# MECHANICAL DESIGN, CONSTRUCTION AND ALIGNMENT OF THE ISAC RFQ ACCELERATOR AT TRIUMF

G. Stanford, P. Bricault, G. Dutto, R. Laxdal, D. Pearce, R.L. Poirier, R. Roper
TRIUMF, Vancouver, BC, Canada
R. Obidowski, W. Teskey
University of Calgary Geomatics Engineering, Calgary, AB, Canada

*Abstract*

The ISAC RFQ is an 8 meter long, 4-rod split-ring structure operating at 35 MHz in cw mode. The rods are vane-shaped and supported by 19 rings spaced 40 cm apart. The stringent, $\pm$ 0.08 mm, quadrature positioning tolerance of the four rod electrodes over the 8 m length was met by adopting a design philosophy based on manufacturing 19 identical rings and mounting them on precision ground plates which are accurately aligned in the vacuum tank prior to ring installation. The vacuum tank is also unique in that it is square in cross-section and split diagonally to obtain full unobstructed side access to the RFQ modules. A seven ring section of the RFQ has been successfully tested with beam at full power.

## 1 INTRODUCTION

The accelerating system of the ISAC radioactive ion beams facility consists of an RFQ and a post - stripper DTL. Ion beams with $A/q \leq 30$, from the on line mass separator will be accelerated from 2 keV/u to 150 keV/u through the RFQ and then to an energy up to 1.5 MeV/u through the DTL structure. The reference design[1] for the RFQ is a four rod split ring structure operating cw at 35 MHz. The RFQ accelerator section is 8 meters long and is designed in 40 cm long modules with a peak potential between the electrodes of 74 kV. Full power tests on a single module[2] and on a three module assembly[3] enabled us to complete the basic electrical and mechanical design for the RFQ accelerator. The alignment philosophy was based on manufacturing 19 identical rings and mounting them on precision ground platens which are accurately aligned in the vacuum tank prior to ring installation. The theodolite intersection method was used to align two platen bases in the tank to allow 7 of the 19 rings to be installed in the first section of the vacuum tank. The alignment of the ring assemblies on the platens was accomplished by the same method. Because of the manufacturing procedures and alignment philosophy adopted, when the electrodes were installed on their mounting surfaces they were aligned by definition, assuming that the fabrication tolerances were met.

## 2 VACUUM TANK

The vacuum tank for the RFQ accelerator is square in cross section (approx. 1 m x 1 m) and 8 m long. It is welded in mild steel and made in two pieces, a base and a lid, with a diagonal split line (Fig. 1) sealed with an ‘O’ ring. The intent is to provide a very rigid base and heavy back wall on which to mount the turbo pumps, diagnostics, gauges and rf coupling loop; leaving the lid a lighter structure easily removable for access. The diagonal split line provides exceptional accessibility. Cooling water manifolds run along the front floor of the tank fed by penetrations in the tank floor. The inside of the tank is completely cyanide bath copper plated. This was accomplished by using each half of the tank as its own bath vessel – tipped 45°. All the mounting pads on the floor are machined in one pass to ensure they are co-planar. The tank base is mounted on a 9 m x 1.5 m x 0.5 m concrete pad with 22 imbedded studs to match the 7 mounting flanges on the tank base. In order to avoid distortion, the tank is set down on epoxy grout which is allowed to set before the nuts are torqued. After final adjustment no movement of the tank base was observed when the lid was bolted down or when the tank was evacuated. Each half of the tank has forty-two 500 W heaters uniformly installed, covered with a glass fiber blanket, for bake out. A tank temperature of 60°C is reached in less than 2 hours creating a longitu-

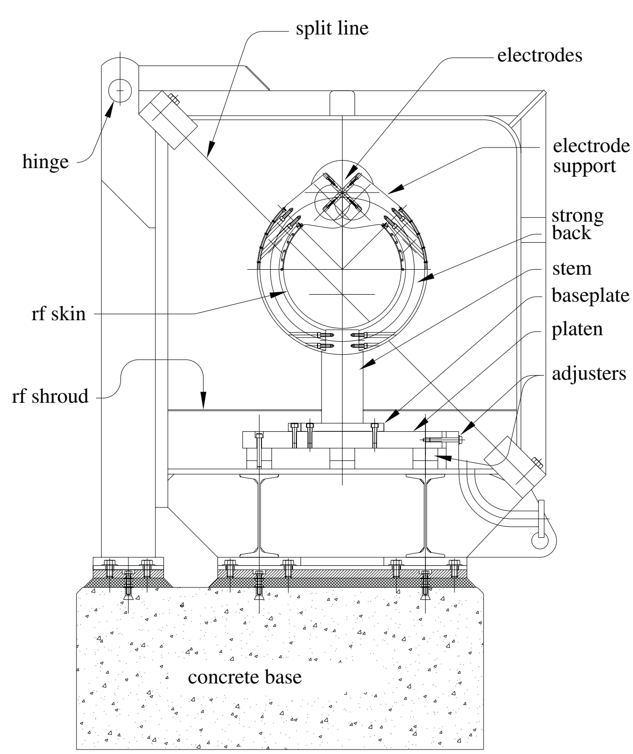


Figure 1: End view of RFQ tank assembly.

dinal growth of $\sim$ 2.0 mm. The elasticity of the mounting system copes with this and growth returns to zero at operating temperature.

