ISBN: 978-3-95450-191-5 doi:10.18429/JACoW-SRF2017-TUPB063

FABRICATION OF A SRF DEFLECTING CAVITY FOR THE ARIEL -LINAC

Douglas W. Storey†,1,2, Robert E. Laxdal2, Ben Matheson2, Norman Muller2
1University of Victoria, Victoria, Canada
2TRIUMF, Vancouver, Canada

Abstract

A superconducting RF deflecting cavity has been designed and is being fabricated at TRIUMF to allow simultaneous beam delivery to both rare isotope production and an energy recovery linac. The 650 MHz cavity will operate in a TE-like mode in CW. The design has been optimised for high shunt impedance and minimal longitudinal footprint, reaching roughly 50% higher shunt impedance with 50% less length than comparable non-TM mode cavity geometries. Due to low power dissipation at 4K at the maximum required deflecting voltage of 0.6 MV, low cost manufacturing techniques have been employed in the construction of the cavity. These include the use of reactor grade Niobium and TIG welding in an inert atmosphere. Development of the manufacturing processes will be presented along with the status of fabrication.

INTRODUCTION

The ARIEL electron linac (e-Linac) is a 0.3 MW continuous wave (CW) accelerator, extensible to 0.5 MW. It will provide up to 10 mA of 30-50 MeV electron beam to TRIUMF's new ARIEL facility to drive the production of rare isotopes [1]. Acceleration is provided by three to five nine-cell TESLA style 1.3 GHz SRF cavities, each providing 10 MV/m accelerating gradient. An upgrade path is planned that would add a recirculation loop to the e-Linac that would allow the electron beam to make a second pass through the accelerating cavities. This could be operated either as a recirculating linac – doubling the electron energy through a second accelerating pass, or as an Energy Recovery Linac (ERL) – decelerating the electrons on the second pass. Operation in ERL mode would provide beam to an infrared or THz band Free Electron Laser in the back leg of the loop.

Rare isotope production is performed using the CW beam with 650 MHz bunch spacing, populating every second RF bucket of the 1.3 GHz accelerating fields. This allows for simultaneous operation of the ERL/FEL by populating the in-between buckets with bunches bound for the ERL loop. RF separation of the bunches is then required after the first pass of the accelerating cavities to direct the bunches bound for either ARIEL or the ERL down the appropriate beamline.

A 650 MHz deflecting mode cavity has been designed to provide opposite transverse momentum to adjacent bunches to initiate their separation. To achieve the required deflection of several mrad, the nominal deflecting voltage of the cavity is 0.3 MV, with up to 0.6 MV being considered. The design of the cavity is based off the RF Dipole geometry developed for the LHC Hi-Lumi upgrade crab cavities [2]. The geometry was optimized for higher shunt impedance, resulting in a so-called "Post-and-Ridge" geometry (Fig. 1), where undercuts to the ridge decrease the on-axis magnetic field component which opposes the deflection imparted by the electric field. This change increases the peak electric and magnetic fields from the RF Dipole design. This however is not a concern in this application as relatively low deflecting voltages are required. The RF performance parameters are listed in Table 1.

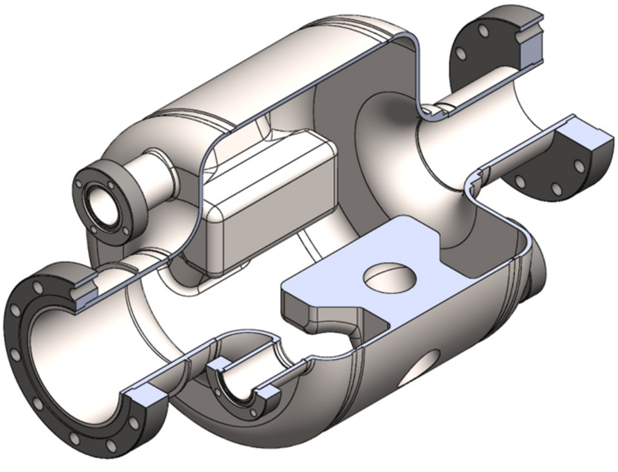

Figure 1: The cavity geometry showing the modified ridge shape. The "undercuts" allow the magnetic field to circulate around the ridges, decreasing the on axis magnetic field component.

