RF SEPARATOR AND SEPTUM LAYOUT CONCEPTS FOR SIMULTANEOUS BEAMS TO RIB AND FEL USERS AT ARIEL*

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Abstract

A ½ MW capable CW electron linac is being designed and constructed at TRIUMF in support of the existing Rare Isotope Beam program. In the simplest configuration, the beam makes a single pass through three cryomodules to the RIB production targets. However, after the construction of a recirculation path, beam could make a second pass through two cryomodules with the RF phase advance adjusted to give energy recovery. Here it is proposed to time-interleave two bunch trains, and via an RF separator and septum, to direct one single-pass train to RIB production and the second train through the energy recovery ring that contains an IR FEL. It is also the intention, in single user mode, to use the ring as an energy doubler. This paper describes the RF separation scheme and options for the extraction optics that satisfy the requirements of "simultaneous" beams to two users.

OVERVIEW

A major goal of the Advanced Rare Isotope Laboratory (ARIEL) project at TRIUMF [1] is to deliver 50-75 MeV, 10 mA CW electron beam as a driver for photo-fission of actinide targets to produce rare isotope beams (RIB) for nuclear physics, and $^9Be(\gamma,p)Li^8$ for materials science research. The electron beam is accelerated by an injector cryomodule (ICM), run at 10 MeV for RIB and 5 MeV for ERL mode, and two 20 MeV accelerator cryomodules (ACM) in the main linac before going to the target. A recirculated linac (RLA) scheme is also under consideration, with the beam taken for a second pass through the main linac, bringing the RIB energy reach up to 75 MeV.

Extension in a future phase to energy recovered linac (ERL) as a driver for 4th generation light source is also envisioned. In this scenario a high brightness electron beam is interleaved with the single-pass RIB beam and accelerated in the same linac. This beam is used to drive an IR free electron laser (FEL) in the back leg of the recirculation loop. After recirculation it is decelerated in the linac and dumped. Conceptual layout of the electron linac with recirculation loop is depicted in Figure 1a.

To separate RIB and ERL beams at the exit of the main linac at bunch frequencies of hundreds of MHz, an RF separation scheme is the obvious choice. Separation geometry and optics are dictated by available space, hardware limitations, beam properties and operational requirements. In addition, the solution should be compatible with aforementioned two-pass RLA-RIB application. These will be discussed below.

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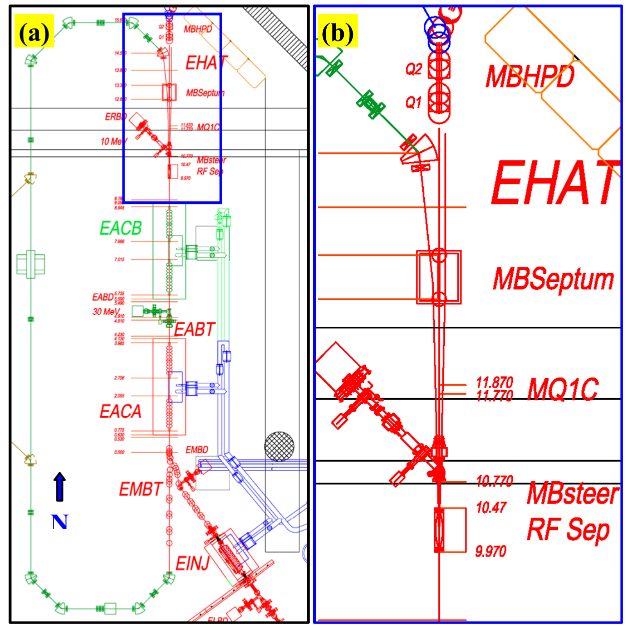

Figure 1: (a). ARIEL Electron Linac and recirculation loop inside E-Hall. (b). RF separation scheme (blue rectangle in (a) magnified).

