DESIGN AND DEVELOPMENT OF BEAM TRANPORT ELEMENTS FOR BARC-ECIL LINAC

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Abstract

A 10 MeV, 2 kW RF electron linac is under development for cargo scanning. It consists of electron gun, RF linac structure, solenoid focusing magnets, steering magnet, beam diagnostics and x-ray target. To obtain properly resolved x-ray images, a beam diameter of 2mm is required at the target. Since the beam diameter at the target is critical; the transverse beam optics of the whole RF accelerator from gun end to the target has been simulated by solving the beam envelope equation. The envelope equation has been solved using Runga Kutta method consisting of external focusing field, RF field, space charge field and emittance. Various combinations of solenoid magnet focusing have been studied. It has been found that two solenoid magnets in the gun region and one after the linac region are sufficient to transport the beam and focus to a diameter of 2mm at the target. Based on these studies three solenoid magnets have been designed and fabricated.

INTRODUCTION

The industrial linacs are now making a major contribution to cargo inspection for manifest verification. This kind of system can easily inspect the contraband goods hidden in high density materials or fully loaded containers/ vehicles and show high quality scanning images. A 10 MeV, 10 kW RF linac for industrial application [1] has been installed at electron beam centre (EBC), Kharghar, Navi Mumbai and commissioned with 10 MeV, 15 mA, 10 μs pulse at 100 Hz PRF. The system consists of LaB_6 based electron gun injected into a standing wave on-axis coupled cavity linac, which accelerate the beam to energy of 10 MeV. A 2856 MHz, 3.5 MW Klystron based RF power source has been used to established the required electric field inside the linac. A similar system with x-ray target is under development at ECIL, Hyderabad for cargo scanning. This linac as a radiation source will be situated in a shielded room with concrete walls.

The electron gun of the linac produces electron beam of 50 keV, 10 μs, 100 Hz with maximum peak current ~1A. The beam is then focused by two solenoid magnetic lenses S1 and S2 and enters in the standing wave linac section L. In the drift section D1, a beam current transformer is incorporated to measure the gun current. The beam after coming out of linac hits the tantalum target T located beyond one meter concrete wall and produces x -radiation. A second beam current transformer is located in the drift region D3 to measure the beam current from the linac. A solenoid magnetic lens S3 is employed in front of the target to focus the accelerated beam to 2mm diameter.

THE ENVELOPE EQUATION

The generalized paraxial rms beam envelope equation for a cylindrically symmetric system which explicitly includes the effects of rf acceleration and external focusing is given as [2]

$$\mathbf{A'' + [\{\gamma'^{\,2} (\gamma^2 + 2)\}/ 4\beta^4 \gamma^4 + K_{r,rf} + K_{r,B}]\, A - \beta\gamma Q/ A - \varepsilon_n/ A^3 = 0} \qquad (1)$$

where, $K_{r,rf} = 1/8\ (e\ E_0/\ \beta\gamma m_0 c^2)^2$ is the rf focusing strength, $K_{r,B} = (eB_z(z) / \beta\gamma m_0 c)^2$ is the solenoidal focusing strength and for the standing-wave accelerating structure, $\gamma' \approx e\ E_0\ /2mc^2$. The normalized rms beam size $A = \sigma_r(\beta\gamma)^{1/2}$, the normalized rms emittance $\varepsilon_n = \beta\gamma\varepsilon$, and the perveance of the beam $Q = I/\beta^3\gamma^3 I_0$, with $I_0 = ec/r_e \approx 17$ kA for electrons. The input beam parameters of the 50 keV beam from the electron gun are the following: r = 5 mm, r' = 25 mrad, and I = 100 mA. The average accelerating gradient E_0 = 12 MV/m.

