FEASIBILITY OF AN RF DIPOLE CAVITY FOR THE ARIEL E-LINAC SRF SEPARATOR*

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Abstract

A megawatt class CW e-linac is being designed and constructed at TRIUMF with the main goal of producing neutron rich isotopes for TRIUMF's Rare Isotope Beam (RIB) program. A possible extension of the beam-line will allow recirculation of the beam for an Energy Recovery Linac (ERL) to operate in tandem with the RIB user program. A superconducting cavity with RF dipole geometry is being considered for separation of the ERL and RIB beams at the end of the linac to provide simultaneous beams to both the ERL and RIB programs. This contribution describes optimization studies performed on the RF dipole design to determine if this geometry will meet the requirements of the ARIEL e-linac. The resulting 650 MHz structure has compact cavity dimensions, low peak fields, and high transverse shunt impedance. Due to the large aperture beam-line and stringent requirement on preserving beam quality, extensive focus has been placed on transverse uniformity of the deflecting fields.

INTRODUCTION

A future extension to the ARIEL e-linac [1] will be the addition of a recirculation path to the beam-line for an Energy Recovery Linac (ERL), the driver for an Infrared or THz Free Electron Laser (FEL). The ERL electron beam will be interleaved with the single-pass beam bound for Rare Isotope Beam (RIB) production in the ARIEL facilities, allowing for simultaneous beam delivery to both FEL and RIB users.

Bunches of electrons bound for either the ERL or RIB will occupy alternating buckets of the 1.3 GHz accelerating RF. The separation of the beams will take place at the exit of the main linac. The basis of this separation scheme is introduced in [2], which describes the layout and deflections required by each element in the separation complex: an RF separator, steering dipole, defocusing quadrupole, and septum magnet. This scheme is driven by the rigid space constraints that require the separation of the beams within a distance of about 3 m.

After energy recovery in its second pass through the accelerating modules, the recirculated ERL beam will reach the RF separator with beam energy of approximately 5 to 10 MeV, and 90° out of phase with the deflecting phase of the cavity. It will therefore pass mostly unaffected through the separator cavity and receive a sharp deflection in the dipole magnet and be directed down a short beam-line to a beam dump.

The initial separation will take place in an RF separator cavity operating at a frequency of 650 MHz, imparting opposing transverse momentum kicks to the ERL and RIB bound beams and deflecting them by ±4.5 mrad in the horizontal direction. This deflection will be amplified by the quadrupole magnet with the final separation of the beams reaching $\sim$ 35 mm by the time they reach the septum. At this point, the ERL beam will be directed around the recirculation loop and the RIB beam back towards the main linac axis.

Additionally, the layout of the separator section of the linac is compatible with a two pass Recirculating Linac in which the beam is directed around the recirculation loop after its first pass to be accelerated a second time in the main linac before continuing on for RIB production. This mode would not employ the RF separator cavity, but would rely on the static magnetic separation of the beams with different energies in the dipole.

The maximum beam energy at the exit of the main linac will be 66 MeV. This translates to a 0.3 MV transverse momentum kick imparted by the RF separator cavity and transverse deflecting field of $E_\perp = 1.3$ MV/m for a single deflecting cavity.

SRF SEPARATOR CAVITY

The RF dipole deflecting cavity is being considered for use in the ARIEL separator complex. This cavity is compact in size and the transverse deflections are high with low peak electric and magnetic fields. Extensive scaling studies have been performed on this geometry [3], however detailed optimization is required to fully access the suitability of this cavity design for the ARIEL e-linac separator.

The geometry of the RF dipole separator cavity is shown in Fig. 1. The inner ridge length of the cavity will be of order $\beta\lambda/2 = 230$ mm at 650 MHz, and the aperture 50 mm, the same as along the rest of the length of the e-linac.

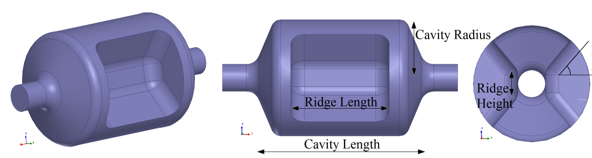

Figure 1: The RF dipole geometry showing the key parameters affecting the cavity performance.

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In the deflecting mode, a transverse electric field is produced between the cavity ridges while the magnetic field circulates around them. The x component of the electric field provides the main contribution to the horizontal deflections while the y component of the magnetic field acts to decrease the deflection, by a relatively small amount. The deflecting mode of this cavity geometry is the lowest order mode of the cavity and the next higher order mode has a frequency far from the fundamental mode.

GEOMETRY STUDIES

The RF Dipole cavity behaviour has been studied using HFSS [4] to determine an optimal separator cavity geometry for the ARIEL separator specifications. The main goals of the optimization were to maximize the transverse shunt impedance while minimizing the peak electric and magnetic fields.