DESIGN CRITERIA

Floor Space

The RF separation complex is housed in a building designated E-Hall at TRIUMF. It shares space along the north-south axis with the electron gun, cryomodules, recirculation loop, beam dumps, and associated beam line elements and supporting equipments, part of which is shown in Figure 1a. The rigid claim of space by all components limits the maximal allowed distance to about 3 m over which the two beams must be separated enough to clear the septum, and about 1 m to develop further separation to accommodate the arc dipole. This geometrical constraint sets the overall boundary condition for all subsequent design parameters.

RF Separator

With the RIB and ERL beams occupying alternating buckets of the 1.3 GHz main accelerating RF, the RF separator operates at 650 MHz, imparting maximal differential transverse kicks to the two flavours of beams at +90° and -90° of the transverse field. The magnitude of desired kick is determined by, among other factors, the intended beam separation at the septum and available distance between the RF separator and the septum. Given the geometry above and septum clearance implied by typical beam parameters, the kick needed is on the order of several mili-radians. At design beam energy of 50

MeV this translates into transverse momentum of a few 100 keV/C. This kick strength is achieved by existing 499 MHz CEBAF RF separators that routinely induce angular deflections on the order of 100 micro-radians in electron beams up to several GeV in energy. The cavity design [2] has considerably larger transverse shunt impedance and smaller radius than conventional deflecting cavities. The CEBAF system frequency is close enough to the current design to allow inferring from it realistic estimates on power and dimension for our case. A 2-cell configuration, each cell being a ½ wave resonating structure, will be our baseline. Despite indication of the RF separator being capable of even stronger kicks, the interest in limiting disruption to the FEL quality beam does set an upper bound on the kick strength.

Septum Magnet

Different septum design options represent trade-off between competing performance emphases. Chief among these are beam separation, bend angle, field quality, and physical dimension, all with implication on power consumption and cooling requirements. A current sheet septum is adopted as the baseline design, with a "strong" chamber bending (≈5°) the recirculated beam to the first arc dipole (Figure 1), and a "weak" chamber with a smaller bend (<2.5°) to steer the extracted beam back to the linac axis. The bending field in these two chambers must be independently adjustable to accommodate different operation modes and energy ratios.

The sheet of conducting coils between the two beam chambers in typical septum magnets is of thickness 1 cm or less. Field strength however is not sufficiently uniform immediately next to this sheet, especially near septum edges. If one further considers sagitta contribution and beam sizes, the minimal safe separation between beam centers easily becomes more than 2 cm.

Beam Properties

The RF separation system works on two 50 MeV electron beams with total current up to 16 mA. The RIB and ERL beams have typical transverse RMS beam sizes of 1 mm and 0.5 mm respectively. These add a combined 0.75 cm to the beam clearance requirement at the septum if we demand that up to 5σ of the distributions stay inside good field regions. In addition the same septum needs to accommodate the RLA mode of RIB operation with 45 MeV and 75 MeV beams in the two chambers. In this case the additional separation needed is more like 1 cm.

Operation Modes

The RF separation complex enables ERL operation for the FEL, and forms part of the RLA operation for RIB applications. The separation geometry should be established such that both modes of operation can share the same fixed beam channels over reasonable range of energy ratios. The RLA mode relies on static magnetic separation of two beams of disparate energies, but needs to follow exactly the same beam pipes and septum apertures as the ERL mode in order to direct recirculated and extracted beams to their proper destinations.

Energy Recovered Dump and Steering Dipole

The ERL beam will be dumped at 5 MeV after energy recovery. To minimally impact the alignment between the main linac and the RF separation complex, the dump dipole is placed after the RF separator, which has no effect on the energy recovered beam. This dipole needs to have adequate strength for the dumped beam to clear the linac axis and subsequent elements, while keeping the other beam orbits well defined. Secondary steering in the dump line may be used to compensate for minor differential effects due to energy ratio variations.

The dump dipole is also necessary as a steering dipole in the RLA mode to initiate beam separation. It should be placed immediately after the RF separator to closely mimic the ERL separation geometry.