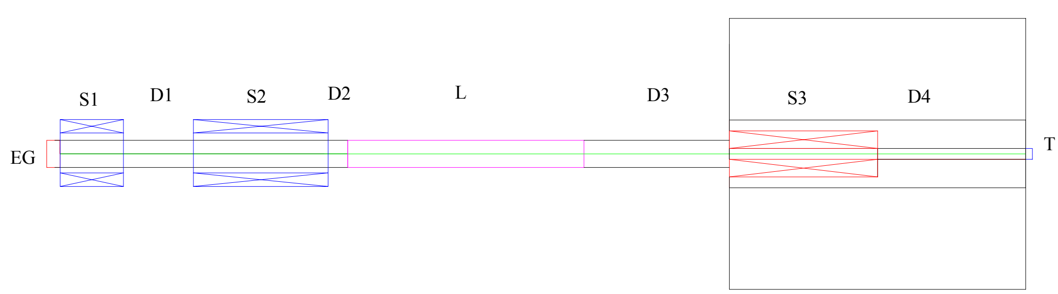

Figure 1: Schematic of beam transport elements: EG-Electron Gun, S-Solenoids, D-Drifts, L-Linac, T-Target.

The beam envelope for the beam line elements in Fig.1 consisting of Electron Gun EG, Solenoid S1, Drift D1, Solenoid S2, Drift D2, Linac L, Drift D3, Solenoid S3, Drift D4, and Target T is shown in Fig. 2. Here, the axial magnetic field $B_z(z)$ for the solenoids S1, S2 and S3 are shown in Figs. 3 and 4. With these input parameters the second order ordinary differential equation (1) has been solved using Runga-Kutta method after reducing to two first order equations. Various combinations of magnetic fields in the solenoids have been studied and it has been found that for the magnetic field configurations in Figs. 3 and 4, the optimum beam transport has been obtained. The 5 mm radius beam from the electron gun EG is focused to 2.4 mm radius by two solenoids S1 and S2 at the linac entrance. The beam in the linac region is focused by accelerating rf field to a radius of 4.2 mm at the linac exit. The beam is then focused by solenoid S3 to a diameter less than 1mm at the target.

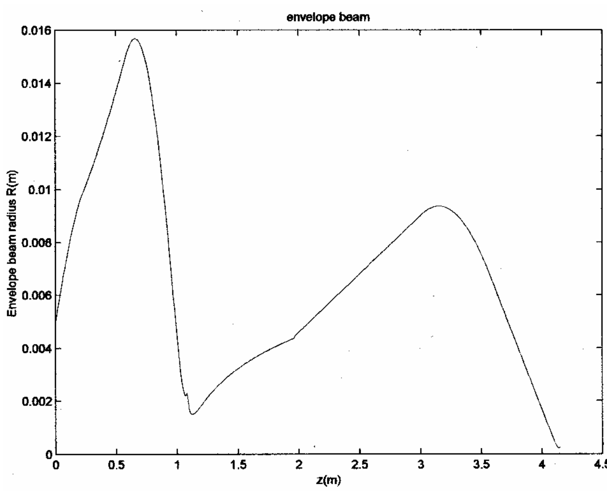

Figure 2: Beam envelope from EG to T: S1 (0<z<0.235), D1 (0.235<z<0.585), S2(0.585<z<0.995), D2 (0.995<z<1.087), L(1.087<z<1.964), D3 (1.964<z<3.014), S3 (3.014<z<3.564), D4 (3.564<z<4.15).

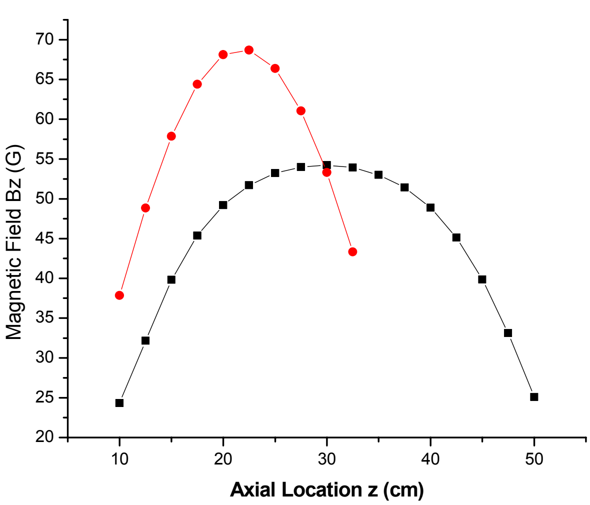

Figure 3: Axial field B_z versus z for S1 (•) and S2 (▪).

