DESIGN AND DEVELOPMENT OF 30 MEV, 3 KW RF ELECTRON LINAC

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Abstract

A 30 MeV, 3 kW on-axis coupled cavity RF electron linac is being designed, developed at BARC and will be installed at Vizag . It will be used as a neutron generator and will produce ~ 10^{12}-10^{13} n/sec. The design of the 94 cell RF structure, rf system, modulator for the electron gun and the Neutron generation target is in the advanced design stage . The design details of the linac are presented in this paper.

INTRODUCTION

Electron beams have played a key role in the field of basic sciences, applied sciences, medicine and agriculture. Over the last decade or so, the focus has shifted more towards industry. Depending upon the beam power and its energy, the electron beams have made tremendous impact in the area of food preservation, medicine, agriculture, biology, etc.[1]. Keeping in tune with the present and future scenario, the Accelerator and Pulse Power Division (APPD) of BARC has initiated the design and development of various types of electron accelerators. The project for Prototype Development of 30 MeV, 3 kW electron accelerator has been proposed based on the experience gained from 10 MeV RF Linac being commissioned at EBC, Kharghar, Navi Mumbai. This Accelerator can be used as a Prototype to study the Production of Medical Radioisotopes, Neutron rich Radioactive Nuclei, Energy Driver, Transmutation of Radioactive Waste, to study Electron beam based Nuclear physics including photonuclear reactions and target optimization for photoneutron production.

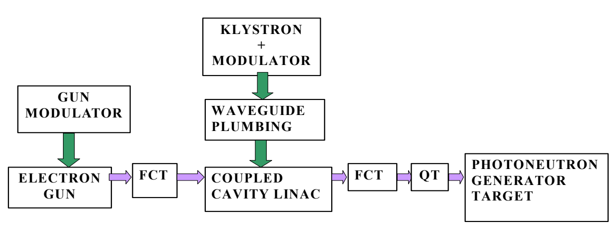

Figure 1: Schematic Diagram of 30 MeV, 3 kW Electron RF Linac System.

The linac is intended to deliver a beam with an average beam power of ~ 3 kW. It will be operated at a frequency of 2856 MHz. The duty cycle is chosen to be 0.1%, with a repetition rate (RR) of 100 Hz. The schematic of the linac is shown in Fig. 1. The electron gun (EG), will be directly coupled to the linac system, will inject a train of pulses into the linac at the rate of 100 pulses per sec, each having a pulse width of ~ 10 μsec. The beam will be accelerated to the required energy of ~ 30 MeV in the coupled cavity RF linac before being passed to the photoneutron generation target. The energy analysis will be done using the depth dose penetration method and the beam current will be monitored with the beam current transformer (ICT). A vacuum of ~ 4x10-7 torr will be maintained with the help of a turbo/sputter ion pump (TP/SIP) combination system. The RF power to the linac will be fed via a waveguide (WG) operated in the TE10 mode. The linac will have a horizontal configuration. The following sections give the brief details of the progress made in the design of various subsystems of the linac.

RF STRUCTURE

For the sake of simplicity of fabrication, constant impedance, on-axis coupled cavity linac configuration has been selected. It consists of two parts. Schematic of one of the part is shown in fig. 2. First part consists of 49 cells

