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GENERAL ATOMICS

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# Performance of a DIII-D Neutral Beam Ion Source with a New Accelerator Grid*

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***Abstract*—The DIII-D tokamak utilizes seven neutral beam ion sources for plasma heating and current drive. These ion sources have performed with high availability and reliability since 1987. However, components of the ion sources, especially the grids of the accelerator, have since developed hardware failures either due to old age or fabrication defects. Due to lack of the plasma grid with diamond shape rails, we have built a plasma grid with circular cross section rails and installed it in one of the ion sources. Tests were performed on this ion source (we will call it the new ion source) and results were compared with one of the original ion sources. The new ion source runs just as reliably as the original ion sources, though the operation window is slightly smaller and the value of the optimum beam perveance is about 4% less (4% less beam current). This new ion source has been used to inject neutral beams into plasmas of the DIII-D tokamak to support physics experiments. No operational problems or difficulties were encountered during more than 5 weeks of operation. Details of the new plasma grid and the operational results will be presented.**

***Keywords-ion source***

## I. INTRODUCTION

Neutral beam ion sources used by DIII-D for plasma heating and current drive were designed by Lawrence Berkeley Laboratory and assembled by RCA high voltage division (currently called Burle Industries). One of the design features is the non-circular cross-section rails used in two (out of four) accelerator grids, achieving the optimum beam optics and beam current. Fig. 1 shows the cross sections of the molybdenum rails [1,2] for the four accelerator grids of DIII-D neutral beam ion source, with the plasma grid closest to the arc chamber of the ion source. A vendor has successfully fabricated the rails for the suppressor grid using the EDM technique. However, due to its longer length and smaller cross section, we have not found a vendor who can fabricate the diamond-shape plasma grid rail, and our internal effort at GA has not been successful. An operational neutral beam system with full capacity is crucial to the success of the DIII-D fusion science research program. It was then decided that a new plasma grid should be built using circular cross-section rails and installed in one of the ion sources to test and compare its performance with the original ion source. Based on nearly 20-year experience in operating ion sources and the not so drastic change in the cross section of rails, we expected little degradation in performance of the modified ion source. Components were either purchased from or fabricated by vendors; however, four plasma grid modules (form a plasma grid) were assembled and brazed at General Atomics. These four plasma grid modules replaced the four modules in one ion source and this ion source was then installed on one beamline. It took about three days to condition the ion source followed by two days' performance test, and it was then used to inject neutrals into plasmas to support physics experiments.

## II. HARDWARE CHANGES AND FABRICATION

The accelerator of a DIII-D neutral beam ion source consists of four grids. Each grid has four identical modules, and each module consists of a pair of stainless steel grid rail holders, 28 small bellows (plasma grid module only), and 14 molybdenum rails. These rails are molybdenum tubing, brazed to the grid rail holders, and actively cooled by water flowing through the center of the tubing. Fig. 2 shows one of the plasma grid modules.

Changes were made only to the rails of the plasma grid module, i.e., from diamond shape to circular cross section and the corresponding changes on the grid rail holders where braze joints are made. Fig. 3 shows the cross section of the original and the new rails. The size of the circular rail is determined such that distances between the rails of same grid module and between the rails of plasma grid and gradient grid are kept unchanged.

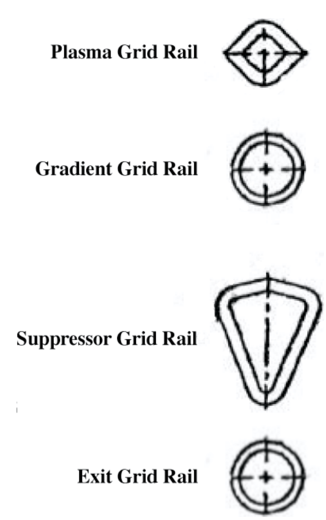


Figure 1. Cross sections of the molybdenum rails for the accelerator grids of the DIII-D neutral beam ion source.