The parameters that have the most significant effect on the cavity behaviour are shown in Fig. 1. These are the height and length of the inner ridge, the angle of the ridge cut-out, and the length and radius of the cavity. For each change to the geometry, the cavity radius was adjusted such that the fundamental frequency of the cavity was held at 650 MHz.

The length of the inner ridge was varied, along with the cavity length, to determine the optimal ridge length. It was found that a ridge length of 0.6 times the cavity length consistently resulted in minimized electric fields, as seen in Fig. 2. The peak magnetic fields followed a similar trend. Increasing the overall cavity length also resulted in lower peak fields, and an increase in the transverse shunt impedance, $R_\perp$. For the remainder of the parameter search, the ridge length was set to 0.6 times the cavity length.

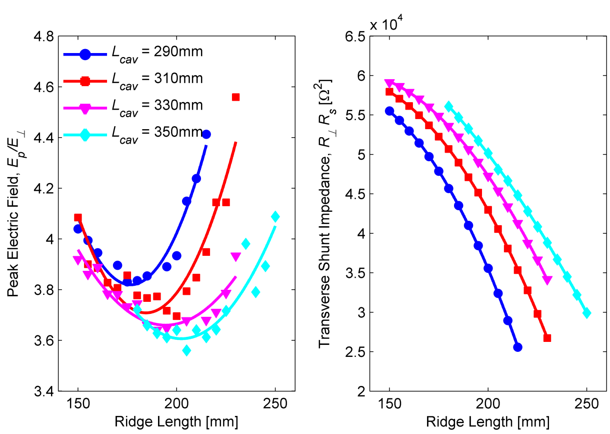

Figure 2: The peak electric fields on the left, and the transverse shunt impedance on the right for varying ridge and cavity lengths. For reference: $\beta\lambda/2 = 230$ mm at 650 MHz.

Next, the height and angle of the ridge were varied simultaneously for different cavity lengths. Again, the outer radius was adjusted to retain a cavity frequency of 650 MHz. The HFSS results show that the peak fields are lowest for larger ridge heights and larger ridge angles, as seen in Fig. 3. In each case, the electric field reaches a minimum value at a cavity length of approximately 380 mm. This corresponds to an inner ridge length of 230mm, precisely the value of $\beta\lambda/2$. The peak magnetic fields show a similar dependency on ridge length and angle.

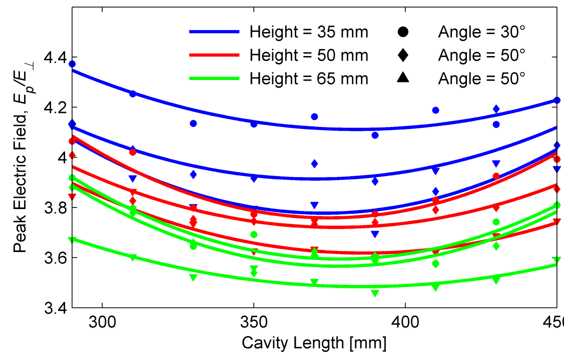

Figure 3: The peak electric fields for varying ridge height and angle and the cavity length. The colour of the line indicates the ridge height and the shape of the data point the angle of the ridge.

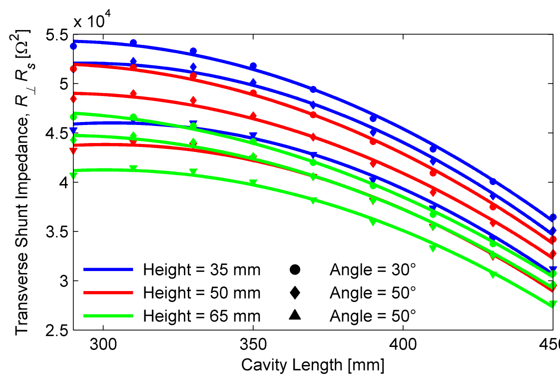

Figure 4: The transverse shunt impedance for varying ridge height and angle and the cavity length.

The transverse shunt impedance, Fig. 4, is seen to decrease with increasing cavity length as well as for larger ridge height and angle. This leads to conflict between the objective to minimize the peak fields while maximizing the shunt impedance.

A compromise of a ridge height of 50 mm and angle of 50° would provide reasonably high transverse shunt impedance while keeping the peak electric and magnetic fields below 5 MV/m and 10 mT for a transverse deflecting voltage of 0.3 MV. These are well below currently accepted upper limits for electric and magnetic fields in SRF cavities. Since the shunt impedance decreases with cavity length, a cavity length of $\sim$ 330 mm provides a compromise between minimizing the peak fields and maximizing the shunt impedance.

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Field Uniformity

Successful operation of an FEL requires a beam with low emittance, and therefore minimal emittance dilution of the ERL beam as it passes through the RF separator. Non-uniformity of the fields across the cavity aperture is one of the main sources of emittance growth.

