Chapter 25

Low Energy Beam Transport in 10 MeV, 5 kW RF Linac

– *Love Mishra*

25.1 Introduction

Beam transport calculation with supportive 3-D simulations is vital in designing beam line and placement of focussing devices along-with for any accelerator. The high beam current space charge forces lead to beam divergence and therefore results in current loss on the beam tube walls and heating. Thus, the beam transport analysis guides through optimum beam transport with minimum beam loss. At Electron Beam Centre, Kharghar, a 10 MeV electron RF accelerator comprising of thermionically heated Lanthanum hexaboride (LaB_6) crystal-based electron gun, followed by 2856 MHz linac is under operation. An inhouse developed solid state modulator generates a negative pulse for accelerating these emitted electrons at 40 keV to beam line at ground potential. Since the e-gun emits electron beam current of about 500 mA at 40 keV energy it is space charge dominated and therefore using the focussing elements could minimize the particle losses and thus may improve the overall accelerator performance. The e-beam emitted from the cathode has diameter less than 3 mm but is highly diverging due to high space charge density. The 40 keV, 500 mA beam dynamics is done over a length of 300 mm and is found that the beam could be focused to 8 mm by 350-450 Gauss magnetic field. We further plan to increase the transmission through the Linac by minimizing the injected beam current losses. It is being proposed and planned that Pre-Buncher (PB) cavity will be installed before the Linac to efficiently inject the electrons for acceleration by compressing the phase of the injected electron bunches to about 90°. The single cell PB cavity will longitudinally compress electron beam into bunches of about 350 ps. The e-beam needs steering for beam alignment which is done by electromagnetic beam steerers. This device steers the beam independently in both transverse axes controlled via bipolar current power supply. In this report we present the design and test results of the Solenoids and steerer developed for 10 MeV e-Linac.

25.2 Electromagnetic Solenoids

Solenoids are mostly used for optical control of the low energy electron beams due to the uniform focusing in transverse plane thus preserving the cylindrical symmetry of the beam. They are also used for measuring the beam emittance and thus to estimate beam envelope parameters. Interestingly, in some applications solenoids are also used for alignment of the beam trajectory. Even though analytical expression for transport matrix of a hard-edge solenoid is well known but, in many cases, it does not give an accurate representation for matrix of a real solenoids used for low energy beam transport. We needed about 350-450 Gauss field based on our beam dynamics simulation. To get the required field electromagnetic solenoid is designed based on the dimensions of the beam tube diameter “R” (this will decide the minimum coil radius of the solenoid) and the required field “B” (this will decide the minimum number of turns and coil current and gauge of the wire). The magnetic field is given by the expression $B = (\mu_0 N I)/l$, where “N” is the total number of turns in the coil, “I” is the coil current, “l” is the length of the solenoid. Now, with B as input parameter, the optimization between N and diameter of wire depending on current is to be made. The electromagnet solenoids of length 55 mm and 280 number of turns is designed and simulated in CST microwave particle studio and also have been fabricated and tested. The model of the solenoid in CST is made to run at various coil current from 1 A to 7 A, and focusing of the 40 keV e-beam is observed decreasing focal lengths. We simulated and made two set of electromagnets: one set with I.D 50 mm and other with I.D 70 mm. The focal length of 1st set of magnets has shorter focal length compared to the second set for same coil current. The measured field profile of the solenoids fairly matches with the simulation results. The solenoids were assembled on a test bench one at a time for testing the performance. The

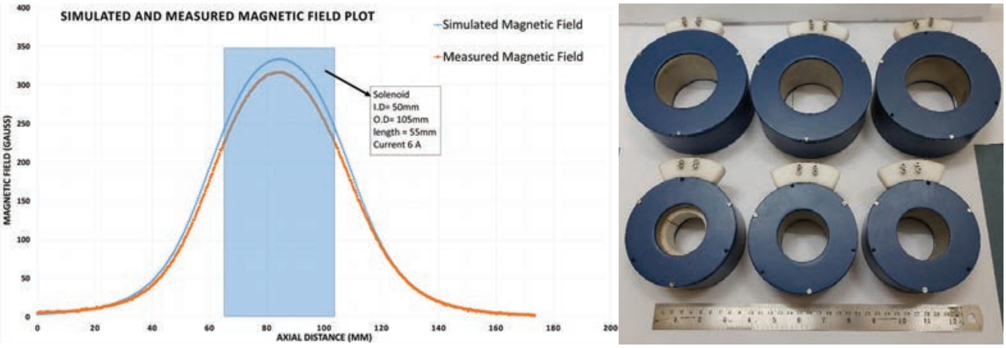


Figure 25.1: Measured and simulated Magnetic Fields (left), and Fabricated Solenoids (right).