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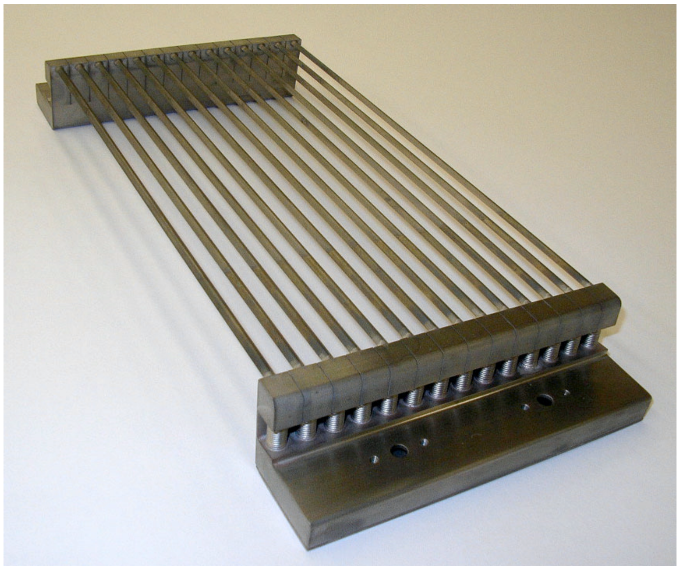

Figure 2. Picture of a plasma grid module.

A local vendor fabricated the stainless steel grid rail holders, and we purchased circular molybdenum tubing and stainless steel small bellows from manufacturers. Four grid modules were assembled and brazed at General Atomics using internally developed braze technique [3]. These four grid modules passed the dimension inspection, pressure test, and vacuum leak check before they were installed and aligned in an ion source.

## II. ION SOURCE CONDITIONING AND PERFORMANCE TEST

This new ion source equipped with a circular rail plasma grid was mounted on the 210 deg beamline. An ion source conditioning procedure developed at DIII-D and used for many years was followed to condition the new ion source. The conditioning procedure includes arc chamber conditioning (producing stable and consistent arc discharges) and accelerator conditioning (producing stable high energy beams with good beam optics). This ion source was conditioned up to 75 keV beam operation without additional run time or difficulties as compared to the original ion sources. Beam optics as measured by the accelerator grid currents and the extracted beam currents were closely monitored during the conditioning process.

Performance of neutral beam ion sources can be, in general, determined by three factors: arc efficiency, beam perveance, and beam divergence. Arc efficiency (unit of Ampere per kilowatt) defines the efficiency of beam extraction for an averaged power applied to the arc chamber of an ion source to initiate and sustain arc discharges. Beam perveance is a measurement of extracted beam ions from the ion source for a specific high voltage applied to the plasma grid (equivalent of beam energy). Beam divergence (in two directions normal to the beam propagation direction) defines the sizes of the beam along the beamline, which is crucial information for the requirements of beamline hardware.

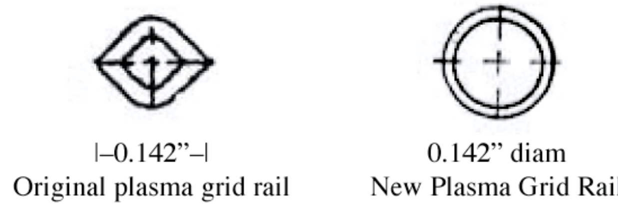


Figure 3. Cross sections of the original and the new plasma grid rails.

Fig. 4 shows the arc efficiency of the new and original ion sources. The new ion source has less arc efficiency, about 6% less than that of original ion source. Optimum beam perveance is the beam perveance at which beam has the best beam optics, either a minimum gradient grid current or smallest beam divergent angles. It is easiest and most accurate (as compared to the divergent angles) to measure the gradient grid current, and it is called ion source tuning (or scanning) when gradient grid currents are measured for various beam perveance (or beam current). Fig. 5 shows the tuning curves, which plots normalized (to beam current) gradient grid current versus the beam perveance. The optimum beam perveance of the new ion source is about 2.7 μp [$\mu p = \mu perv = 10^{-6}$ Ampere/(Volt)$^{3/2}$] which is about 3.6% less than the optimum beam perveance of the original ion source. It means that if the ion source is operated at optimum beam perveance, the new ion source will produce 3.6% less beam power available for plasma heating or current drive. This is a small and reasonable price to pay when cost saving and availability of using circular molybdenum rails for the plasma grid are taken into consideration. Fig. 6 shows the divergent angles of the ion source. The minimum angles are close to values (0.65 and 1.2 deg) measured in the past for the original ion source, however, accuracy of measured angles is not as good as the gradient grid current.