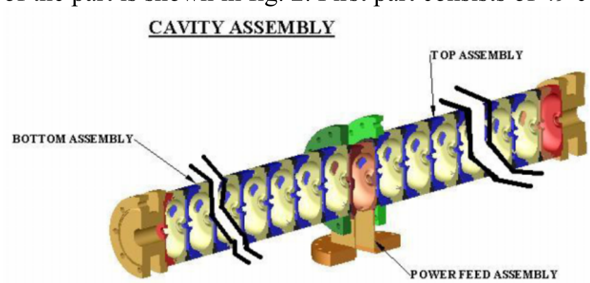

Figure 2: One part of On-Axis Coupled Cavity RF Linac

including 3 buncher cavities followed by 22 acceleration cavities and 24 coupling cavities. Second part consists of 45 cells, 23 acceleration cavities and 22 coupling cavities. These two parts will be separated by a drift space of ~ 15.7 cm. The length of the acceleration cavity is 52 mm, whereas the buncher cavities are 45, 48 and 50 mm respectively. A total length will be ~ 250 cm. An acceleration field gradient of 15 MV/m to 18 MV/m has been used for design considerations, leading to a Kilpatrick value of ~ 1.4, with a maximum field on the boundary as 62.712 MV/m. The corresponding maximum magnetic field is found to be 36.072 kA/m. The effective shunt impedance for the buncher cavities is ~ 80MΩ/m, while for the accelerating cavities, it is ~ 90MΩ /m. Some of the salient features of the two ½ accelerating cavity, sandwiching the coupling cavity, are shown in Fig. 3. The electric field distribution and profile are shown in Fig.4. The outer and inner nose radii have been optimised to be 3 mm and 1 mm respectively. The electric field in the bore has been found to be uniform within 3.5%. Most of the design features of the linac have been worked out using SUPERFISH[2,3]. The total RF power dissipated into the structure at the operating frequency of 2856 MHz is estimated to be 5.083 MW (peak).

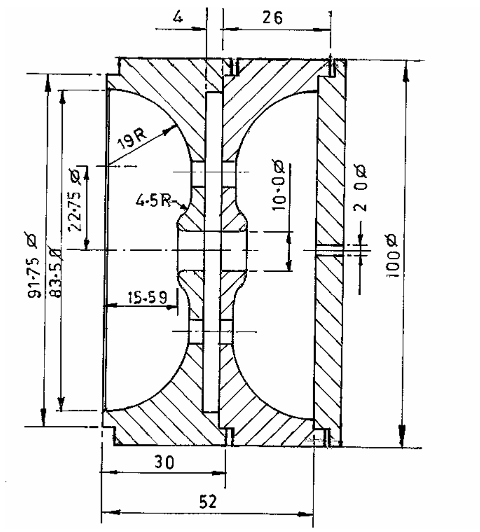

Figure 3: Two ½ Acceleration and one coupling cell

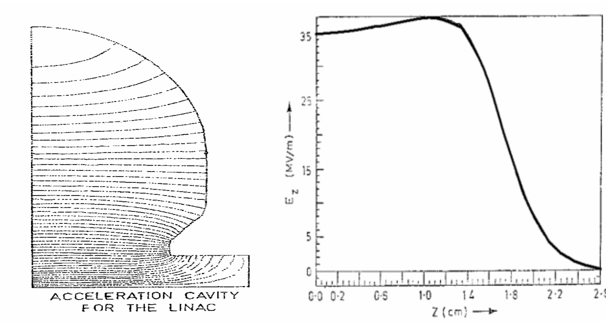

Figure 4: Electric field distribution and profile in the acceleration cavity

For the feedpoint at the central cell of the 49-cell (25 accelerating cells, 24 coupling cells) linac, the droop at the last cell works out to be 0.35%. Its variation along the cell is shown in Fig.5a and 5b. This would otherwise have been 1.40% if the feedpoint was chosen as the beginning or the end of the accelerator. The droop and phase shifts between the adjacent cells for a random frequency deviation of ± 1000kHz, due to fabrication errors etc., have been estimated and are shown in Fig. 5c. The annular aperture of size 10 mm width and 300 length along radius of 26 mm achieves rf coupling of ~ 4.6 % between adjacent accelerating and coupling cell. The RF preliminary tests have been done on the second part of the linac. The Q0 measured to be ~ 12000. The field flatness measured to be within ± 5%. The above parameters will be improved by acid cleaning of the cavities.