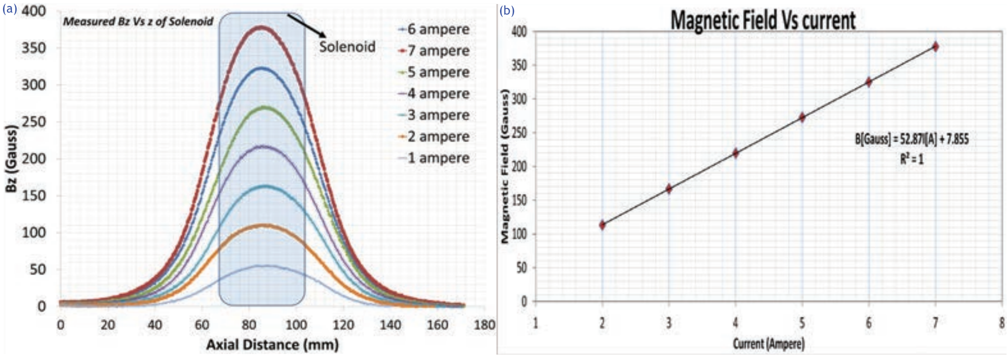


Figure 25.2: (a) Measured magnetic field, and (b) plot of B vs coil current.

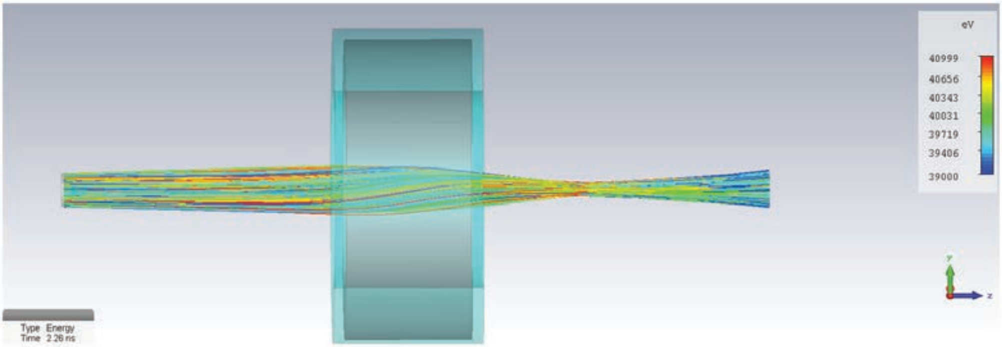
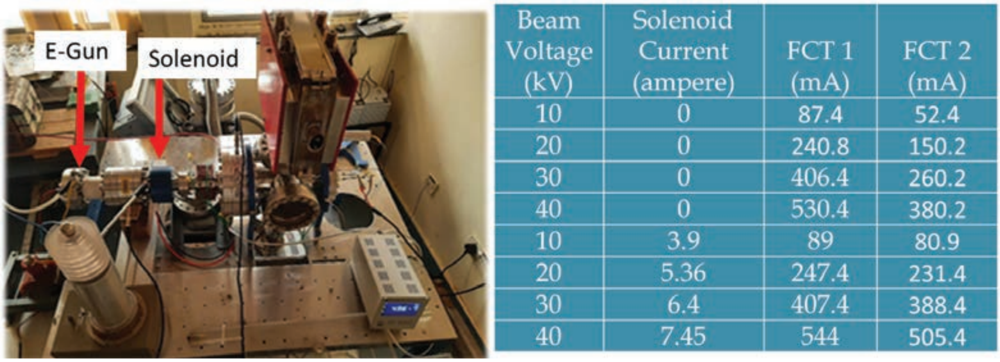


Figure 25.3: 3-D particle tracking for solenoid focusing in CST.

solenoid with I.D 50 mm were made for fixed type arrangement for CF 40 flange with the advantage of focussing the e-beam with low coil current as compared to 70 mm I.D. solenoid and subsequent low joule heating. The latter has the advantage of adjustment along the beam line as required for optimum solenoid positioning experimentally. The beam line consisted of e-gun, FCT1, solenoid, steerer, FCT2 in sequence as named. The e-gun heating power was adjusted to get emission current upto 554 mA measured in FCT1. This curent was then compared to the current in FCT2. With the aim to maximize the transmitted beam current, solenoid coil current was increased and beam focussing was observed as the FCT2 current increased close to readot in FCT1, however increasing solenoid coil current beyond that point resulted in overfocussing and beam current loss, thus reducing the readout in FCT2. The results were compiled and are presented in the tabular form below in Fig. 25.4.