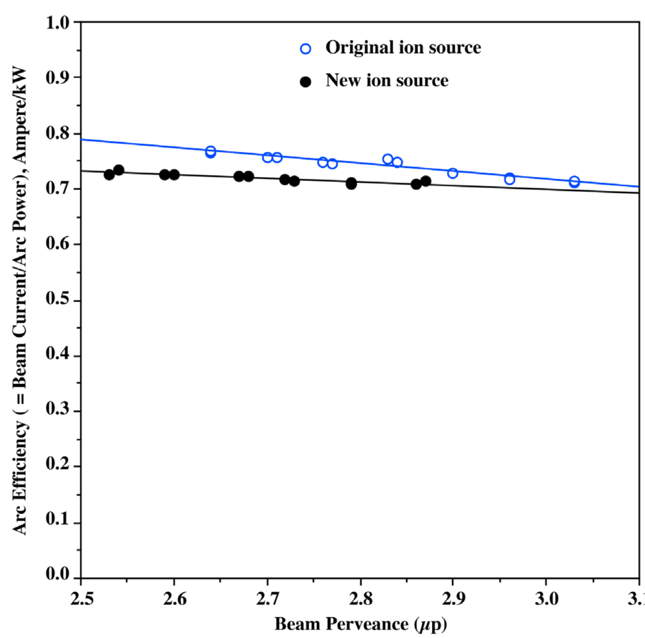


Figure 4. Arc efficiency of ion sources with 75 keV deuterium beams.

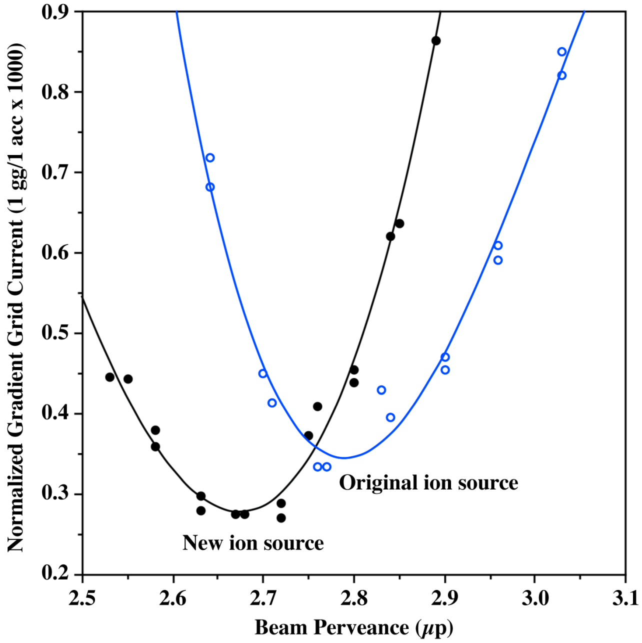


Figure 5. Tuning of ion sources with 75 keV deuterium beams.

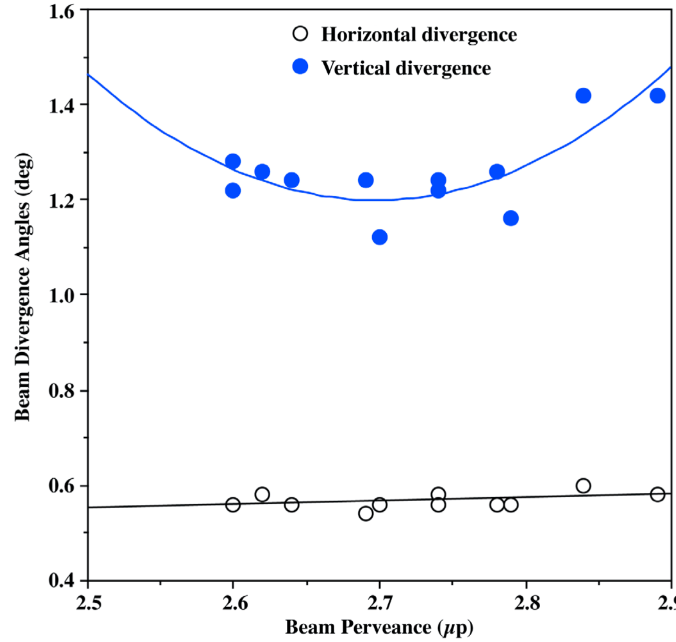


Figure 6. Divergence angles of the new ion source with 75 keV deuterium beams.

## CONCLUSIONS

We have stated the necessities and described the hardware changes to a DIII-D neutral beam ion source. Success in assembling and brazing the plasma grid modules internally at General Atomics provided timely opportunity for undertaking performance test of the new ion source just prior to a long period (more than 1 year) DIII-D facility shutdown for system upgrades and improvements. A five-week problem-free operation of this new ion source, injecting neutral beams into tokamak to support plasma physics experiments, proves that this new ion source is reliable and the decision and efforts making the changes are correct and fruitful. It proves that the useful lifetime of these ion sources for supporting plasma physics and fusion science research can be extended, and new ion sources can be built at less cost with a very small sacrifice in performance.

## ACKNOWLEDGMENT

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