AN ELECTRON LINAC PHOTO-FISSION DRIVER FOR THE RARE ISOTOPE PROGRAM AT TRIUMF

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Abstract

A 0.5 megawatt electron linear accelerator is being designed at TRIUMF in support of its expanding rare isotope program, which targets nuclear structure and astrophysics studies as well as material science. The first stage of the project, a 25 MeV, 5 mA, c.w. linac matching the isotope production target power-handling capability in the next five-year plan, is planned to be completed in 2013. The injector cryomodule development, which is being fast tracked, is the subject of a scientific collaboration between TRIUMF and the VECC laboratory in Kolkata, India. The paper gives an overview of the accelerator design progress.

INTRODUCTION

TRIUMF has operated its ISAC radio isotope complex since 2001. It is considered to be one of the forefront Rare Isotope Beam (RIB) facilities in the world for its record RIB intensities for a number of species. International demand for ISAC beam time dramatically exceeds present potential of the macine, which delivers the beam to a single user at a time. TRIUMF's 2010–2015 Five-Year Plan outlines a strategy to at least double the RIB program. The centre piece of this program is the high average current continuous-wave electron linear accelerator (e-linac) founded on superconducting RF technology. The e-linac will serve as a driver to produce RIBs via photofission of ^{238}U.

ACCELERATOR BASELINE LAYOUT

The major components of the e-linac are a 10 MeV *injector,* followed by a *main* linac section accelerating from 10 to 50 MeV (see Fig. 1). Three goals have shaped the conceptual design of the e-linac: (1) c.w. operation at high average power; (2) the utilization of existing technology wherever possible; and (3) flexibility towards operation and re-configuration. Machine main parameters and bunch vital statistics are reflected in Table 1 & 2. Detailed description of the components can be found elsewhere [1, 2].

Table 1: E-linac Baseline Major Parameters

Final energy	50 MeV
Beam current	10 mA
Beam power	0.5 MW
Bunch repetition rate	650 MHz
Accelerating frequency	1.3 GHz
Accelerating gradients	10 MV/m
Duty factor	100 %

One of the major constraints affecting the accelerator layout was a power limitation of available RF power couplers and klystrons. Reference components of the design were 50 kW coupler design of Cornel ERL injector and 135 kW E2V klystron. In this configuration one RF unit would feed one 9-cell superconducting cavity via 2 high power couplers, delivering 100 kW of RF power to the beam.

Splitting the machine into injector and main linac will ease injector tuning and allow for an expansion to test–bed for Energy Recovery Linac (ERL) with beam intensity of 20 mA at 70 MeV, or Recirculating Linear Accelerator (RLA) with corresponding beam parameters of 2 mA and 160 MeV.

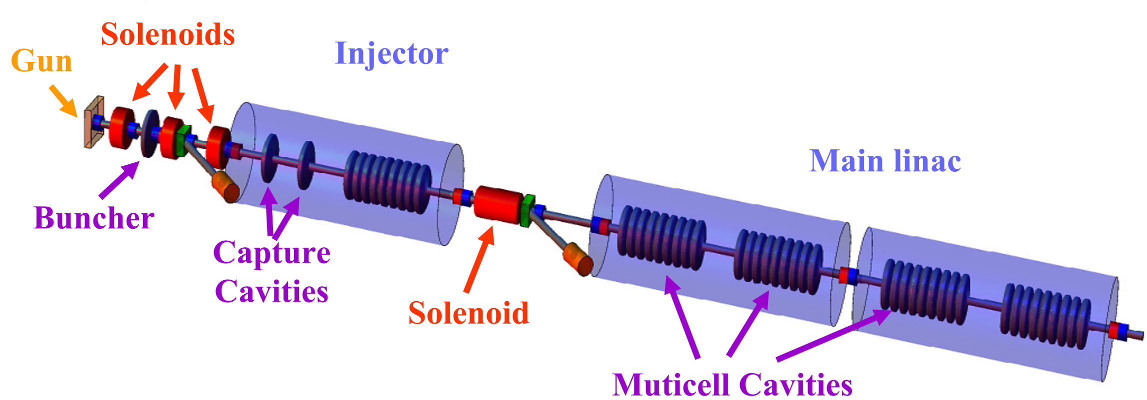

Figure 1: E-linac schematic layout.

*TRIUMF receives federal funding via a contribution agreement through the National Research Council of Canada.

