows that a 60keV, 18 A H^+ ion beams was produced during 200 s without degradations of the beam production and optics. The beam energy defined as product of beam power and pulse duration time is the same as that required for JT-60 SA. When the high current beam was produced for long-pulse duration, the temperature rises of the acceleration grids was measured to be saturated to be allowable level of 8 ^{o}C with a short thermal time constants of < 30 s. This shows that the ion source have a sufficient water cooling capability for a 100 s injection without modification. These results suggest that the JT-60 positive ion source has the potential of the beam production capability to be used in JT-60 SA without modification. In 2014, a 100 s beam production at 85 keV, 27.5 A is planned to be demonstrated.

As for the RDI, water cooling capability is confirmed to be sufficient for a 100 s injection from the measurement of temperature rise. In addition, the damage of the RID by sputtering and erosion is

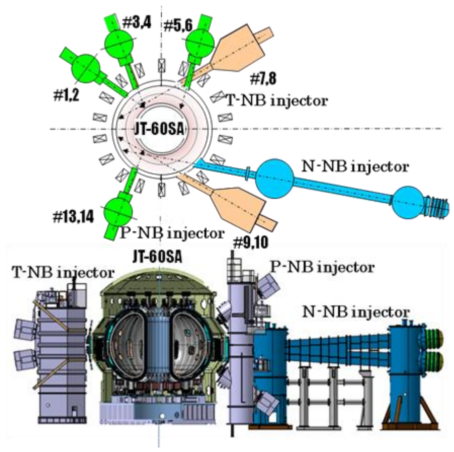

Fig.1 Schematic of NB injectors on JT-60 SA

estimated. A part of the cooling channels used for 20 years in the P-NB on JT-60 was sampled to measure the inner and outer diameters of the water cooling channel and compared with unused channel. There are negligibly small differences of the inner and outer diameters between before and after the 20-year use. In addition, the sputtering calculation shows that the diameter reduction is as low as 3 μm for 20-year operation and much smaller than the thickness of channels of 2 mm. These results suggest the reuse of the JT-60 RID without modifications for JT-60 SA.

The other NB components in the P-NB injector are re-used in JT-60 SA without modification except for a drift duct, a magnetic shield and power supplies, which have been designed to fulfill the requirement for JT-60 SA.

3. N-NB injector development

In the previous operation, the N-NB injector achieved a 3.0-3.2 MW injection during 30 s at 320-340 keV and was limited by the performance of the JT-60 negative ion source. The beam energy, current and pulse duration time should be increased up to 500 keV, 22 A and 100s, respectively to fulfill the requirements for JT-60 SA. Through the energetic developments to improve the performance of the JT-60 negative ion source, the followings have been achieved so far;

- The vacuum insulation characteristics in a gap between the large grids have been clarified to improve the voltage holding capability of the JT-60 negative ion source. Through this result, the gap length was optimized to endure high voltage without degrading beam optics. This increases the beam energy to 500 keV at 2.8 A through a 20% of the ion extraction area in the JT-60 negative ion source [2].
- The beam current was limited by a poor spatial beam uniformity that was caused by a direct interception of the negative ions with the acceleration grids in JT-60 negative ion source. To improve the beam uniformity, the magnetic structure has been modified from the previous transverse filter to a tent-shaped filter. This modification allows to increase the beam current from 10-15A to 32 A for the pulse duration time of 0.8 s [3].
- The pulse duration time of the high current beam was limited by the temperature of the plasma grid (PG) where the cesium (Cs) are covered to lower the work function and atoms (D^0/H^0) and ions (D^+/H^+) are converted to D^-/H^- ions via surface production. The PG was modified from an inertia cooling to an active cooling in order to suppress the degradation of the negative ion production due to overheat of the PG. The PG temperature has been actively controlled to be constant value of 200-250 ^{o}C. A fluorinate fluid with boiling point of > 200 ^{o}C at 0.1 MPa is actively flowed into the PG with controlling the temperature by the chiller. As the result, the pulse duration time has been extended from 30 s to 100 s at beam current of 15 A that was 68% of the required for JT-60SA. To increase the beam current during 100 s, the arcing in the discharge chamber is being mitigated by further conditioning [4].

In parallel with the development of the negative ion source, the control system is being developed. Instead of the previous sequencer specialized for the N-NB system, Programmable Logic Controller (PLC) of versatile devices are utilized for an ease extension of the functions. The PLCs with different speed are allocated to control the power supplies of the negative ion source. The control system is being tested with the power supplies upgraded for JT-60 SA and stably produces the beam during 100 s. Through this test, the controllability of this system has been confirmed to be feasible for JT-60 SA operation.

References

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