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Long Pulse Production of High Current Negative Ion Beam for JT-60SA and ITER

JT-60SAおよびITERに向けた大電流負イオンビームの長時間生成

Atsushi Kojima, Masaya Hanada, Mieko Kashiwagi, Kazuhiro Watanabe, Naotaka Umeda, Hiroyuki Tobari, Masafumi Yoshida, Jyunichi Hiratsuka, NB Heating Technology Group.
小島有志, 花田磨砂也, 柏木美恵子, 渡邊和弘, 梅田尚孝, 戸張博之, 吉田雅史, 平塚淳一, NB加熱開発グループ

Japan Atomic Energy Agency
801-1, Mukoyama Naka, Ibaraki 311-0193, Japan
日本原子力研究開発機構 〒311-0193 茨城県那珂市向山801-1

Developments of high-current, long-pulse hydrogen negative ion beam has beens significant progressd to realize the neutral beams injectors for fusion devices such as JT-60SA and ITER. The pulse duration of the high-current beam of 15 A has been extended from 30 s to 100 s on the JT-60SA negative ion source, which satisfies 70% of the rated beam current for JT-60SA. This progress was based on the R&D efforts toward the temperature control of the plasma grid where the Cs coverage was formed to lower the wok function of the grid surface. For this purpose, the PG temperature control system has been developed with the high-temperature fluid having high boiling point of 270 ºC at 0.1 MPa. In order to accelerate such high-current beams, the extraction grid having high-transmission high-cooling capabiliy with beam steering tecniques has been developed on the MeV accelerator. The pulse duration of high-power-density beam of 70 MW/m^2 has been extended from 0.4 s to 60 s. These developed technologies are applied to the modification and design of the JT-60SA and ITER negative ion sources.

1. Introduction

High-energy neutral beam injectors (NBI) based on large-size negative ion sources are promising candidates for the plasma heating and current drive systems on nuclear fusion devices such as JT-60SA and ITER, where 10 MW D^0 beam for 100 s and 16.5 MW for 3600 s are required. In order to realize such NBIs, the long pulse production of the powerful negative ion beams of 500 keV, 22 A (130 A/m^2) and 1MeV, 40 A (200 A/m^2) are essential R&D target for the negative ion sources.

In Japan Atomic Energy Agency (JAEA), after the success of the high energy beam acceleration by improving the voltage holding capability [1], one of the remaining common issues for JT-60SA and ITER is the extensions of pulse durations. Toward this issue, the key technologies for the long pulse production/acceleration of the negative ions has been developed by using the JT-60SA ion source and the MeV accelerator.

2. Long Pulse Production of High-Current Negative Ion Beam

Since the negative ion production is strongly dependent on the work function on the plasma grid (PG) given by the coverage of cesium (Cs), the negative ion current can be controlled via the temperature of the PG [2]. The pulse duration with the original inertially-cooled PG on the JT-60SA negative ion source (Fig.1) was limited up to 30 s due to strong degradation of the negative ion production by overheat of the PG over the optimum temperature of 200-250 ºC. In order to extend the pulse duration, the active-control system of the PG temperature with a high temperature fluid has been newly developed as shown in Figure 2. The fluorinated fluid (GALDEN HT-270) was used as the primary fluid, which has an advantage of a high

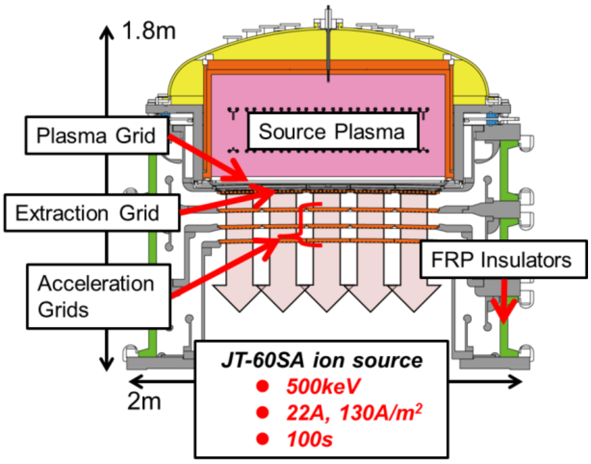

Fig.1. Schematic views of the JT-60SA negative ion source. KAMABOKO-type arc-driven ion sources with a three-stage accelerator insulated by fiber-reinforced-plastic (FRP) rings. The ion sources composed of plasma grid (PG), extraction grid (EXG) and acceleration grids.

