Acceleration of 500 keV negative ion beams by tuning vacuum insulation distance on JT-60 negative ion source

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High voltage holding is one of key techniques and common issues for ion sources. Although the JT-60 negative ion source was designed to produce 500keV 22A D^- beams by using a three-stage accelerator, the ion source was suffered from the issue of the relatively low voltage holding capability of 420 keV for long years. Recently, a lot of efforts have been made on the improvement of the voltage holding capability and suggests that breakdowns often occur at a gap between acceleration grids. As a result of investigations of the voltage holding in vacuum gaps, the acceleration of 500 keV beams has been achieved by tuning vacuum insulation distances in the ion source. This paper reports the experimental results of the voltage holding tests on the large ion source in terms of the vacuum gaps.

In order to increase the beam energy up to 500 keV, the maximum break down voltage V_{BD} of a single-stage of the ion source has been investigated by varying the gap length between the acceleration grids. Although V_{BD} increases with the gap length, V_{BD} tends to be saturated in longer gap than original one. This saturation suggests that the minimum length around the corner region of the grid supports limits V_{BD} when the gap length is extended. After extending the minimum length in this region, high voltage of 190 kV exceeding the rated voltage of 163 kV for a single-stage has been sustained. Toward the three-stage experiments, the minimum length and the gap length have been adjusted so as to ensure the voltage holding of 500 kV. In addition, the beam radiation shield around the corner region has been optimized to satisfy the required minimum length, electric field and the shielding effect. As a result, acceleration voltage of 500 kV has been stably sustained for the first time, which is the limitation of the acceleration voltage. Moreover, the beam acceleration up to 2.8 A has been attained with beam energy of 500 keV. It is noted that no degradation of the voltage holding has been observed during the enhancement of the negative ion current with cesium seeding.

For the future ion source, the design criteria are required to predict V_{BD}. As for the JT-60 ion source, a vacuum insulation distance was derive from experimental results of a Rogowski-electrode with a diameter of 160 mm which sustained more than 300 kV with a gap length of 55 mm. However, a single stage of the previous ion source sustained only half of that. In order to investigate the reason of the low voltage holding and obtain the empirical law, sample experiments of the Rogowski-electrode has been carried out by simulating the acceleration grids. The electrodes have locally strong electric field around apertures which are same size as the acceleration grids. It is found that V_{BD} depends on the surface area of the aperture edge S_{edge} ($V_{BD} \propto S_{edge}^{-0.14}$) which indicates the extent of the strong electric field. Although breakdown mechanisms with long gaps in vacuum have not been fully understood yet, these results suggest that the reduction of area of strong electric field is effective to increase V_{BD}.