VECC/TRIUMF INJECTOR FOR THE E-LINAC PROJECT

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Abstract

TRIUMF (Canada) and VECC (India) are both planning to use photo-fission route for producing neutron-rich Radioactive Ion Beams. With this common goal the two institutes have entered into a collaboration to jointly design and develop a superconducting 1.3 GHz, CW electron linac. First phase of the collaboration aims at the development, production and full technical and beam test of a 10 MeV injector for the e-Linac. The design and technical development of the injector is presented.

INTRODUCTION

Photo-fission of actinide targets is a highly promising route for producing exotic Radioactive Ion Beams (RIB) [1,2]. Photo-fission being a cold process creates higher yields for neutron-rich nuclei as compared to light-ion induced fission. Yields of around 10^{11} f/s have been experimentally measured using 25MeV, 20μA electron beam on uranium target [3]. It is expected that exotic beams such as ^{92}Kr, ^{132}Sn, that are of interest to super-heavy element research and r-process nucleo-synthesis, may be produced with significantly higher intensity using this method. In-target fission rates of 10^{13} f/s are estimated with 30MeV, 100kW electron beams [2].

VECC RIB Project and e-Linac Development

An ISOL type RIB facility is being built around the existing K130 cyclotron at VECC with the aim to accelerate 1.3 MeV/u beams. Presently 289 keV/u stable isotope beams are available from the facility.

Further details about the VECC RIB project can be found elsewhere [4]. We also plan to develop a 30 MeV, 100 kW superconducting electron linac fission driver for the RIB facility. Owing to VECC and TRIUMF's converging goals, the two institutes have recently signed a MOU for collaboration on SC e-Linac development. In the first phase, a 10 MeV, 2 mA injector will be built.

TRIUMF e-Linac Project

TRIUMF plans to add a 50 MeV, 0.5 MW super-conducting electron linac photo-fission driver to support its expanding RIB programme in the 2010–2015 five year plan. This will be an independent and complimentary primary accelerator to the present 500 MeV, 100 μA proton cyclotron that has driven the highly successful ISAC-I and ISAC-II programmes [5]. In July 2009, TRIUMF along with University of Victoria and other partners was awarded federal government funds for construction of the electron linac. Provincial funds for construction of the building were announced in July 2010. This funding will create a new centre called the Advanced Rare IsotopE Laboratory (ARIEL) [6]. In the first phase of the project 25 MeV, 100kW beams will be accelerated in 2014.

LAYOUT OF THE E-LINAC

The e-Linac consists of *Injector* and *Accelerator* sections and is based on 1.3 GHz, 2K SRF technology. Schematic layout of a 25 MeV, 100 kW e-Linac is shown in Fig.1. The e-Linac will be operated in CW mode.

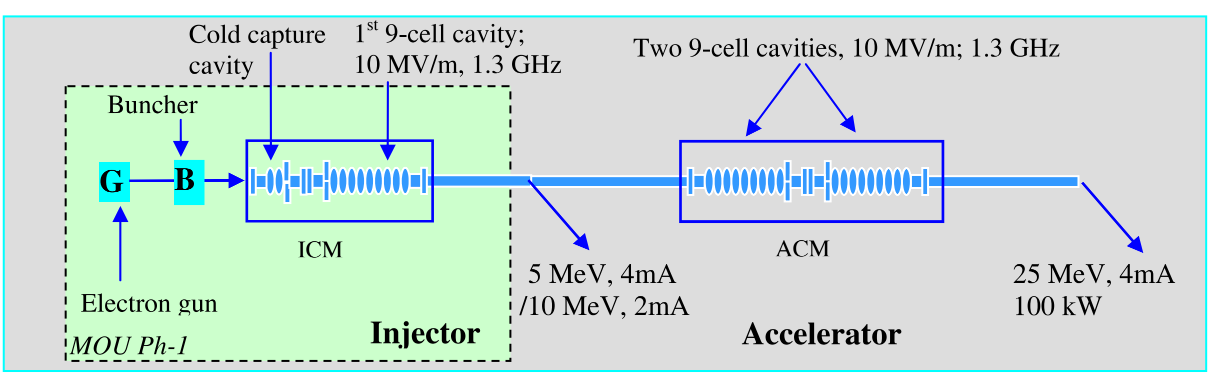

Figure 1: Schematic layout of the e-Linac.

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The *Injector-Accelerator* split allows for reconfiguration flexibility. TRIUMF plans installation of return arcs and operation of the *Accelerator* either in energy recovery mode for a light source or re-circulating linear accelerator mode in the future. The *Injector* will deliver 5/10 MeV, 4/2 mA beams and comprises of an electron gun, a buncher, low energy beam transport (LEBT) line and an Injector Cryo Module (ICM). The ICM is the most critical component of the e-Linac where electrons are accelerated from 100 keV to 10 MeV. The ICM is followed by an accelerator Cryo Module (ACM) consisting of two 9-cell niobium cavities. TRIUMF plans to add another ACM for taking the beam energy to 50 MeV in the future.

