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Electrostatic Analysis and Improvement of Voltage Holding Capability of the 1 MeV Accelerator for ITER NBI

ITER NBI用1MeV加速器の電界解析と耐電圧性能向上

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In Japan Atomic Energy Agency (JAEA), R&D of the MeV accelerator for the ITER NBI has been conducted. An issue for stable beam acceleration at 1 MeV was voltage holding in vacuum. The voltage was limited up to 835 kV for the previous accelerator configuration due to breakdown in vacuum. Discharge marks were observed on the grid supports. In an electrostatic analysis, it was found that the electric field concentrated at screen shield and the corner of the grid support. The accelerator was modified to lower the local electric filed at these parts. As the results, MeV accelerator was succeeded in sustaining 1 MV in vacuum.

1. Introduction

The neutral beam injector (NBI) for ITER is required to produce 16.5 MW of deuterium neutral beams per one injector at the energy of 1 MeV. Acceleration of 40 A (200 A/m^2) D$^-$ ion beams up to 1 MeV is required so as to fulfill the requirement. A multi-aperture multi-grid (MAMuG) accelerator called “MeV accelerator” has been developed at Japan Atomic Energy Agency (JAEA) [1]. A goal of the MeV accelerator is to demonstrate H$^-$ ion beam acceleration up to 1 MeV at the current density of 200 A/m^2 for several tens seconds. An issue for the realization is to improve voltage holding capability of the accelerator [2]. In the present work, electrostatic analysis was carried out and the accelerator was modified to improve the voltage holding capability.

2. MeV accelerator

Figure 1 shows a cross sectional view of the MeV accelerator. The MeV accelerator is an electrostatic accelerator composed of five acceleration stages which are formed with six electrodes such as EXG, A1G, A2G, A3G, A4G and GRG. Each stage is insulated with fiber reinforced plastic (FRP) ring. Inside of the FRP ring is vacuum and outside of the ring is filled with SF_6 gas at 0.6 MPa. Voltage of 200 kV is applied to each stage (1 MV for five stages). Left side of Fig.1 shows the previous accelerator tested in 2008. In this accelerator, grid and grid support structure of A2G were removed for simplicity. So voltage of 400 kV was applied between A1G and A3G.

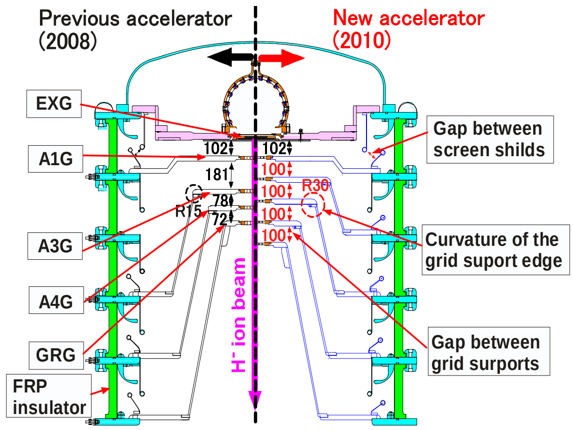

Fig.1 Cross section of the MeV accelerator

Voltage holding test for each stage and full stages were carried out with the previous accelerator. Table I shows a result of the test. Voltage of only one stage between A3G and A4G reached to rated voltage of 200 kV and the maximum voltages of other stages were lower than rated voltage. Voltage holding of the full stage was limited to 835 kV.

After the test, the accelerator was disassembled and its interior was inspected in detail. Many discharge marks were observed in the

Table I. Result of the voltage holding test

Stage	Minimum gap	Maximum voltage
EXG-A1G	102 mm	181 kV
A1G-A3G	181 mm	334 kV
A3G-A4G	78 mm	205 kV
A4G-GRG	72 mm	184 kV
Full stage	-	835 kV