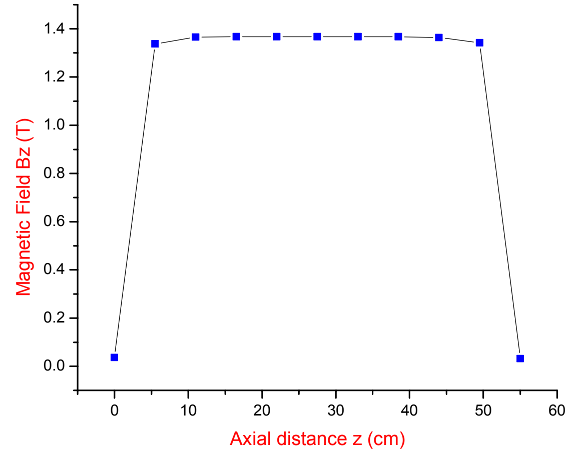

Figure 4: Axial field B_z versus z for S3 (▪).

SOLENOID MAGNETS

The solenoid magnets S1, S2 and S3 have been designed using POISSON code [3]. The field contour for S1 is shown in Fig. 5. The axial magnetic field variation B_z with distance z for S1, S2 and S3 are shown in Fig. 3 and 4.

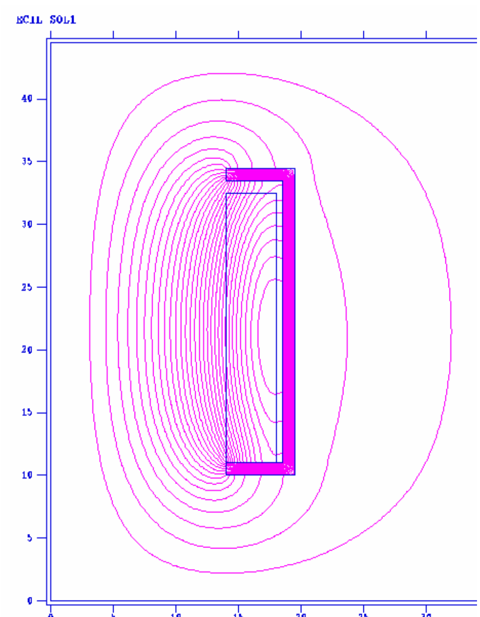

Figure 5: Field contour for solenoid S1.

The design parameters for the solenoids S1, S2 and S3 are shown in table 1. The solenoids coils after winding are baked for moisture removal and then vacuum impregnated in epoxy. The yoke materials for the solenoid magnet are low carbon steel grade-1010. The solenoid magnet S3 and its power supply have been fabricated by M/s Danfysik, Denmark.

Table1: Parameters of Solenoid Magnet

Sl. No.	S1	S2	S3
Inner Dia. (mm)	280	230	40
Outer Dia. (mm)	360	310	170
Length (mm)	215	400	550
Max. field (G)	200	200	2000
Conductor size (mm)	1.5 x 5	1.5 x 5	5 x 5
Resistance (Ω)	0.99	0.89	0.198
Voltage drop (V)	9.9	8.9	21.3
Power (kW)	0.1	0.09	2.2
No. of cooling circuit			4
Pressure drop (bar)			5
Flow rate (lit/min.)			0.5
ΔT (^{0}C)			0.49

BEAM CURRENT MEASUREMENT

The beam current will be measured at two locations, one after the electron gun in the drift region D1 and the other at the exit of the linac in the drift region D3. Two Beam Current Transformers (BCT's) procured from M/s Bergoz Instrumentation, France, will be used to measure the beam current. The transformers have been specially designed to be mounted inside the vacuum chamber. Two alumina (>99.8% purity) casing have been fabricated to mount the BCT's. Signals from the BCT's are brought out of the vacuum using Kapton insulated UHV grade coaxial cable and a ceramic to metal brazed double shielded BNC vacuum feedthrough. The BCT with ceramic casing is shown in Fig. 6.