DETAILS OF THE INJECTOR

The Electron Gun

The electron gun is similar to the one operating at the FELIX facility [7]. The 100 kV DC Thermionic Gun with grid delivers 100 keV, 170 ps (±20°), up to 10 mA electron beam at 650 MHz pulse repetition rate. It is chosen because of simplicity, low cost and ease of maintenance. The thermionic electron source formerly used at Jefferson Laboratory became available to TRIUMF. It has been equipped with a gridded cathode and tested in stand alone mode in a test stand. The electron gun set-up will be soon moved to the ISAC-II hall and installed in the Injector beam line.

Beam Dynamics Simulation

Main parameters of the e-Linac are listed in Table 1. For the fission driver a low brightness beam (100 keV, 16 pC charge per bunch) is considered. The beam dynamics studies however have also been done for high brightness beam (300 keV, 100 pC per bunch) in order to accommodate the future ERL upgrade at TRIUMF.

Table 1: Summary of TRIUMF e-Linac parameters

Parameter	Value
Energy from gun; low(high) brightness	100 (300) keV
Energy after ICM	10 MeV
Energy (final)	50 MeV
Charge per bunch; low(high) brightness	16 (100) pC
Electron gun modulation frequency	650 MHz
Initial transverse emittance (norm)	30 π mm mrad
Initial energy spread ±ΔE	±1 keV
Initial phase width ±Δφ	±20 degree
Buncher RF frequency	1.3 GHz
ICM and ACM RF frequency	1.3 GHz
Length of 50 MeV e-Linac (approx)	15 m

The beam dynamics simulation is done and cross-checked using the codes ASTRA [8], PARMELA [9] and TRACK [10]. Space charge effects have been included in the calculations. The beam-line components and layout has been optimized keeping cost and practicality in mind [11]. The 100 keV, ±20 degree beam from the gun is further bunched in a normal conducting 1.3 GHz buncher and injected into the ICM. The 2-cell cold capture section and one 9-cell cavity in the ICM ensure that the low beta beam is smoothly accelerated and matched to the subsequent beta=1 acceleration section. It is practical to use beta=1 cells for the capture cavities although the beam from the gun has a beta=0.55. The simulation shows that for the low brightness case and the constraints suitable for the fission driver, even with beta=1 capture cavities a stable solution is achieved. The results for this case are shown in Fig. 2.

For the high brightness case, the parameters are more stringent. Further, the initial energy from the gun is higher, considering a future 300 keV photo-cathode gun. This provides an opportunity to eliminate the cold capture section entirely and directly inject the beam into a 9-cell cavity. This will significantly simplify the ICM and reduce the overall length of the beam-line. Further, if the gridded thermionic gun is operated at 300 keV instead of 100 keV, simultaneous fission and light source operation with two independent injectors and common ICM+ACM may become possible. The 300 keV thermionic gun option is presently being studied in detail.

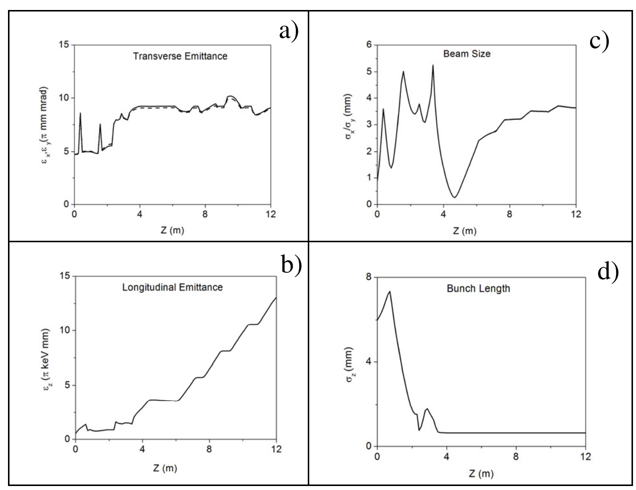

Figure 2: Optimized beam dynamics parameters for low brightness case & 50 MeV acceleration. (a) transverse & (b) longitudinal emittance, (c) beam-size and (d) bunch length variation along the length is shown.

Injector Cryomodule Engineering Design

The ICM engineering design is guided by the following considerations – (a) the e-Linac will be operated in CW mode with high average beam power (b) the total number of multi-cell cavities and cavities per cryomodule is limited (c) operational experience at TRIUMF with ISAC cryomodule (d) and finally, the available floor space for the e-Linac facility in the existing real estate. Based on these parameters, the design incorporating a rectangular cryostat with top-loading cold-mass and integrated 2K cold-box has been adopted.

Layout of the ICM is shown in Fig.3. The rectangular vacuum vessel will be made of stainless steel. The strong-back supports the cold-mass and forms a rigid assembly unit. The cold-mass includes the niobium cavities, two phase helium gas return pipe (HGRP), supply pipe, tuners, coupler cold-part, bellows, isolation gate valves and ancillary components. The strong-back is supported from the top flange of the cryostat through support struts. The top flange also supports the 4K to 2K cold-box. Two Cornell/CPI 60 kW couplers will be used to feed rf power to the 9-cell cavity whereas the independently phased capture cavities will be fed via two TTF-3 type 5 kW couplers. The tuner is CEBAF scissor-type tuner with room temperature control motor.