A rectangular waveguide operating in TE10 mode will be used to transfer power of 20 MW (peak), with duty cycle

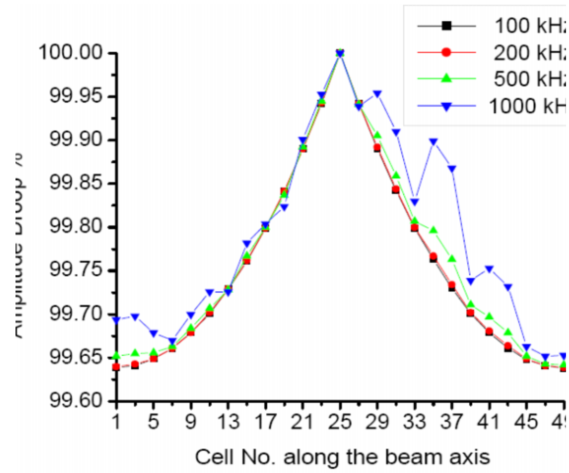

Figure 5 a: Electric field in accelerating cells

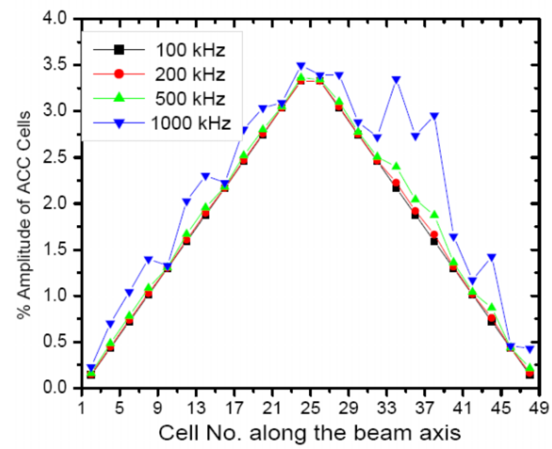

Figure 5 b: Electric field in coupling cells along the Beam Axis

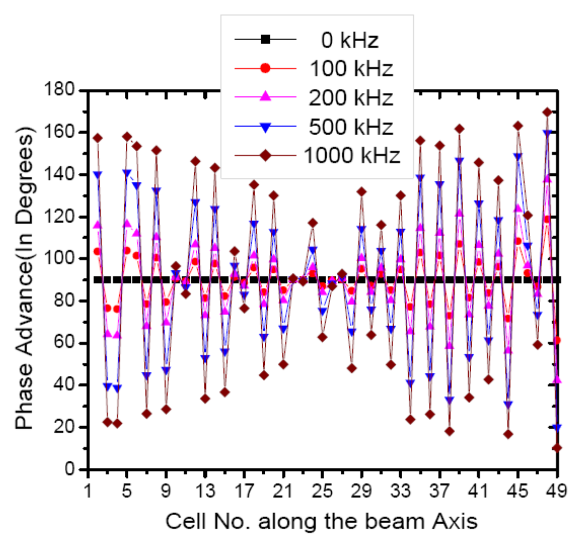

Figure 5c: Phase Advance between adjacent cells along the length of the linac.

of 0.1%, from klystron source to both the parts of the linac using 3 dB coupler. At a frequency of 2856 MHz, with air as dielectric 72.14 mm x 34.04 mm waveguide has an attenuation coefficient of 0.0157 dB/m and power handling capacity of ~ 6.15 MW. By using SF6, at 1 bar pressure, the power handling capacity will be enhanced to ~ 24.61 MW.

STUDIES OF THE BEAM BEHAVIOUR

The beam behaviour in the linac has been studied by using the computer code PARMELA[3]. 6-dimensional phase space with random distribution have been taken for evaluation of the beam properties. The beam injection is done at 85 keV with an energy spread of 0.5 keV and emittance of 25 π mm-mrad. A phase width of 180o has been considered for the beam pulse. About 1000 particles

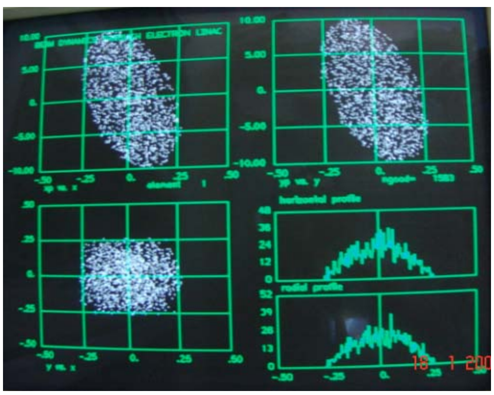

Figure 6: Phase space, Intensity distribution used as input for the linac.

