DESIGN & DEVELOPMENT OF 10 MeV RF ELECTRON LINAC FOR APPLIED RESEARCH AND INDUSTRIAL APPLICATIONS

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Abstract

A 10 MeV, 10 kW on - axis coupled cavity RF electron linac is being designed and built at BARC. It will be a multipurpose facility. The design of the 33 cell RF structure , rectangular waveguide, the modulator for the electron gun and the magnetic sweep-scanner is in advanced stages of completion. The design details of the linac are presented in this paper.

1 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 and the 10 MeV RF linac is one of them. This will mainly be used for food preservation, medical sterilisation, semiconductor irradiation, radiography, radiation therapy, etc. In addition, bremsstrahlung radiation generated from the electron beam will be employed for studying the radiation damage and chemistry of special materials like zirconium and its alloys.

The linac[2] is intended to deliver a beam with an average power of 10 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 200 Hz. The schematic of the linac is shown in Fig.1. The electron gun (EG), directly mounted on the linac, will inject a train of pulses into the linac at the rate of 200 pulses per sec, each having a pulse width of 5 μsec. The beam will be accelerated to the required energy in the coupled cavity linac before being passed to the magnetic sweep scanner (MSS) for usage. The energy analysis is done through the 90º magnetic analyser (MA) and the current is monitored with the help of beam current transformer (DB). A vacuum of the order of 10^{-7} torr will be maintained with the help of a turbo & ion pump (TP/IP) 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 vertical configuration so that the products to be irradiated can be moved horizontally on the conveyor belt. The 90º line of the linac will be used for studying the radiation damage and chemistry of various materials

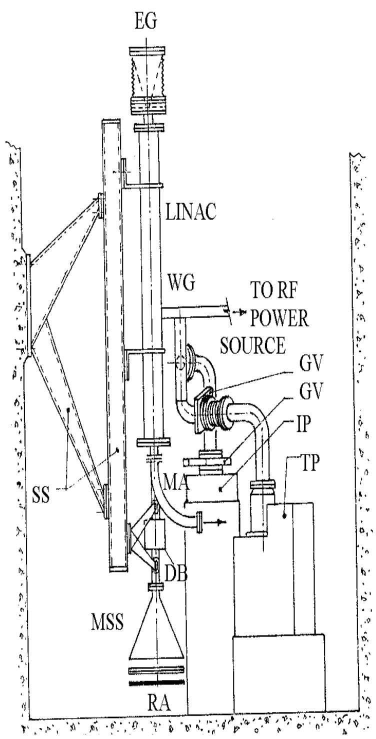


Fig.1 - RF Electron Linac

like zirconium and its alloys, etc. Both x-rays and electron beams will be available for the purpose of irradiation. The following sections give the brief details of the progress made in the design of various subsystems of the linac.

2 RF STRUCTURE

For the sake of simplicity of fabrication, constant impedance, on-axis coupled cavity linac configuration has been selected, as sketched in Fig.2. It consists of 3 buncher cavities followed by 14 acceleration cavities, comprising a total length of 871 mm. The length of the acceleration cavity is 52mm, whereas the buncher cavities are 45, 48 and 50 mm respectively. 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,

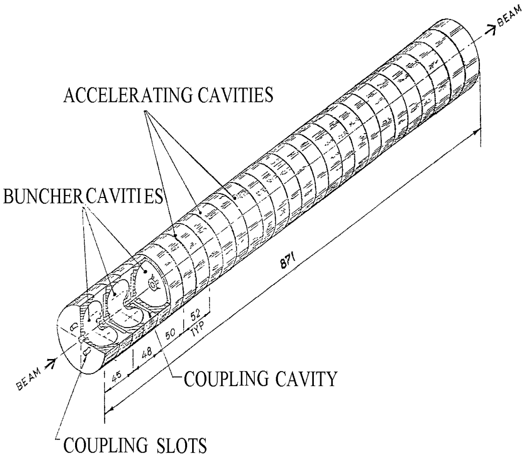


Fig.2 - On - Axis Coupled RF Linac

while for the accelerating cavities, it is ~ 90MΩ/m. Some of the salient features of the 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%. The total RF power dissipated into the structure at the operating frequency of 2856 MHz is estimated to be 1.083 MW (peak). Most of the design features of the linac have been worked out using SUPERFISH[3].

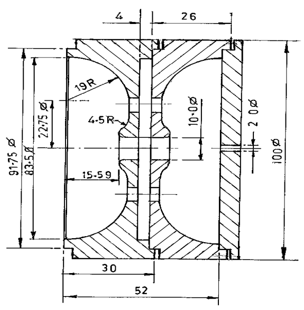


Fig.3-Acceleration Cavity for Cold Modelling and Testing

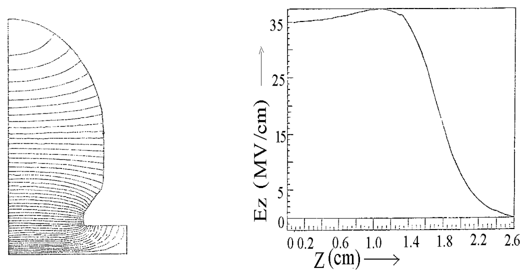
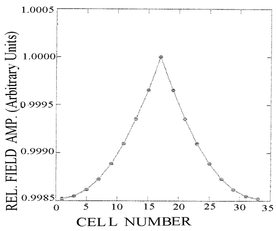


Fig. 4 - Electric field distribution and profile in the acceleration cavity

For the feedpoint at the central cell of the 33-cell (17 accelerating cells, 16 coupling cells) linac, the droop at the last cell works out to be 0.15%. Its variation along the cell is shown in Fig.5. This would otherwise have been 0.66% if the feedpoint was chosen as the beginning or the end of the accelerator. The phase shifts between the adjacent cells for a random frequency deviation of ± 150 kHz, due to fabrication errors, have been estimated and are shown in Fig.6.