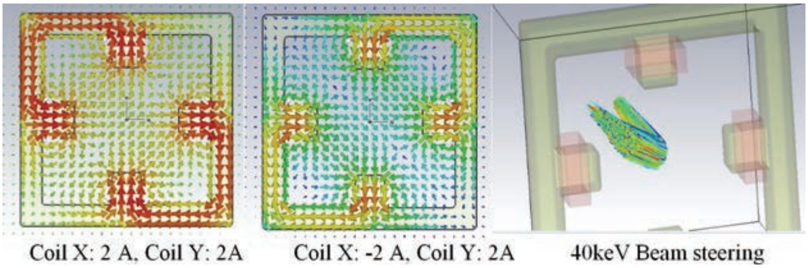


Beam Voltage (kV)	Solenoid Current (ampere)	FCT 1 (mA)	FCT 2 (mA)
10	0	87.4	52.4
20	0	240.8	150.2
30	0	406.4	260.2
40	0	530.4	380.2
10	3.9	89	80.9
20	5.36	247.4	231.4
30	6.4	407.4	388.4
40	7.45	544	505.4

Figure 25.4: Test Bench for solenoid testing and focusing measured data of the test experiment.

25.3 Beam Steerer

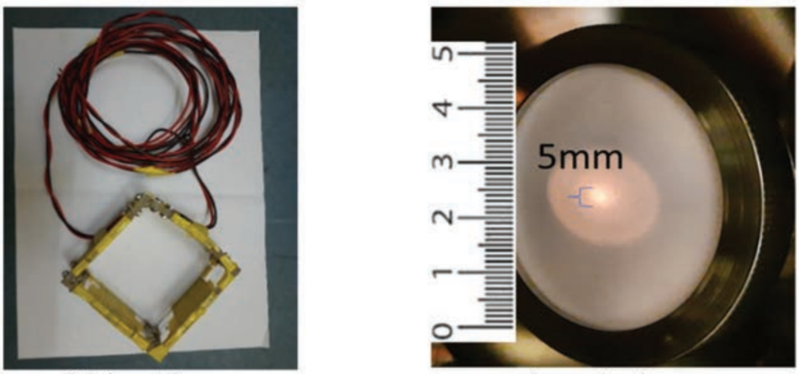
The real beam line due to limitations in machining and workmanship has finite tolerances which can't be corrected but could be compensated. Hence the e-beam needs to be steered electromagnetically to match with the acceptance aperture of the accelerating or bunching cavity using "Beam Steerer". The steerers are either electrostatic type or electromagnetic type. We choose the magnetic steerer for ease of fabrication cum assembling (are being mounted outside the vacuum and could be moved along the beam tube) and also to avoid high voltages. The electromagnetic beam steerer uses a coil wound around a magnetic material forming a closed loop on either side of the beam laterally. Two such pair of coils are used for steering in either axis of the transverse plane. The steerer is designed based on the expression $B = \mu_0 N I$, where "N" is the total number of turns in the coil, "I" is the coil current. A 3D model is then made in CST and simulated to get the B field of around 10 Gauss. The design parameters are:



Coil X: 2 A, Coil Y: 2A   Coil X: -2 A, Coil Y: 2A   40keV Beam steering

Figure 25.5: Magnetic Field arrows for current in X and Y axis steering coils and beam steering.

- Pole Gap: 50 mm (Both X and Y),
- Number of turns: 100 each,



Fabricated Steerer

e-beam glow image

Figure 25.6: Fabricated steering magnet for 40 keV e-beam (left) and glow image of e-beam on chromalux (right).

- Coil current: 2 A(max),
- Pole length: 10 mm,
- Pole width: 20 mm,
- Yoke Material: Soft Iron but used Perspex due to availability,
- Wire Gauge: 22 AWG (0.6 mm dia).

The opposite set of coils are connected in series to a power supply with variable polarity and current control.

The same experimental setup which was used as test bench for solenoids was used with steerer placed after the solenoid. Current signal of FCT2 was maximized by varying the coil current and polarity. The beam steering was observed by placing a scintillating screen of chromalux after the FCT2 and movement of beam glow (fluorescence) image was seen on the scintillator screen. The image of simulated beam steerer and the one fabricated in-house with available resources is shown in Fig. 25.6. While performing the experiments it was observed that solenoid axis has to have best alignment with the electron beam longitudinal axis for better beam transmission.

25.4 Conclusions

This Chapter discuss the magnet design aspects for RF linac beam transport.

Suggestions for Further Reading

a) [127–132]