Optics and Additional Components

To enhance beam separation over limited distance, a horizontally defocusing quadrupole is inserted in the optimal location, halfway between the steering dipole and the septum. This relatively strong quadrupole forced the horizontal β in the linac to increase for both passes to create favourable matching conditions into downstream RIB channel or recirculation arc.

The optics inside the separation complex will be off limits to online tuning to avoid arbitrary impact on separation geometry. All optical adjustments will be done in matching sections outside the main linac.

BASELINE LAYOUT & HARDWARE

Design criteria above resulted in an optimized solution for the ARIEL RF separation complex. The proposed baseline layout is depicted in Figure 2, showing 2-beam trajectories in ERL-FEL+RIB and 2-pass RLA-RIB modes. The two quadrupoles are integral to the system in defining trajectory and matched optics. The beam center separation at septum entrance is about 3 cm to provide the safety margin discussed. Sufficient beam clearance (~26 cm) is achieved at the arc dipole. The trajectories in these 2 modes track closely. The ERL dump line, branching off the steering dipole to the same side as the arc at a large angle, is not shown. Table 1 presents the RF separation geometry numerically. The 2-pass RLA geometry is identical after the D-Quad.

Parameters for major components are listed in Table 2. In deriving the RF separator power we assumed a transverse shunt impedance of 250 MΩ/m, a value typical of those used at CEBAF [2]. The EM field code OPERA was used to model the septum. Considerable effort also went into establishing feasibility of water-cooled septum with 0.8-1.0 cm central current sheet dividing the two septum chambers, each 5 cm wide. All prototypes, with length varying from 0.25 m to 1 m, prove capable of delivering requisite B fields over operating energy range while staying within envelope set by water cooling requirements, such as current density, power density, maximum water pressure drop etc. Variation in integrated field over ±5 mm transverse offset is typically below 0.5% in both chambers. Further optimization study is needed when the RF separator and septum are integrated into the beam dynamics model.

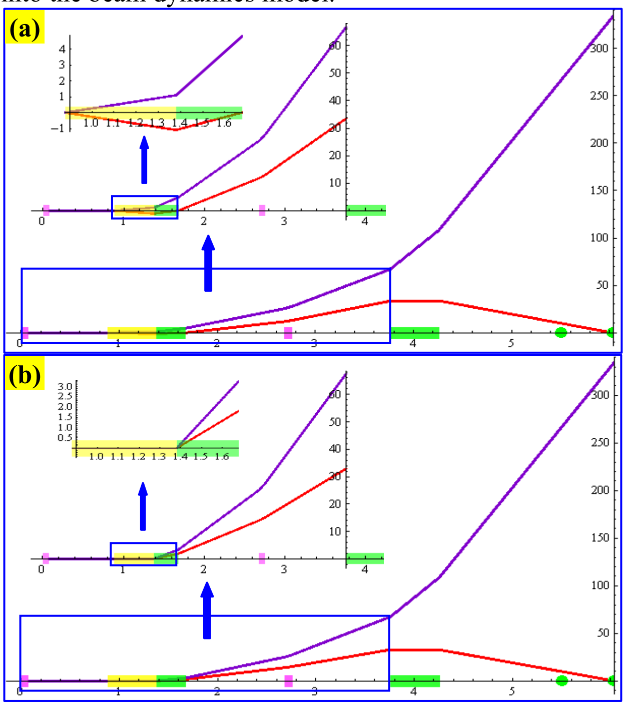

Figure 2: Beam separation geometry in (a) simultaneous ERL-FEL+RIB and (b) 2-pass RLA-RIB modes, showing horizontal offset (mm) vs longitudinal distance (m). Each plot contains 3 layouts of increasing detail, with red/purple line for extracted/recirculated orbit. Coloured elements are, left to right: Magenta: F & D quads; Yellow: RF separator; Green: steering dipole, septum, Locations (circles) of first arc dipole and high power dump dipole.

