BEAM DYNAMICS OPTIMIZATION OF THE TRIUMF ELINAC INJECTOR

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Abstract

TRIUMF proposes a half megawatt electron linac (elinac) for radioactive ion beam production via photofission. The e-linac is to operate CW using 1.3 GHz superconducting (SC) technology. The accelerator layout consists of a 100 keV thermionic gun, a normal conducting buncher, an injector module, and main linac modules accelerating to a final energy of 50 MeV. The design beam current is 10 mA. The beam dynamics of the injector, where electrons make the transition to the fully relativistic state, has been identified as the most critical part of the design and is the subject of simulations (starting at the gun cathode) using realistic EM fields in ASTRA, PARMELA and TRACK. CW operation demands the novel choice of adopting an SC capture section. A preliminary design of the injector foresees a capture section composed either of two independent or two coupled single-cell cavities, $\beta\leq1$, that increase the energy to about 500 keV, followed by one nine-cell cavity that boosts the energy up to 10 MeV. The design parameters are subjected to a global optimization program. In this paper we present results from the beam dynamics study as well as details and final outcome of the optimization process.

INTRODUCTION

TRIUMF is proposing to expand the facility for production and post acceleration of radioactive ion beams (RIBs) with a new Advance Rare IsotopE Laboratory (ARIEL).

ARIEL (see Fig. 1) is an extension of the existing ISAC facility [1]. The new facility includes a driver, two target stations, two mass separators and a post acceleration section. The expansion is planned in stages.

The first step is the design and fabrication of the new driver, a superconducting electron linac (elinac). The new target stations can be fed either with electrons or with protons from a new cyclotron extraction line [3].

The electrons produce radioactive isotopes via photofission [2]. This type of production is complementary to the production from proton bombardment in that the range of RIB species are peaked more on the neutron rich side with less isobaric contamination.

In order to produce RIBs a relatively low charge per bunch (15.4 pC, low brightness) is requested. The beam dynamics studies consider also a higher charge per bunch (100 pC, high brightness) in order to accommodate a possible future development of the linac working in energy recovery mode (ERL) for light production.

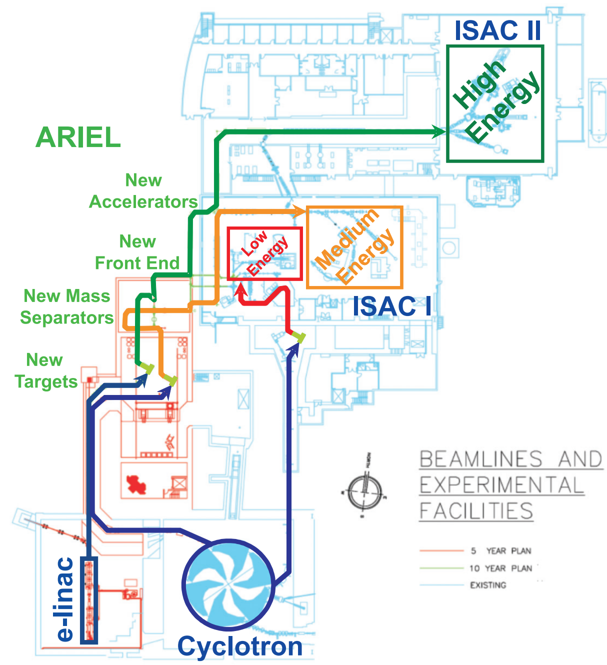

Figure 1: Overview of the present ISAC facility at TRIUMF and the future ARIEL expansion. The new elinac is a complementary driver to the existing cyclotron.

THE ELINAC LAYOUT

The elinac uses superconducting technology. TRIUMF has already an operating heavy ion superconducting linac. The cavities considered for the design are the elliptical single cell and nine cell ILC type.

The general layout of the machine (see Fig. 2) is composed of an injector cryomodule (ICM) followed by two accelerating cryomodules. The ICM is the most critical part where the electrons are accelerated from 100 keV to 10 MeV. The injector module has a capture section consisting of two single cells and an injector cavity to match the beam to the β=1 section downstream.

The electron beam is produced with a modified thermionic gun. The beam is modulated out of the gun by means of an RF biased grid. The beam is bunched using a normal conducting buncher before being injected into the ICM.