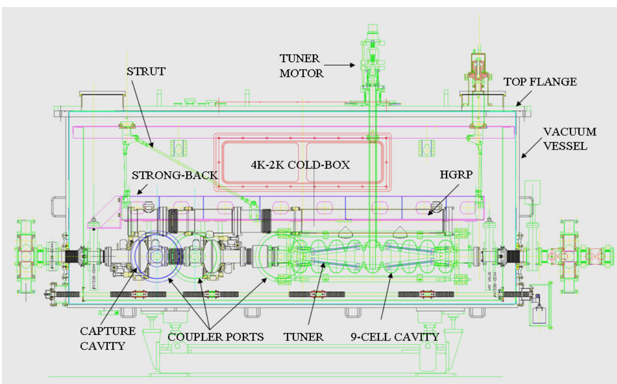

Figure 3: Layout of the Injector Cryo-Module (ICM).

The estimated cryogenic heat load for the ICM for the 2K, 4K and 77K circuits is 15 W, 6 W and 275 W respectively considering 10 MV/m acceleration gradient. CW operation is expected to result in high dynamic loads on the input couplers and the niobium cavities. Two 90 mm inner diameter chimneys connect the multi-cell cavity to the HGRP to take care of the heat load. The 4K thermal shield is avoided however the coupler intercepts are cooled to 4K. LN2 will be used to cool the 77K shield. A conceptual layout of the cryogenic cooling circuit of the ICM is shown in Fig. 4.

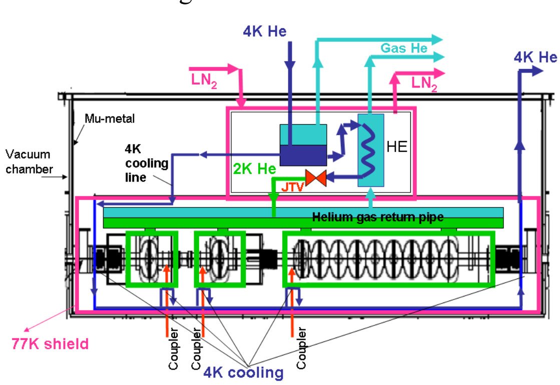

Figure 4: Layout of ICM cryogenic cooling circuit.

1.3 GHz Cavity Fabrication

The e-Linac will be using TTF type single-cell and 9-cell elliptical niobium cavities with modified end cells and larger diameter beam pipe. A 1.3 GHz SRF programme has been started at TRIUMF with the goal to produce and characterize the niobium cavities. The cavities will be fabricated at PAVAC Industries, a Vancouver based machining and electron-beam welding industry. The existing clean-room and SRF test facilities of ISAC-II will be used and necessary upgrades are being put in place. Already two single cell cavities have been fabricated and are undergoing rf-tests in the modified Vertical Test Cryostat. Further details of the 1.3 GHz SRF programme can be found elsewhere [12].

ICM Test Schedule

The *Injector* will be initially installed at the ISAC-II test area and later moved to the proton hall e-Linac site. The construction and beam tests of the injector at the ISAC-II site are scheduled to be completed by the end of the year 2012. The idea is to test all the engineering and beam acceleration related issues before starting the ACM construction. Two ICMs will be built – one each for VECC and TRIUMF. After the beam tests, one ICM will be shipped to VECC. The electron gun, buncher and LEBT line will be constructed at Kolkata separately for the VECC e-Linac programme.

REFERENCES

[1] W.T. Diamond, Nucl. Instrum. and Meth., A432 (1999)47.
[2] SPIRAL-II Project (Electron Option), Preliminary Design Study, GANIL/SP12/007-A.
[3] Yu. Ts. Oganessian et.al., Nucl. Instrum. and Meth., A701 (202)87c.
[4] A. Bandyopadhyay, et.al., Proc. 23rd Particle Accelerator Conference, Vancouver, Canada May 2009, FR5REP117.
[5] R.E. Laxdal, et.al., Proc. XXIV Linear Accelerator Conference, Victoria, Canada Sept-Oct 2008, MOP018.
[6] S. Koscielniak, et.al., Proc.IPAC'10 Conference, Kyoto, Japan, May 2010, THPD001.
[7] R.J. Bakker et.al., Nucl. Instrum. and Meth., A307 (1991)543.
[8] http://tesla.desy.de/lfroehli/astra/
[9] L. Young and J. Billen, PAC03, Portland, USA, May2003, p3521.
[10] http://www.phy.anl.gov/atlas/TRACK/
[11] M. Marchetto, et.al., Proc. 23rd Particle Accelerator Conference, Vancouver, Canada May 2009, TH6PFP097.
[12] R.E. Laxdal, et.al., Proc. XXIV Linear Accelerator Conference, Victoria, Canada Sept-Oct 2008, THP002.