OPTICS

The RF separation complex is also an integral part of the optical transport from the linac to the RIB target or the FEL. It must also ensure proper transport of 2 simultaneous passes of beam in the RLA mode. The optical solutions of the linac plus the RF separation area for all cases are shown in Figure 3, where the need to form a waist at the defocusing quad is obvious. Matching into downstream sections has been demonstrated.

CONCLUSION

A baseline solution is presented of the RF separation scheme for the TRIUMF AREIL project making possible simultaneous RIB and FEL operations, and higher energy reach for RIB through recirculation. Hardware feasibility studies showed the design is realistic and consistent with proven technology. Refinement will come as a result of integrating all components into the framework of beam dynamics study, especially for high intensity FEL beams.

Table 1: RF Separation Geometry

	Extracted Beam		Recirculated Beam		Separation	
Exit at:	X (mm)	X'(mrad)	X (mm)	X'(mrad)	X (mm)	X'(mrad)
RF Separator	-1.1	-4.4	1.1	4.4	2.2	8.8
Steer. Dipole	0.0	11.8	4.8	20.5	4.8	8.8
D-Quad	13.1	20.4	27.8	39.0	14.7	18.6
Septum Entry	33.5	20.4	66.8	39.0	33.3	18.6
Septum Exit	33.8	-19.1	108.1	126.3	74.3	145.4
Arc Dipole	9.9	-19.1	266.9	126.3	257.0	145.4
Dump Dipole	0.0	-19.1				

Table 2: Hardware Parameters

Operation Mode & Energy		ERL 50/50 MeV	RLA 45/75 MeV
RF Separator L=50 cm (≈2× λ/2)			
	Deflection angle	±4.4 mrad	0
	Power	387 W	0
Steering Dipole L=30 cm			
	Bend angle	+0.93°	+1.25°/+0.69°
	B Field	≈92 G	≈111 G
Defocusing Quad L=10 cm			
	K·dL	1.2 kG	1.08 kG
Septum Magnet L=50 cm			
	Bend angle	+5.0°/-2.26°	+4.94°/-2.17°
	B Field	290/132 G	267/200 G
	Power	270W/57W	220W/130W

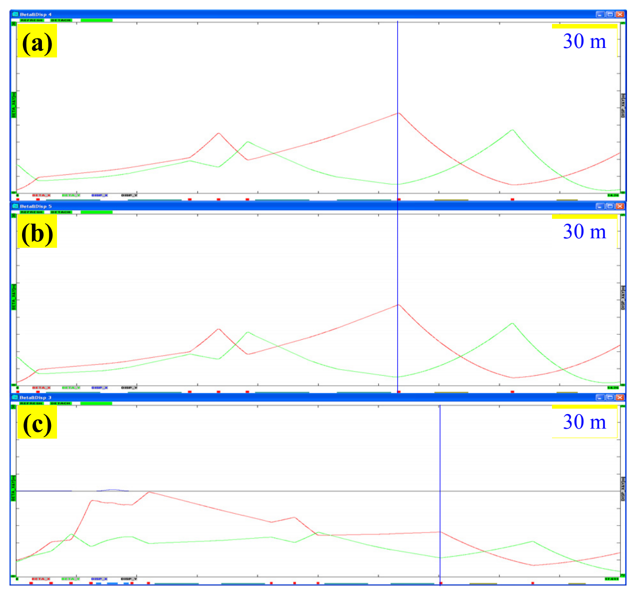

Figure 3: β_X (red) and β_Y (green) for (a): Pass 1 ERL, (b): Pass 1 RLA and (c): Pass 2 RLA beams through entire linac including separation complex (after blue lines).

ACKNOWLEDGMENT

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REFERENCES

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[2] A. Krycuk et al. "Construction of the CEBAF RF Separator", 1993 Particle Accelerator Conference, and reference therein.