Table 1: Cavity Performance Parameters

Parameter	Value	Unit
Resonant frequency	650	MHz
Inner Diameter	204	mm
Inner Length	175	mm
Aperture	50	mm
Deflecting voltage	0.3 – 0.6	MV
Shunt impedance, $R_{\perp}/Q$	625	Ω
Geometry Factor	99	Ω
Peak electric field	9.5 – 19	MV/m
Peak magnetic field	12 – 24	mT
RF power dissipation at 4.2 K	0.35 – 1.4	W

The resulting cavity design provides the required deflecting voltage within a compact cavity with high shunt impedance and low RF power dissipation. The cavity will operate at 4.2 K, simplifying the cryomodule design and making use of the liquid helium services supplying the e-Linac accelerating cavities. Additionally, due to the low fields on the cavity walls, non-standard fabrication

---

† dstorey@triumf.ca

techniques were developed in the manufacturing of this cavity, including machining the parts from bulk reactor grade niobium, and TIG welding for all Nb-Nb welds.

FABRICATION TECHNIQUES

Operation at 4.2 K can lead to larger fluctuations in the pressure exerted on the cavity walls due to boiling helium than at 2 K. Experience with TRIUMF's ISAC II cryomodules has shown ~2 mbar fast oscillations in helium pressure. To stabilize the cavity to within 10% of its bandwidth, a goal pressure sensitivity of less than 10 Hz/mbar has been set.

To reach this pressure sensitivity, the ridges have been machined from solid niobium. This is also beneficial in terms of manufacturing as the ridge shape would be difficult to fabricate using standard methods. The remaining cavity walls have a thickness of 3 mm, resulting in a simulated pressure sensitivity of the supported cavity of about 1 Hz/mbar.

The cavity is being fabricated from reactor grade niobium (RRR = 45) to reduce the cost of the large quantity of niobium required to fabricate solid ridges. All parts were machined from three solid blocks, with the beam pipes and RF ports machined from the offcuts from the centre body piece. In Fig. 2, the rough shape of the cavity has been cut by wire Electric Discharge Machining (EDM), and in Fig. 3, the final shaping has been completed by CNC machining.

Figure 2: The niobium pieces after EDM. Clockwise from top left: The centre body piece, the offcuts, and the end cap piece with offcut.

Figure 3: Clockwise from top left: the fully machined centre body, a beam pipe and RF tubes, end cap, and the welded RF port assemblies.

RF simulations with thermal feedback have been performed using ANSYS, showing no significant temperature rise of the RF surfaces, and good stability to normal conducting defects up to 100 µm diameter at 0.6 MV deflecting voltage. Cooling channels machined into the ridges will increase the cooling efficiency by allowing the liquid helium closer to the ridge faces.

TIG WELDING

The cavity welds are all located in low field regions, seeing peak magnetic fields of only 8 mT at the maximum required deflecting voltage. Due to the low risk locations of the cavity welds, a TIG welding technique has been developed for fabricating this cavity which builds upon previous coupon studies performed at MSU [3].

TIG welds are performed at atmospheric pressure rather than under vacuum. To avoid degradation of the welded region, the welds are performed in a high purity argon environment which does not react with niobium. This is achieved by welding inside a glove box with the welded region purged directly with argon.

To develop this method, weld studies were performed by welding together strips of niobium, 2 mm thick by 12 mm wide, of both RRR and reactor grade niobium under different oxygen concentrations. The oxygen concentration in the glove box was continuously monitored during welding by a GE O2X1 oxygen transmitter sensor.

For the initial purge of the glove box, a lower purity argon (4.8) was used with the final purge using grade 5.0 ultra-high purity argon. The chamber was found to reach ~50 ppm oxygen within about 2 hours, and <10ppm within another 1-2 hours. After welding, argon was purged directly onto both sides of the weld for 4 minutes while the coupons cooled. The welded samples were removed from the glove box only after completely cooled.

The RRR of the welded region was measured by machining a 5 mm strip from the weld coupons containing the weld. The RRR was measured using a 4-wire resistance measurement at room temperature and at ~9.5 K, or immediately above the superconducting transition, yielding a RRR value defined here as:

$$RRR = \frac{R_{300K}}{R_{9.5K}} = \frac{V_{300K}}{V_{9.5K}} \tag{1}$$

In Fig. 4, the results of the relative RRR measured for welds in different ambient oxygen concentrations are shown. With an oxygen concentration of less than 10 ppm in the glove box, the reduction in RRR of the RRR grade Nb was limited to 20-25% while the degradation for reactor grade Nb was even less, with the RRR dropping by only ~10%, from 45 to 40 post-weld.

