BEAM DYNAMICS SIMULATION AND OPTIMIZATION FOR 10 MeV SUPERCONDUCTING E-LINAC INJECTOR FOR VECC-RIB FACILITY

S.Dechoudhury#, Vaishali Naik, Alok Chakrabarti, DAE/VECC, Kolkata, India
Gabriel Goh, SFU, Burnbay, British Columbia, Canada
Friedhelm Ames, Richard Baartman, Yu-Chiu Chao, Robert Edward Laxdal,
Marco Marchetto, Lia Merminga, Fang Yan, TRIUMF, British Columbia, Canada

Abstract

In the first phase of ongoing collaboration between VECC (India) and TRIUMF (Canada) a 10 MeV superconducting (SC) electron linac injector will be installed at VECC. This will constitute a 100 keV DC thermionic gun with grid delivering pulsed electron beam at 650 MHz. Owing to low beam energy from the gun, a capture cryomodule (CCM) consisting of two beta=1, 1.3 GHz single cell elliptical cavities will be installed for pre-acceleration of electron beam to around before it enters an Injector Cryomodule (ICM). The ICM consists of one 9-cell beta=1 elliptical cavity that will provide acceleration to 10 MeV. The present paper depicts the beam dynamics simulation and optimization of different parameters for the injector with a realistic simulated beam emittance from the electron gun.

INTRODUCTION

The proposed electron linac would eventually accelerate 10mA CW electron beam (16 pC/bunch) to 50 MeV with 1.3 GHz superconducting RF cavities. The e-Linac consist of a thermionic gun with 650MHz RF modulated grid followed by a buncher and the two cryomodules. The injector cryomodule (ICM) consisting of a single 9-cell 1.3 GHz niobium cavity followed by an accelerator cryomodule (ACM) having two 9-cell cavities [1]. Systematic optimization of the beam line with wide range of objectives and constraints has been carried out for this e-Linac. The TRIUMF machine would also be used in ERL or RLA mode [3]. Keeping this in mind, option of accelerating high brightness beam of 100pC/bunch charge with better longitudinal beam quality has been kept in the base-line design considering a 300 keV thermionic gun [2].

However, for the VECC facility a 100 keV electron gun would be developed for initial tests of the injector [1] because the present site has several limitations. The ICM would be identical to the TRIUMF machine and would be built and tested at TRIUMF and will be shipped to VECC. Since the 100 keV beam with a $\beta \approx 0.55$ is ill suited to be directly injected into the ICM, some pre-acceleration of the beam to an energy $\geq$ 300 keV will be needed. To achieve this, a capture cryo-module having two independently phased $\beta = 1$ single cell cavities will be added before the Injector Cryo Module (ICM). The beam dynamics optimization of the 10 MeV injector for the VECC e-Linac facility will be presented.

sdc@vecc.gov.in

ELECTRON GUN SIMULATION

The electron gun consists of a cathode with a grid placed 150 micron away from the electron emitting surface, on which the modulating voltage would be applied. First the electrostatic field between electron emitting surface and grid and finally up-to anode was simulated using SIMION [4]. The electric field distribution thus generated was then used in GPT [5] for estimating the longitudinal and transverse emittance of 100keV electron beam. GPT simulation was done for different geometries essentially varying the cathode angle and cathode-anode distance. An optimum gap of 9.5 cm was chosen between the anode and cathode for good beam quality and a robust solution [6].The conduction angle of the gun was varied in order to estimate the beam structure both longitudinally and transversely for $\pm 16^0$ and $\pm 20^0$ beam.

For both the cases the bunch charge was 16pC which yields 10mA average current for conduction angle of $\pm 20^0$. Two factors are expected to influence transverse emittance growth - temperature of electron emitting surface (1400 K~ 0.13eV) and influence of grid due to the lens action of the micro holes in the mesh. It can be seen analytically that grid induced emittance dominates over the thermal effect. The "*Reiser model*" [7] for grid induced emittance cannot be used since the angle is not << 1. The analytically calculated grid effect was therefore included in the simulation.

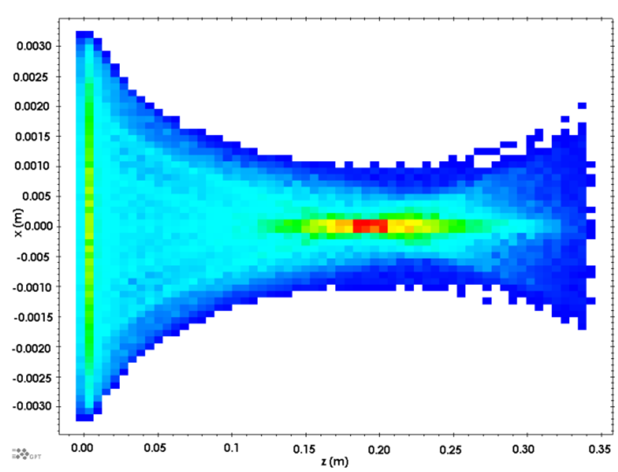

Figure 1: GPT simulated density distribution of 100 keV electron beam with 16pC, conduction angle of $\pm 20^0$