The transverse focus from the gun to the injector cryomodule will be provided using quadrupoles or solenoids. Both options have been included in the simulations.

Table 1 includes the main parameters of the linac.

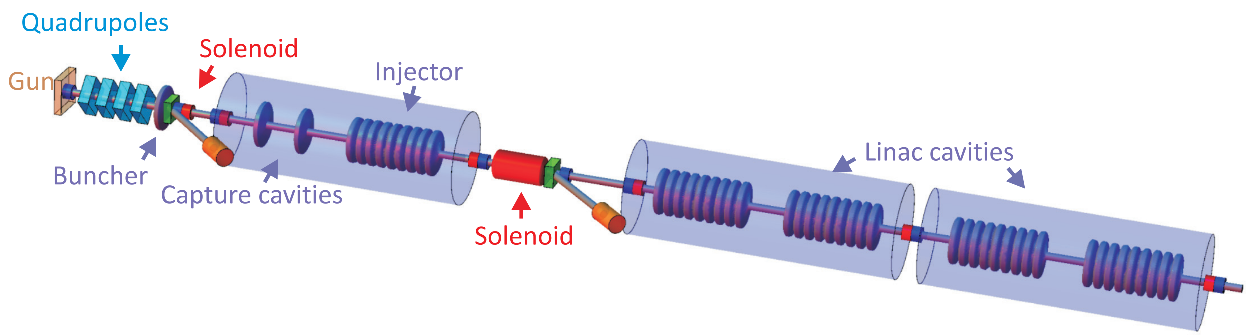

Figure 2: Possible layout of the TRIUMF elinac. Other options include the use of solenoids instead of quadrupoles.

Table 1: Main Parameters of the TRIUMF elinac.

Parameter	Value
Gun modulation	650 MHz
Buncher frequency	650 MHz
Linac frequency	1.3 GHz
Q_{bunch} low brightness	15.4 pC
Q_{bunch} high brightness	100 pC
Initial transverse ε_{4rms}	30 π mm·mrad
Initial longitudinal ε_{4rms}	0.085 π keV/u·ns
Initial ΔE	$\pm$1 keV
Initial $\Delta\phi$	$\pm$40 deg at 1.3 GHz
E_{gun} low brightness	100 keV
E_{gun} high brightness	200-300 keV
E_{ICM}	$\sim$ 10 MeV
E_{final}	$\sim$ 50 MeV

BEAM DYNAMICS STUDIES

The beam dynamics studies focus on the injector cryomodule. Three different codes are used to cross check the simulations: ASTRA [4], PARMELA [5] and TRACK [6]. In particular the new code TRACK is bench-marked against the other two [7].

The space charge effect is significant also in the low brightness case. Space charge forces are included in all calculations.

The capture section is the most critical part of the ICM. Two general configurations of this section are considered: the first has two independently phased single cell cavities, the second has a single two-cell cavity. The first configuration has less tail formation in the longitudinal phase space.

The two single cells option is simulated for cavities of different design beta. The first practical solution is to use two β=1. In this case the electrons entering at $\beta\simeq$0.55 experience a negative decelerating field inside the cavity. This seems to impact more the transverse emittance than the longitudinal. A better match can be achieved by reducing the design beta to β=0.7. The electrons still experience a decelerating field but the impact in the transverse emittance growth is less important.

Besides the design beta, the operating gradient and the synchronous phase of the cavities are the main parameters used to find the optimum solutions. The objective is to avoid tail formation in the longitudinal phase space as well as to minimize the transverse and longitudinal emittance growth. Another parameter we consider to reach this goal is the bunch length at the entrance of the injector cryomodule. This parameter is modified by varying the distance between the buncher and the ICM.

Some configurations of the ICM capture section are listed in the Table 2. Downstream of each capture section configuration, a nine cell cavity (the injector) operating at 10 MV/m and 0 degree synchronous phase completes the ICM RF elements. All Table 2 cases are simulated in PARMELA. The two linac cryomodules are also included in the simulations. Each of them contains two nine cell operating at 10 MV/m and 0 degree synchronous phase. These simulation outputs in terms of transverse and longitudinal emittance growth are represented in Fig. 3.

Table 2: Examples of ICM Capture Section Configurations Simulated in PARMELA.