Table 2: Bunch Vital Statistics

Parameter	inject	eject
Normalized emittance (μm)	<30π	<100π
Longitudinal emittance (eV.ns)	<20π	<40π
Bunch length (FW), inject (ps)	<170	<30
Energy spread (FW)	<1 keV	<1%
Bunch charge (pC)	16	16

PROJECT TIMELINE

U.Victoria/TRIUMF has applied for Canadian Foundation for Innovation (CFI) funding for the e-linac project. The application is under approval, contingent on matching funds for the civil construction from the Provincial government. Final decision is expected in spring 2010. E-linac project also represents an integral part of TRIUMF's 2010-2015 5-Year Plan in support of the lab's flagship RIB program at ISAC. This plan envisages early "new physics" outcome based on an intermediate phase of e-linac construction. This first stage will produce 100 kW beam power at 25 MeV, which will provide sufficient amount of photo-fissions to initiate neutron-rich physics program. The injector and one main linac cryomodule fed by 35 kW IOT and one high power klystron amplifier will be put on the floor by 2013 to meet these minimal beam requirements. In order to fast track further this already challenging schedule TRIUMF has entered into a collaborative agreement with Variable Energy Cyclotron Centre (VECC) in Kolkata for development of 1.3 GHz SCRF technology. E-linac Injector Cryo-Module (ICM) development and beam test is a subject of the present stage of collaboration. Two identical ICM's will be constructed and tested to a 100 kW (10 mA, 10 MeV) of beam power in 2011. Engineering design has already started with intensive beam dynamics studies and a cryomodule development [3, 4]. Final machine specification matching photo-fission converter/target capability (yet to be developed) will be achieved in 2017.

SIMULATION METHOD APPROACH

The components of the e-linac proper and their operating parameters are being determined by a design process taking into account beam dynamics and operational considerations as well as future upgrade path to a high brightness light source mentioned below. The final design is expected to reflect the optimal balance between performance goals and realistic constraints such as space and cost. The beam dynamics modelling is done with simulation codes Astra [5], Parmela [6] and Track [7]. The complementary features of these codes ensure that no important performance aspect is overlooked, whereas confidence is attained through redundant validation. Design and operating parameters in some cases are obtained using a genetic optimization program, originally adapted for accelerator design at Cornell University [8], with extended features developed for the current e-linac design. The program has been used for optimizing parameters in Astra and Track models. Beam dynamics based optimization is iterated to improve operability of the system, such as tuning strategy, observability, controllability etc. Several design prototypes are being finalized and will be subjected to a global evaluation based not only on performance, but also on construction and operating costs.

It was realized that the design requirements for the photo-fission driver (16 pC bunch charge) were sufficiently forgiving, therefore the test of viability for any machine layout will rest with the high brightness case (100 pC) where space charge issues limit the geometry options. An iterative process was undertaken to reconcile optimized layout and machine parameters dictated by high brightness beam on the one hand, and consideration for operability on the other. This has resulted in the current machine geometry, which can support quality transport of beams with both 16 pC and 100 pC bunch charge, while allowing implementation of sound schemes of tuning, monitoring and machine studies.

A sensitivity study of the final design will be performed to understand its robustness and range of allowed input and operating parameters. This may result in last-stage fine tuning of the design.

ACCELERATOR COMPONENTS DESIGN

Despite an ongoing approval process for the e-linac project funding has not been finalized, TRIUMF decided to initiate an early start in development of the crucial components of the accelerator. Thus an electron source test stand is being constructed based on the e-gun obtained from the TJNAF. The collaboration with VECC allowed a fast progress in the 1.3 HGz technology development. Following sections describe some details of the recent achievements.

Electron Gun

The electron gun design is based on a thermionic gun with a gridded cathode. The beam can be modulated by applying a high frequency field in between the cathode and the grid. The method has been developed by R.J. Bakker et al. for the FELIX facility [9]. In our case the gun should deliver an average current of 10 mA with a modulation frequency of 650 MHz at a pulse length of 170 ps (+/- 20 degree). In order to test the method and explore the operating parameters of such a source, a thermionic source formerly used at Jefferson Laboratory will be equipped with a gridded cathode and set up at TRIUMF. Simulations of the beam parameters have been performed with the code SIMION 3D Ver. 8.0. It allows tracking of particle bunches including space charge forces and application of variable electrical potentials. First the modulation parameters have been determined calculating the cathode grid region separately. The result has been taken to trace the particles through the electrical field of the extraction electrodes of the 100 kV gun. Longitudinal and transverse emittances of the extracted beam pulses have been determined. At a bunch charge of 29 pC, which is slightly higher than the requested one, the normalized transversal rms emittance is 2.76 mm mrad and the normalized longitudinal rms emittance is 6.66 deg-keV. Figure 2 shows a longitudinal distribution obtained.