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The normalized emittance of electron beam was taken to be 19 mm mrad (4 times RMS emmittance) assuming a transverse spread same as that of the longitudinal energy spread [8]. GPT simulated beam for 16 pC, ± 20^0 conduction angle, cathode-anode distance of 9.5cm is shown in Figure 1. Maximum electron density at the axis occurs at a distance of 200 mm from the electron emitting surface. The simulated parameters for the 100 keV electron beam for ±16^0 and ± 20^0 conduction angles are listed in Table 1.

Table1: Parmeters of 100 keV electron beam (simulation)

Conduction Angle	±16^0	± 20^0
εn,rms (X) π mm mrad	5.02	4.85
εn,rms (Y) π mm mrad	5.01	4.84
εn,rms (long.) π keV mm	0.92	1.694
Bunch Charge (pC)	15.5	16

BEAM LINE CONFIGURATION

The 100 keV electron beam simulated from GPT with realistic features was used for optimization of the base-line configuration for the VECC injector. The beam tracking was carried out in ASTRA [9], where the input fields for elliptical cavities, buncher and solenoids was created using SUPERFISH [10]. In order to test for robustness of the baseline configuration, multivariate optimization technique involving genetic algorithm was utilized as described in reference [2]. In continuation with work carried out earlier, the base line configuration starts with a 1.3 GHz normal conducting buncher after the gun. Earlier it was already established that compared to 650 MHz buncher, the present buncher perform better in terms of bunching the beam without substantial tail longitudinally.

In the next stage two β = 1 single cell elliptical cavities were used. The acceleration is achieved in the first single cell cavity whereas the second cavity essentially only bunches the beam. The additional bunching in the capture section comes with the cost of transverse defocusing. The required transverse focusing is achieved with a solenoid placed between the CCM and ICM. A 10mm virtual aperture is defined through the cavities and any solution where the electron hits this aperture is discarded. This in other words takes care of electron hitting the superconducting cavity. Layout of the proposed beam-line is shown in Figure 2. The last solenoid is redundant for 10 MeV case but would be needed if we would like to further enhance the energy to 30 MeV in subsequent two 9-cell cavities. Also at 10 MeV the last solenoid would be needed as a part of diagnostic equipment.

A genetic algorithm was used to find the above optimized layout by using variables as field strength of solenoids, electric field and phases of cavities to achieve particular sets of constraints and objectives. This algorithm was useful to search for robust solutions against near singularities in the modeling process. Distances have been kept considering required space for hardware as well as space constraints in mind. The solution sets for which the objectives of minimizing EmitX and energy width ΔE (rms) and constraint of achieving final energy greater than 10 MeV with ±16^0 GPT simulated beam were achieved are shown in Figure 3 and the same for ±20^0 case are shown in Figure 4.

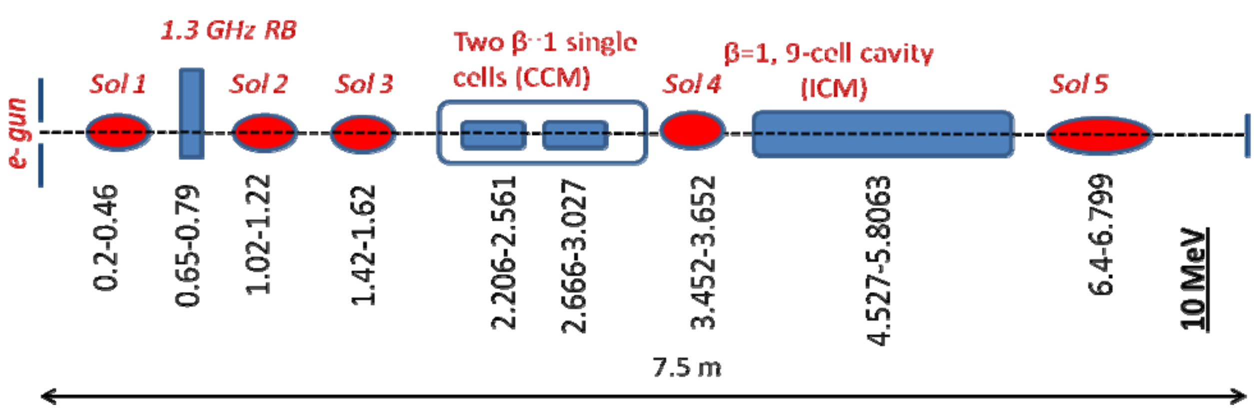

Figure 2. Layout of 10 MeV injector for VECC e-Linac

The optimized beam dynamics parameters for one of the solution with $\pm 16^0$ GPT simulated beam are shown in Figure 5. The first single cell cavity accelerates the 100 keV electron beam to 600 to 800 keV while the second cavity acts as mainly as a buncher with energy at its exit of around 1 MeV. The required solenoid fields are in the range of 300 to 400 Gauss. The required acceleration gradient E_{acc} in the first and second capture cavity is around 4.5 MV/m and 0.5 MV/m respectively. The rms bunch width at 10 MeV for most of the solution is less than 6mm going down to as low as 1-2mm, while transverse and longitudinal emittance are found to be within acceptable limits.