Solution	Bunch length (deg)	Capture1		Capture2	
		β	Gradient MV/m	β	Gradient MV/m
1	10	1	6	1	10
2	10	1	6	1	11
3	10	1	6	1	12
4	10	0.7	7	1	14
5	10	0.7	3.5	1	10
6	10	0.7	7	0.7	14

BEAM DYNAMICS OPTIMIZATIONS

The design and operating parameters are also obtained using a genetic optimization program, originally developed for accelerator design optimization at Cornell University [8], with extended features developed for the current elinac design. A typical optimization program involves the selected evolution of control parameters toward progressively

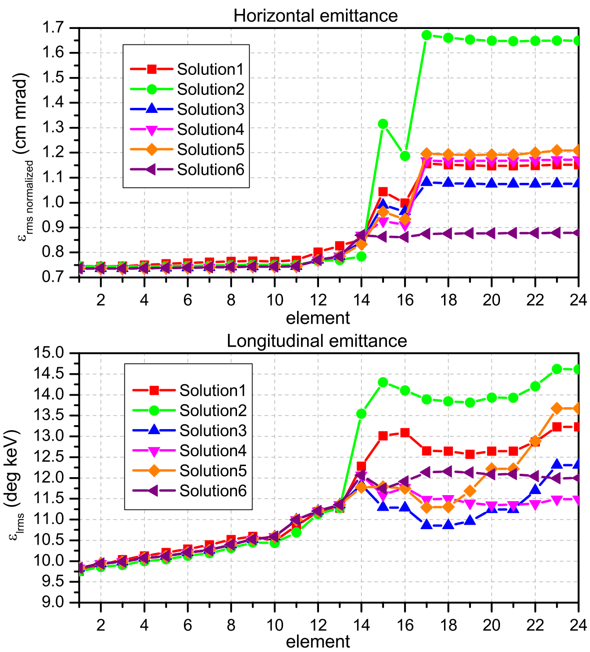

Figure 3: Transverse (top) and longitudinal (bottom) emittance growth for different configurations (see table 2) as function of the linac element: buncher=10, capture1=14, capture2=15, injector=17 and cavity1-4=19-20-22-23

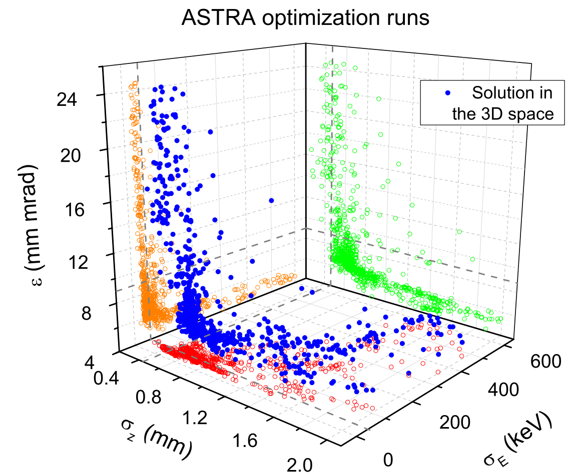

Figure 4: The 3D graph shows a population of ASTRA optimized solutions. The dotted lines on the three projection planes represent the PARMELA solution six.

improved design objectives, such as beam parameters and performance measures. A genetic algorithm is superior in its robustness against near singularities in the modeling process. The particular algorithm used allows multiple competing objectives and has proved competent in homing in onto globally optimal solutions in reasonable time.

Plans for extended functionality include the following:

- incorporating different design prototypes not related through continuous variation of tuning parameters into a single selection process subject to common selection criteria;
- generalized optimization procedure with multiple modules modeling complimentary aspects of the design, or consecutive sub-steps of the process;
- Integrating the optimization program as a tuning component in the study of machine robustness and acceptance.

This program optimizes parameters using Astra and Track. The figure 4 shows a family of solutions obtained through optimization. The dotted lines in the projection planes represent the parameters of PARMELA solution six.

This optimization process guides the search for an optimal machine layout that can support quality transport of both low and high brightness beams while allowing a sound scheme for instrumentation and control. Initial simulations for the high brightness case show that a common solution is achievable.

CONCLUSION

The components of the elinac and their operating parameters are determined by a design process taking into account beam dynamics and operational considerations. The final design is expected to reflect the optimal balance between performance goals and realistic constraints such as space and costs. A sensitivity study of the final design is going to be performed to understand its robustness and range of allowed input and operating parameters.

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