A larger ridge height and angle results in the most uniform fields within the central portion of the cavity, leading to lower emittance growth. However, as noted in the previous section, a large ridge height and angle would also result in a lower shunt impedance.

Another way to achieve more uniform deflecting fields is to modify the shape of the inner ridge in such a way that forces the uniformity of the fields between the ridges. Giving the inner faces of the ridges a slight curvature allows the bars to come slightly closer together while maintaining the 50 mm diameter aperture, as well as shaping the fields in a more uniform way. This geometry is shown in Fig. 5, along with the cavity geometry with flat inner ridges.

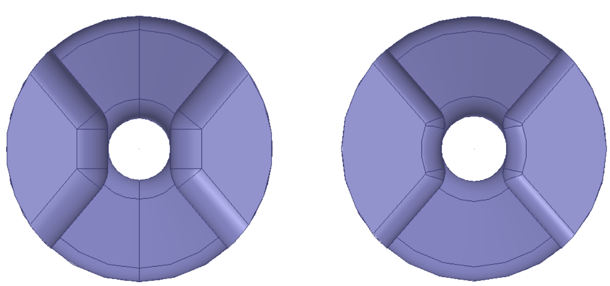

Figure 5: The cross section of the original RF dipole geometry, with flat inner ridges on the left and the modified separator cavity shape on the right, showing the curved faces of the inner ridge.

To quantify the field uniformity, the momentum gain in the x direction relative to the kick received by an on-axis particle was plotted across the aperture of the separator cavity, Fig. 6. The transverse radius within which the relative momentum kick is less than 2% of the on-axis kick strength was found to be 8.5 mm for the flat ridged cavity, compared to 12.5 mm for the curved ridge geometry. The shunt impedances of the two geometries are very similar and the peak electric and magnetic fields are slightly higher for the curved ridge cavity, but are still well below operational limits.

An in depth analysis of the beam dynamics has been performed to access the emittance growth of the ERL and RIB beams passing through the RF separator cavity [5]. It was found that under nominal beam conditions, the flat ridged cavity will contribute to acceptable emittance growth. For beams with larger RMS width or requiring stronger transverse momentum gain, the curved ridge may be useful to limit the emittance growth.

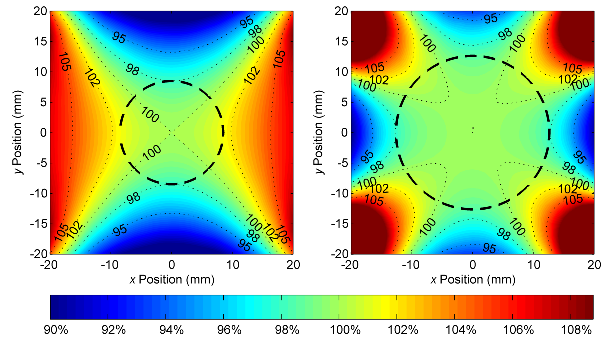

Figure 6: A comparison of the kick-uniformity for the RF dipole with flat ridge geometry on the left, and curved ridges on the right. The dashed circle shows the area in which the momentum kick is within 2% of the on axis kick strength.

CONCLUSION

The RF dipole cavity has been determined to be compatible with the requirements for the ARIEL e-linac RF separator. The main properties of the cavity with flat inner ridges are summarized in Table 1.

Table 1: Properties of the RF Dipole Separator Cavity Optimized for the ARIEL e-linac Requirements

Parameter	Value	Units
Frequency of the deflecting mode	650	MHz
Cavity length	330	mm
Cavity diameter	210	mm
Inner ridge length	198	mm
Transverse deflecting voltage, $V_\perp$	0.30	MV
Transverse deflecting field, $E_\perp$	1.30	MV/m
Geometry Factor, G	117	Ω
Transverse Shunt Impedance, $R_\perp/Q$	411	Ω
Peak electric field, E_p	4.5	MV/m
Peak magnetic field, B_p	7.8	mT

REFERENCES

[1] S. R. Koscielniak, "ARIEL Electron Linac," MOOBA1, NA-PAC'13.

[2] Y. Chao, S.R. Koscielniak, and C. Gong, "RF Separator and Septum Layout Concepts for Simultaneous Beams to RIB and FEL Users at ARIEL," IPAC'11, San Sebastian, Spain, September 2011, WEPC002, p. 1998 (2011).

[3] S.U. De Silva and J.R. Delayen, Phys. Rev. ST Accel. Beams 16 (2013) 012004.

[4] `http://www.ansoft.com`

[5] D.W. Storey, Y. Chao, and L. Merminga, "Beam Dynamics Driven Requirements on the ARIEL e-linac SRF Separator Cavity," THPBA01, NA-PAC'13.

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