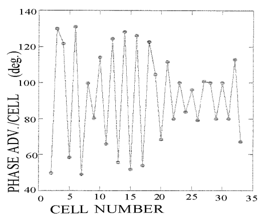


Fig.5 - Droop along the length of the cell

Fig.6 - Phase Advance between adjacent cells

A rectangular waveguide operating in TE10 mode is used to transfer power of 20 MW (peak), with duty cycle of 0.1%, from klystron source to the linac. At a frequency of 2856 MHz, with air as dielectric, it is found that 7.89 cm x 3.95 cm waveguide has an attenuation coefficient of 0.0157 dB/m and power handling capacity of 6.15 MW. By using SF_6 , at 1 bar pressure, the power handling capacity for the waveguide increases to 24.61 MW[4].

3 INJECTOR

The electron gun, with a triode geometry, will deliver a pulsed 3 Amp, 50 keV electron beam, with a width 5μsec, at a RR of 200 Hz. It is necessary to provide a pulsed input both at the grid and the cathode of the gun. The cathode will be floated at a voltage of −50 kV with respect to the anode. For the cathode modulator, power from the 440 V, 50 Hz mains is transformed to 5 kV, rectified and filtered. This is fed to the line type modulator[5]. Inductive charging is used to achieve high efficiency. The pulse forming network (PFN) consisting of 8 stages will have a total inductance of 125 μH and capacitance of 50 nF. A 1:10 pulse transformer will raise the voltage to the required 50 kV level.

4 STUDIES OF THE BEAM BEHAVIOUR

The beam behaviour in the linac has been studied by using the computer code PARMELA[6]. 6–dimensional phase space with random distribution have been taken for evaluation of the beam properties. The beam injection is done at 50 keV with an energy spread of 0.5 keV and a normalised emittance of 25 mm.mrad.MeV/c. A phase width of 180º has been considered for the beam pulse. About 10,000 particles are scanned. Optimum transmission of the beam is obtained at an injection phase of −50º. Since the linac does not use any solenoid or focussing element, the beam loss in the first four cavities is found to be 16%, 13%, 9% and 5% respectively. In the remaining cavities, the beam loss is found to be negligible. The total transmission through the linac is 48% with an average energy of 11.676 MeV and a beam power of 11.248 kW. The beam power lost to the linac structure is 0.774 kW. The maximum energy of the beam is 12.547 MeV with energy spread as ~ 1 MeV and a phase spread of ~ 90º. The output beam has a gaussian distribution with FWHM as ± 2.5 mm and maximum divergence as ± 2.5 mrad. Some of these properties are shown in Figs.7,8. The energy of the beam can be varied between 7 to 11 MeV.

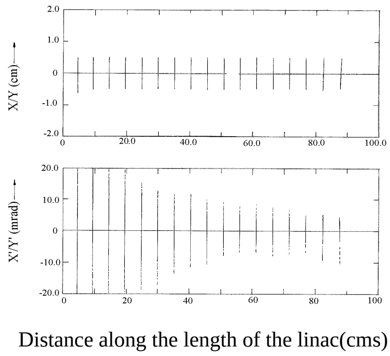


Fig.7- Beam Behaviour along the length of the Linac

The beam extraction process from the accelerator, for the purpose of irradiation of targets, consists of sweeping the beam over a target and the extraction of the beam from a titanium window. .An electromagnetic scanner[7] has been designed, using TRANSPORT[8] and POISSON[3]. The C-shaped electromagnet made of silicon steel laminations will give a beam deflection of ± 30º at ~3 kG. A 90º magnet will be coupled to the linac as an energy analyser. To overcome the limitation posed by the limited range of the 10 MeV electron beam for irradiation, a scheme for generating bremsstrahlung radiation[9] has also been adopted. The analyser channel will be used for this purpose. The dose rate distribution corresponding to suitable high Z elements have been worked out.

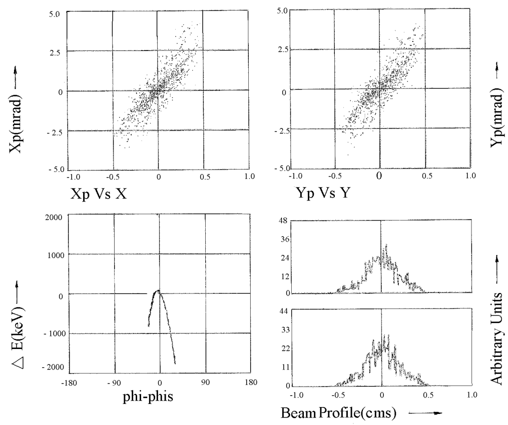


Fig.8-Phase Space, Intensity and Energy Distribution of the beam at the end of the Linac

5 CONCLUSION

Design studies for the electron gun are in progress. Studies for coupling the waveguide to the linac are under way. The slot size evaluation to achieve a coupling coefficient of ~ 0.06 is being done. Modelling of the cavities and the tuning procedures are being finalised. By the end of 1998, we hope to complete the design of the linac.

6 ACKNOWLEDGEMENT

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