Figure 6: BCT and alumina enclosure

The signals obtained from the BCT's installed in the beam line of the Industrial RF linac at EBC, Kharghar is shown in Fig 7 and 8. Fig. 7 shows the electron gun current waveform (bottom trace) of 400 mA, 10 µs flat peak obtained at 50 kV (top trace). The current wave form from the exit of the linac is shown in Fig. 8 with the peak current measuring 15 mA.

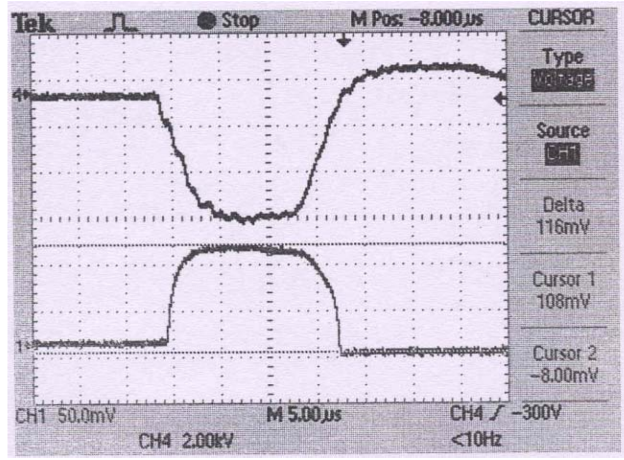

Figure 7: Voltage and current waveform of the electron gun measured using a divider and a FCT.

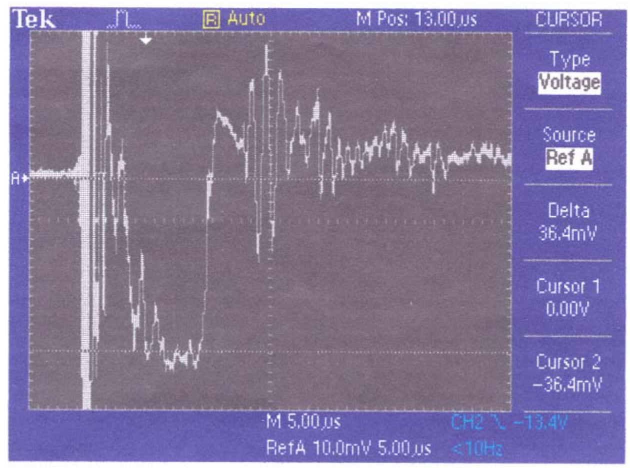

Figure 8: BCT signal for the beam current at the linac exit.

CONCLUSION

The transport of the electron beam from gun end to the x-ray target has been simulated by solving beam envelope equation consisting of external focusing field, RF field, space charge field and emittance. It has been found that two solenoid magnets in the gun region and one after the linac region are sufficient to transport the beam and focus to a diameter of 2mm at the target. Based on these studies three solenoid magnets have been designed and fabricated. Also to measure the beam current in the gun region and at the linac exit two BCT's have been procured.

REFERENCES

[1] V.T. Nimje et. al., "Present status of 10 MeV, 10 kW Industrial RF electron linac", InPAC-06, Mumbai, Nov. 2006, p - 171.
[2] J. D. Lawson, The Physics of Charge-Particle Beams, 2nd ed. (Oxford University Press, New York, 1988).
[3] http://laacg.lanl.gov.