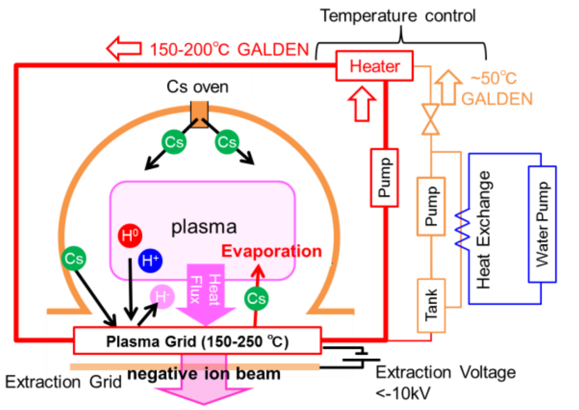

Fig. 2. PG temperature control system for the JT-60SA ion source.

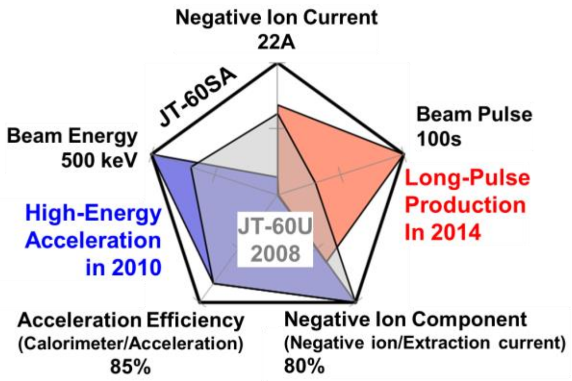

Fig. 3. Progress on the development of the JT-60SA negative ion source.

boiling point of 270 oC at 0.1 MPa [3].

Applying this system to large-size extraction area (110 x 45 cm^2) of JT-60SA negative ion source, the PG temperature has been successfully saturated and controlled for 100 s as designed. As a result, the pulse duration of high-current negative ions of 15 A has been significantly improved from 30 s in JT-60U to 100 s as shown in Fig 3. This developed technology contributes to the design of the ITER ion source where the PG temperature control is planned. The experiment for the long pulse production at the rated current of 22 A is on-going by adjusting the conditions of the arc discharge and cesium seeding.

3. Long Pulse Acceleration of High-Power-Density Beam

To realize the long pulse acceleration for JT-60SA and ITER, a new extraction grid (EXG) has been designed [4] and tested with the MeV-class beam in the MeV accelerator. To receive the high heat flux of 5 MW/m^2 for 3600 s due to the co-extracted electron on the EXG, the water-cooling capability has been modified from that of JT-60 type for 1 MW/m^2, 10s (Fig.4). The cross section of the cooling channels for long-pulse type is enlarged three times than that of JT-60 type, and the position was moved closer to heat receiving area. The thermal analysis showed that this modification reduces the surface temperature of the EXG from 250 $^{\circ}$C to 100 $^{\circ}$C of an allowable temperature for 5 MW/m^2, 3600 s. In addition, since the magnetic field profile near the EXG for long-pulse type is largely different from that for JT-60 type, the aperture displacement to compensate the beam deflection due to the magnetic field has been newly designed through a 3D analysis of the beam trajectories [5]. The aperture displacement for long-pulse type is designed to be 0.8 mm to suppress the grid heat load of the acceleration grids downstream.

Applying this EXG to the MeV-class beam acceleration in the MeV accelerator, the pulse duration has been successfully extended from 0.4 s in the previous operation to 60 s at a beam energy of 683 keV with current density of 100 A/m^2. Since no limitation has been observed at this power density level, further increase of the pulse duration is expected.

References

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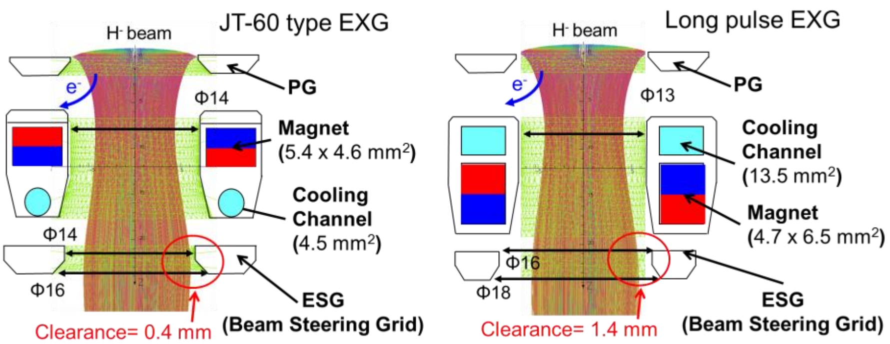

Fig. 4. Schematic view of the extraction grids of (a) JT-60 type and (b) EXG for long pulse.