## 3 ACCELERATOR COMPONENTS

### 3.1 Design Considerations

Each ring is identical and consists of a base, a stem, a split strong back, two electrode supports and an rf skin (Fig. 1). To achieve thermal stability all rf surfaces are water cooled (except for the outer rf skin). This is done by using two separate water circuits. Circuit 1 supplies cooling water from the inlet manifold to a tube array soldered on the inside of the inner rf skin; from there the water enters a circuit drilled into the electrode support (Fig. 2) and then returns to the outer manifold. Circuit 2 transports water from the inlet manifold to the electrode supports through the electrodes to the adjacent ring. Hence, with a 3-ring platen, number 2-ring supplies water to the 4 electrodes, and number 1 and 3 rings receive and return the water. The rf skin encloses the strong back but is attached only where it meets the electrode supports, thus allowing for thermal growth of the skin without loading the structure and causing electrode misalignment. Prototype tests indicate a very small movement during voltage ramp-up but this returns to zero at steady state. Tests on the seven rings showed no movement at all.

As mentioned the philosophy of mechanical positioning, or alignment of the rings, in order to control the accuracy of the electrodes around a true datum line in space (i.e., beam centerline), is to make each ring identical such that when sitting in a jig on its baseplate the electrode mounting pads are within 25 $\mu$m, of true position. In the tank there are 6 platens – the first supports 4 rings, and the remaining five 3 rings each. Each platen consists of a special steel 63.5 mm thick with an offset longitudinal rail bolted and doweled in place. The platen and rail are accurately ground in one set up, thus providing accurate datums for mounting and locating the ring bases (the flatness tolerances, i.e., $< 12$ $\mu$m). The platens have 5 adjustable mounting points - 3 vertical and 2 lateral. Each platen is adjusted in the tank using special targets for each platen and aligned by the theodolite intersection procedure which is covered in a later section. Once the platens are aligned they are locked in position and are ready for installation of the rings.

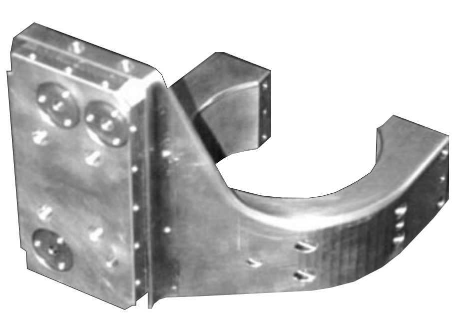

Figure 2: Electrode support showing holes drilled for water cooling circuits.

### 3.2 Fabrication Considerations

In order to achieve the manufacture of identical rings a philosophy of fabrication and assembly had to be decided upon. The key to this is that the mounting surface on which the vane shaped electrodes are mounted are machined as the last major operation. In order to achieve this with such an awkward shape it was decided to use Electrical Discharge Machining (EDM) and employ a master fixture that would engage datum features on the ring base (the same features that would eventually engage the datums on the platen) and accurately hold the ring in the EDM machine for final machining, thus ensuring that all rings are machined in an identical set up. This master fixture also had provision for addition of inspection tooling to check the result. The same fixture was also used to manufacture special targets previously mentioned which are used to align the platens. Finally, each ring is inspected by an independent organization using a coordinate measuring system. This method of ring manufacture means that individual components can be held to reasonable tolerances with enough machine allowance on the electrode platform to accommodate the accumulated assembly tolerances. Prior to EDM machining at final assembly, all components are doweled together and cleaned.

The electrode support is also of some complexity due to the cooling circuits drilled within the shape of this component (see Fig. 2). This is a fully NC machined component produced to a better than 0.80 $\mu$m surface finish in chromium copper (tellurium copper was chosen due to a higher machinability and conductivity rating but pieces of this size are unavailable).

The only other components that require special mention are the electrodes and the rf skin. The electrodes are $\sim$ 13 mm x 38 mm x 120 cm long (except the first two sets which are 80 cm long) and made from tellurium copper for improved machinability and good conductivity. The rods are rough machined, gun drilled for water cooling channels and straightened by the supplier. The cooling holes are plugged at either end with silver soldered plugs. They are then finally machined and profile cut on an NC machine to an overall tolerance of $\sim$ 25 $\mu$m. Both the electrode and electrode support quality and accuracy met or exceeded our expectations.

The rf skin is made from 2.2 mm thick C110 copper and the u-shaped ring was created by spinning over a mandrel in two pieces that were later brazed together. Mounting frames and flanges are soldered and finished machined and the cooling array is then soldered in position.