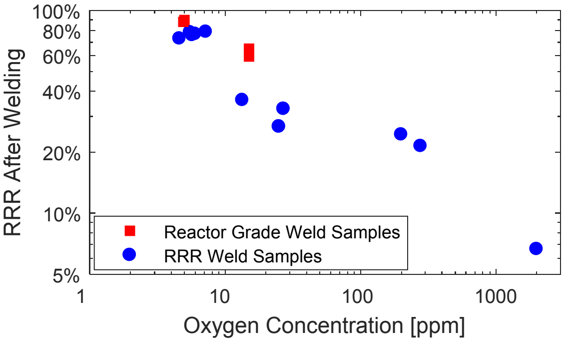

Figure 4: The relative RRR measured after TIG welds performed in the glove box with different ambient oxygen concentrations, compared to the pre-weld RRR.

These results show significantly less reduction in RRR under the same oxygen concentration than previously reported in [3]. This can possibly be explained by the fact that the oxygen concentrations at the welding region are lower than are being measured by the sensor. The welded area is purged directly with 5.0 argon, with a specified concentration of oxygen of < 0.5 ppm, whereas the concentration measurement is being made at the top corner of the weld chamber, far from where the weld takes place. The cavity welds will be performed in the glove box with less than 10 ppm oxygen and purging both upper and lower surfaces with argon.

The beam pipe and RF port flanges are all machined from Grade 5 Titanium and have been welded to the niobium tubes using a small electron beam welder. A titanium jacket has been designed that will be welded to the beam pipes and the RF port flanges.

STATUS OF FABRICATION

A copper prototype has been fabricated to test the fabrication procedures, tuning procedure, and to allow low power field measurements of the cavity. Bead pull measurements of the operating mode and higher order modes (HOMs) show good agreement to the field profiles simulated using HFSS for all the modes measured up to 3 GHz. Additionally, the frequencies of all the simulated HOMs were measured with a greatest deviation of ~0.2% and no missing or extra modes were found.

Fabrication of the niobium cavity has commenced and all machining of all components is complete. Welding of the cavity is being completed in stages to reach the goal room temperature frequency of the cavity of 649.06 MHz. The Nb to Ti welds on the beam pipes and RF tubes to flanges have been completed by EBW.

The next step is welding the tubes onto the end caps to complete the end cap assemblies. These TIG welds will be performed from the RF surface side and need not be full penetration. Stitch welding from the back side will provide additional support. A frequency measurement will be competed at this point to determine how much material to trim from the centre body piece. One side of the centre body will be trimmed to make up half the measured frequency error.

The centre body will be welded to one end cap, on the trimmed side. This TIG weld will performed from the outside surface of the cavity, requiring full penetration to achieve a good RF surface. The material has been reduced to 2 mm at the weld location and an interlocking weld prep machined into both sides of the weld to aid in alignment. Before the final weld is done, the remaining side of the centre body will be trimmed, based on another frequency measurement taking into consideration the weld shrinkage observed from the previous weld.

Frequency measurements are performed using a jig designed to hold the individual pieces together without deforming the cavity shape. Figure 5 shows the first RF stack up measurement performed before any welding or trimming was completed, yielding a frequency of 637.3 MHz.

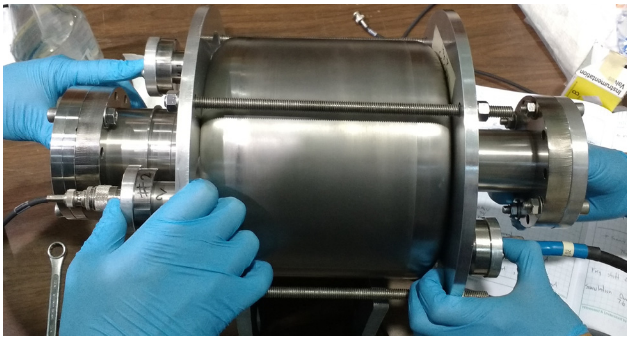

Figure 5: Initial RF stack up of un-welded components.

CONCLUSION

The fabrication of the Nb cavity has commenced using bulk reactor grade niobium. A TIG welding procedure has been developed and will be applied to the cavity welds in a glove box with less than 10 ppm oxygen. Welding of the cavity is ongoing, with a cold test of the completed cavity commencing shortly.

REFERENCES

[1] S.R. Koscielniak *et al.*, “TRIUMF ARIEL e-Linac ready for 30 MeV”, in *Proc. IPAC’17*, Copenhagen, Denmark, May 2017, paper TUPAB022, pp. 1361-1364.

[2] S.U. De Silva and J. R. Delayen, Phys. Rev. ST Accel. Beams, vol. 16, p. 082001, 2013.

[3] C. Compton *et al.*, “Studies of alternative techniques for niobium cavity fabrication”, in *Proc. SRF’07*, Beijing, China, Oct. 2007, paper WEP01, pp. 429-433.