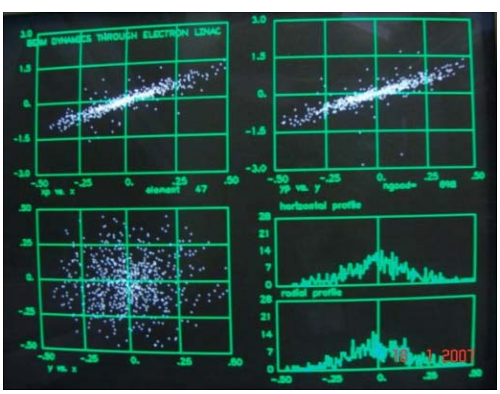

Figure 7: Phase Space, Intensity Distribution of the beam at the end of the Linac

are scanned. Optimum transmission of the beam is obtained at an injection phase of -35o. Since the linac does not use any solenoid or focussing element, the beam loss in the first five cavities is found to be 11.0%, 1.2%, 5.2%, 2.2% and 1.8% respectively. Using solenoids also the total beam losses comes out same. In the remaining cavities, the beam loss is found to be negligible. The total transmission through the linac is 73.4 % with an average energy of 30 MeV and a beam power of ~ 9.73 kW. The beam power lost to the linac structure is ~ 0.18 kW. The maximum energy of the beam is ~ 33.8 MeV with energy spread as ~ ± 3 MeV and a phase spread of ~ 90o. The output beam has a gaussian distribution with FWHM as ± 2.5 mm and maximum divergence as ± 1.5 mrad. Required input phase space and output beam emittance after 94 cells are shown in Figs. 6, 7.

INJECTOR

The electron gun, with a Diode/triode geometry, will deliver a pulsed 500 mA, 85 keV electron beam, with a width 10 μsec, at a RR of 100 Hz. The power for the injector will be derived from 230V, 50Hz AC mains. A solid-state modulator switching at ~ 1kV will be used to generate the required pulse output. The rise time targeted is less than 1μs. 1kV dc will be switched using an IGBT and a 1 : 85 pulse transformer will step up the primary voltage to 85 kV. The iron based METGLAS amorphous alloy cut C core will be used. The transformer will have bucket type geometry, to minimize the leakage inductance. The IGBT with V_{ce}s of 1700V and Ic = 220A(150A) at Tc = 25(80)oC will be used. The typical rise and fall time of these IGBT's is 100 ns and 40 ns respectively[4].

TARGET

Neutrons will produced in a water-cooled tungsten copper alloy (75% W and 25% Cu) target aligned horizontally in line with the electron beam. It will be Solid piece of ~ 9 cm long and ~ 7 cm diameter. It will be welded to the linac side by conflat flange to hold the vacuum. With a total beam power of ~ 3 kW, the face of the target which is inside the vacuum port, will heat up to several hundred ^{o}C. This will be conducted throughout the massive target (> 6kg.) and will be dissipated from its much lower temperature surface by circulation of water. The system will produce about $2x10^{-3}$ neutrons per electron, or $2x10^{10}$ n/s per μA of electron current at 30 MeV. With a projected time-averaged beam current of 100 μA and electron energy of 30 MeV, we expect to produce a driving source in excess of 10^{12} n/s. also, other targets will also be studied to have optimum neutron Source.

CONCLUSION

Design studies for the electron gun are in progress. Studies for coupling the waveguide to the linac are under way. By the end of 2007, we hope to complete the design of the 30 MeV linac Assembly.

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