### 3.3 *Assembly*

Rings were assembled in a semi-clean room environment. The base, stem and strong back and electrode supports were bolted together and aligned in a fixture. These components were then drilled and reamed to allow repeatability during the cleaning and subsequent disassembly in order to fit the rf skin. Once the ring was completely assembled it was shipped to the EDM shop in a special protective container. Handling was a major issue due to the awkward shape, high centre of gravity, and fragility of the rings, hence several handling devices were employed to avoid accidents.

After final EDM machining and inspection the rings were cleaned and installed onto the previously aligned platens and the accuracy of their placement in situ was measured, the results of which are discussed in the next section.

## 4 ALIGNMENT OF PLATENS AND RINGS

Alignment of the first 2 platens was done as a two step process involving a direct on beam axis sighting with an alignment telescope to position the platens, and confirmation of the position using a three dimensional theodolite intersection technique. Four alignment monuments with targets on the beam axis for direct position and off the beam axis to eliminate rotation about the beam axis were manufactured in the ring assembly jig using EDM. These monuments which simulated the rings were placed on the upstream and downstream ends of both platens. The platens were then adjusted so that the monument targets were on beam axis defined by a line of sight telescope with a resolving power of 3.4 arc sec (0.08 mm) and offset micrometer resolution of 0.001".

The three dimensional theodolite technique involves locating two theodolites within a known grid then measuring the angles to monument targets to compute their coordinates. Two 1 sec electronic theodolites (KERN E2) and their in-house software, SIMS (SLAC industrial measurements system), were used to process the data. Simulations using a grid of five fixed points and two independent measurements of the targets with both theodolites indicated measurement accuracy of 0.04 mm in the vertical off axis and on beam axis directions and 0.075 mm in the horizontal off axis direction. Physical constraints that required the theodolites and the grid to be only along one side of the RFQ meant that the horizontal off axis measurement are less accurate because they are along the theodolite sight line.

The grid was established by measuring angles to 17 points with both theodolites and the distance between two of the points which was defined by an invar scale with a tolerance of ±0.013 mm. All measurements were done twice to improve the accuracy. Five points in the concrete base beneath the RFQ were used to establish the fixed points for the grid. The alignment of the platens was then confirmed by theodolite intersection of the alignment monuments to be on a straight line within 0.010 ± 0.025 mm vertically and within 0.080 ± 0.100 mm horizontally. Following this measurement the seven rings were installed on the platens and a datum face on one side of each ring was measured with the theodolites. The relative aligment of the rings shown in Fig. 3 shows that the rings were aligned to a straight line within 0.060 ± 0.045 mm horizontally and 0.040 ± 0.010 mm vertically which is well within the strident alignment requirement of ±0.080 mm. The remaining 12 rings will be aligned by extending the grid to the adjacent platen to be aligned and then aligning the platen to the line defined by the previously aligned platens. This process will be repeated as the grid is extended to the next platen to be aligned. Each platen will be aligned to the new straight line.

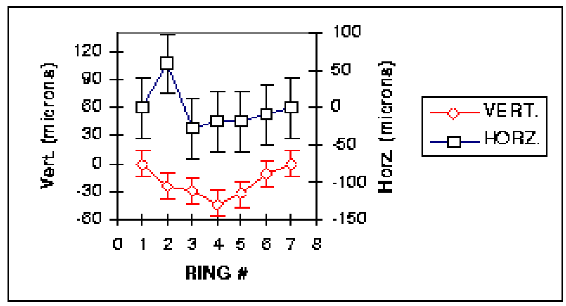


Figure 3: Relative alignment of RFQ rings.

## 5 CONCLUSION

The outstanding results obtained with beam at full power[4] is a positive indication that the mechanical design, construction and alignment philosophy adopted was a success.

## 6 ACKNOWLEDGEMENT


A special thanks to Bhalwinder Warich, Peter Harmer and Tim Emmens for the assembly and installation of the RFQ components, and the beam line/alignment group for their help in the alignment of the tank, platens and rings. TRIUMF would also like to thank the alignment group at SLAC for the loan of the two theodilites and their in-house software.


## 7 REFERENCES


[1] P.G. Bricault and H.R. Schneider, "Simulation of the TRIUMF Split Ring 4-Rod RFQ with MAFIA", Proc. 1995 Particle Accelerator Conf. and Int. Conf. on High-Energy Accelerators, 1125 (1995).

[2] R.L. Poirier, P.J. Bricault, K. Jensen and A.K. Mitra, "The RFQ Prototype for the Radioactive Ion Beams Facility at TRIUMF", Proc. XVIII LINAC Conference, CERN, 405 (1996).

[3] R.L. Poirier, P. Bricault, G. Dutto, K. Fong, K. Jensen, R. Laxdal, A.K. Mitra, and G. Stanford, "Construction Criteria and Prototyping for the ISAC RFQ Accelerator at TRIUMF", Proc. 1997 Particle Accelerator Conference.

[4] R. Laxdal, "First Beam Tests with the ISAC RFQ", this conference.