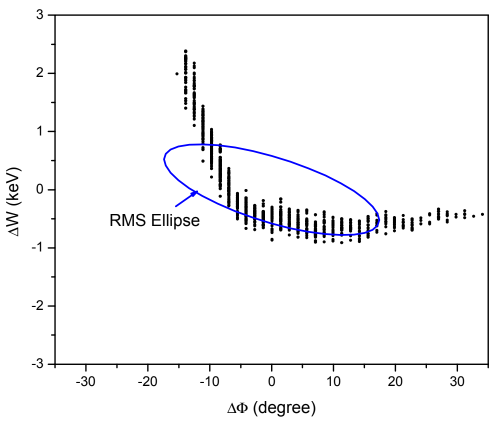

Figure 2: Particle distribution in the ΔΦ ΔW space at the gun exit. The ellipse is calculated from the longitudinal rms emittance.

Cavity

Pursuing the 1.3 GHz technology development TRIUMF has joined the Tesla Technology Collaboration (TTC). In addition to SRF knowledge exchange in a framework of this agreement, TRIUMF has obtained from DESY and Fermilab a few niobium cavities to gain an expertise in a 1.3 GHz domain through the cavity cold tests. Collaboration with VECC has pushed the e-linac development forward and helped setting up a 1.3 GHz test stand. A single cell cavity test at 2K has validated the infrastructure required for the cavity development. The Vancouver based company PAVAC is in the process of fabricating a couple of single cell and one 9-cell cavities in a framework of the e-linac cavity development program.

LLRF

The 1.3 GHz LLRF control system is based on the existing ISAC-2 106/144 MHz design, which operates under self-excited phase-locked mode.

The 1.3 GHz signal is first down-converted to an IF of 138 MHz, and then down-converted to base band to separate amplitude and phase detection. An IF is necessary because the digital phase detector, a Type 4 phase/frequency detector built using a Xilinx Spartan FPGA, can only provide 300 degree phase detection at less than 250 MHz. The demodulated amplitude and phase signals are sampled by two separate 18-bit ADCs to eliminate crosstalk between channels. The digitized signals are then processed by a Freescale 24-bit integer DSP. The processed signals are first up-converted to 138 MHz and then to 1.3 GHz.

UPGRADE PATH: LIGHT SOURCE

Synchrotron-based facilities provide photon beams with high flux and brightness from the far infrared to hard x-rays. At both ends of this spectrum, a strong case exists for linac-based sources. Compton Scattering Source (CSS) offers the possibility to produce hard x-rays with sufficient flux and brightness to do interesting research or exploit potential industrial or medical applications, at a fraction of the cost of ring or FEL-based facilities. The CSS is based on the scattering of photons from an intense laser by a relativistic electron beam. Retro-fitted with a photo-cathode electron gun and equipped with a bunch-compression magnet chicane and low-beta beam optics insertion, the e-linac could provide a 100 MeV capable electron source for this R&D effort.

Alternatively, configured as a 20 mA × 70 MeV ERL by the addition of return arcs and boosted cryogenic capacity, and coupled to a suitable high-Q cavity FEL, the e-linac could produce hundreds-watts-level infrared radiation in the range 2–200 μm. The SRF-linac offers the advantage of highly stable operation and high average power. Applications of IR FELs are starting to become mature; two examples that exploit the photon-power advantage are near-field microscopy and materials processing.

Terra-Hertz radiation is a frontier area for research in the physical sciences, biology and medicine. A 10–20 MeV e-linac is sufficient to produce THz radiation. With a number of modifications, the e-linac could be configured as a THz source: either a narrow-band FEL-based source similar to FELIX, or a broadband Coherent Synchrotron Radiation source similar to the TJNAF THz facility.

This range of applications has motivated a parallel beam dynamics study with the aim of ensuring that the ICM design is compatible with a high-brilliance beam, in addition to the low brightness beam for the photo-fission RIB application. Beam parameters for this exercise are selected as follows: 100 pC/bunch, repetition rate 100 MHz, transverse r.m.s. emittances of 10 μm and rms bunch length of 1 ps at the user.

REFERENCES

[1] S. Koscielniak *et al*. Proceedings of EPAC08, Genoa, Italy, pp 2728-2730
[2] S. Koscielniak *et al*. Proceedings of LINAC08, Victoria, Canada, pp 376-378
[3] M. Marchetto et al. Beam Dynamics Optimization of the TRIUMF e-Linac Injector, this conference
[4] R. Laxdal et al. The TRIUMF/VECC Collaboration on a 10MeV/50kW Electron Injector, this conference
[5] http://tesla.desy.de/~lfroehli/astra/
[6] L . Young and J Billen, Proceedings of the 2003 Particle Accelerator Conference, pp 3521.
[7] http://www.phy.anl.gov/atlas/TRACK/
[8] I. Bazarov and C. Sinclair, PRST-AB **8**, 034202 (2005), and references therein.
[9] R.J. Bakker et al. Nucl. Instr. Meth Phys. Res. A307 543-552 (1991)