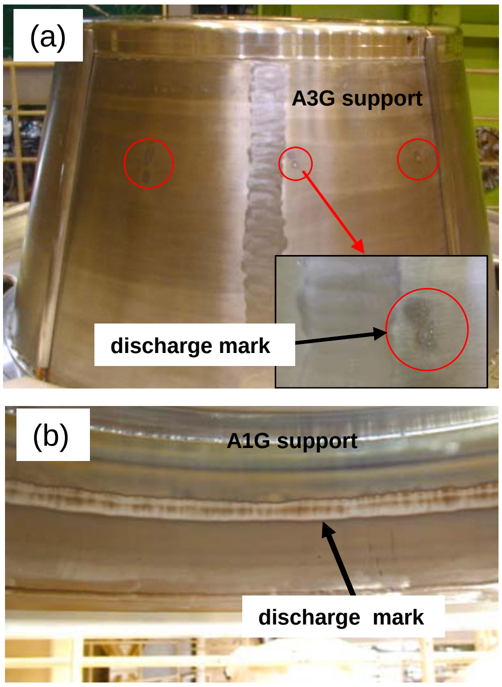

Fig. 2 Discharge marks (a) on the A3G support (anode side) and (b) back side of A1G support (cathode side)

accelerator as shown in Fig. 2. The spotted discharge marks were left on A3G support (Fig. 2 (a), anode side). From the positions of these marks, it seems as if negatively charged particles were produced on the screen shield at -1 MV potential and pass through the holes opened at A1G support for pumping. While the ring shaped discharge mark was left at the back side of A1G support (Fig. 2 (b), cathode side) and seems to be triggered from the corner of A3G support. From these discharge marks, it seemed that discharge could be triggered from both anode and cathode sides. From the Cranberg's clump theory [3], breakdown occurs when the power density of a clump colliding with the electrode exceeds a constant value. The power density is a product of voltage and charge density. The charge density is in proportion to the local electric field at the detached electrode surface. The charged clump would be released from both anode and cathode surfaces. So it is necessary to reduce electric filed at both cathode and anode sides.

3. Electrostatic analysis

A two dimensional electrostatic analysis was carried out with ANSYS code [4] to clarify electric field intensity at parts which could originate the discharges. Figure 3 shows electric field profile simulated with the previous accelerator when 200 kV is applied to each acceleration stage. Electric field at the screen shield of -1 MV potential, which seemed as an origin of the discharge as shown in fig. 2 (a), was 6.7 kV/mm. Electric field at the corner of

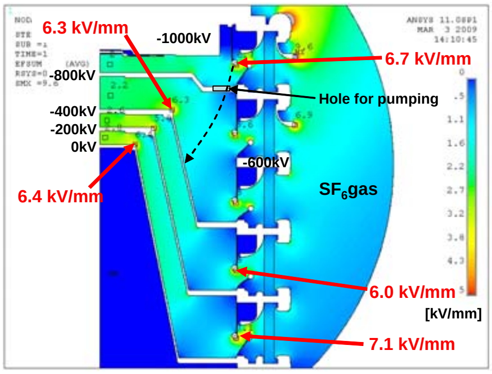

Fig. 3 Analysis result of the previous accelerator

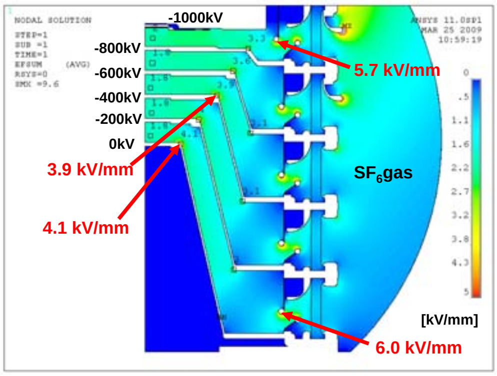

Fig. 4 Analysis result of the new accelerator

the A3G support, which supposed to be a trigger of the discharge as shown in fig.2 (b), was 6.3 kV/mm. While electric filed at the screen shield of A3G was 6.0 kV/mm, and A3G-A4G stage could sustain more than 200 kV as shown in Table I.

To reduce the electric field at these high stress points, modification of the accelerator was proposed as follows: 1) increase gap length between grid supports to 100 mm, 2) increase curvature radius of the corner of the grid support from 15 to 30 mm, 3) increase gap length between screen shields more than 60 mm. Figure 4 shows the electric field distribution for the new accelerator. By the modification, electric field at the screen shield and at the corner of the grid support was reduced less than 6.0 kV/mm and 4.1 kV/mm, respectively. These modifications were actually implemented to the MeV accelerator.

4. Voltage holding with new accelerator

Voltage holding test was carried out with the new accelerator. After 60 hours of conditioning, voltage has reached to 1MV without gas feeding and sustained more than 1 hour stably. Thus, it is important to reduce local electric field intensity at both cathode and anode sides.

References

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