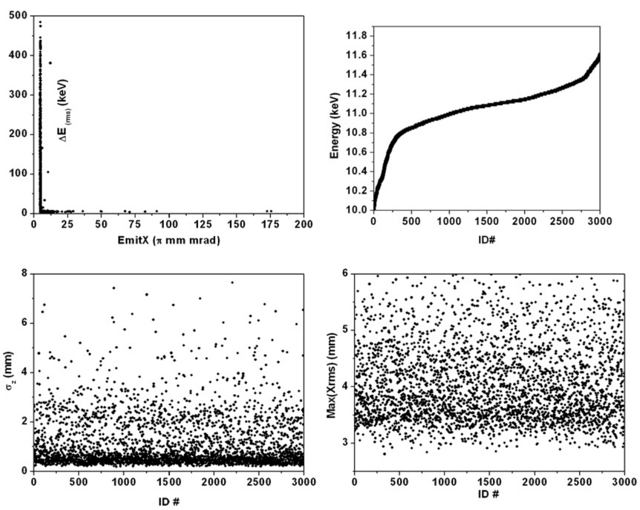

Figure 3. Solution sets with $\pm 16^0$ GPT simulated beam

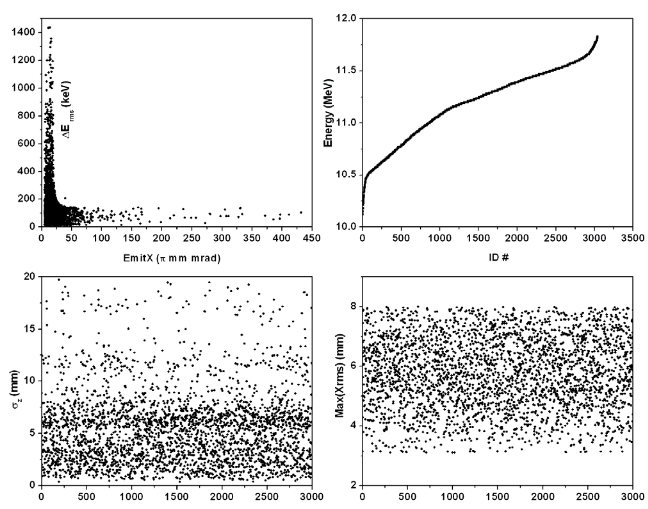

Figure 4. Solution sets with $\pm 20^0$ GPT simulated beam

For most of the solutions the maximum value of Xrms is less than 6-8mm. The beam does not develop appreciable longitudinal tail. As far as acceleration upto 10 MeV, both $\pm 16^0$ and $\pm 20^0$ perform in similar fashion in terms of longitudinal and transverse beam quality. Just out of academic interest, optimisation was extended upto 50 MeV with both type of GPT simulated beam. $\pm 16^0$ beam does not develop appreciable longitudinal tail thus not creating problem when accelerated to 50 MeV. This is not the case with 20 degree beam which is although comparable to 16 degree beam upto 30 MeV. But it seems to perform inferior in terms of number of solutions and also in terms of value of end parameters at 50 MeV. This is due to increase in number of particles in tail part of longitudinal structure of beam.

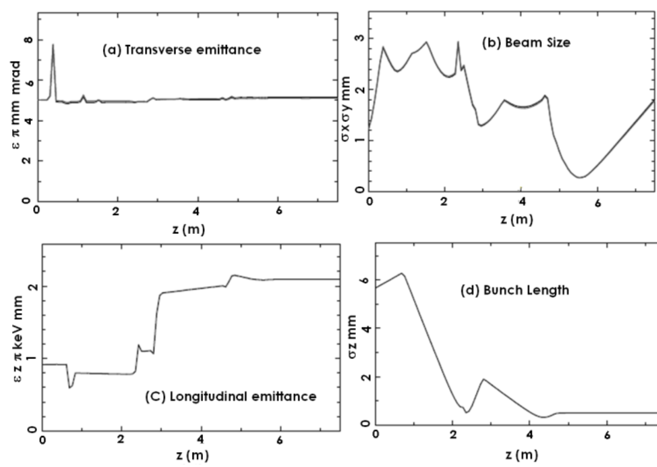

Figure 5. Optimised beam dynamics parameters with $\pm 16^0$ beam;(a) transverse emittance, (b) beam size, (c) longitudinal emittance, (d) bunch length variation along the length.

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