# Design and Development of 100 MeV, 100 kW RF Electron Linac for Experimental Neutron Facility Using Electron Accelerator (ENFEA) at BARC, Mumbai

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**Abstract.** A 100 MeV, 100 kW RF Electron Linac is proposed for the Experimental Neutron Facility using Electron Accelerators (ENFEA) at BARC, Mumbai. The neutron yield will be $\sim 10^{14}$ n/s. An experimental neutron facility using electron accelerator will be used for measurement of Neutron cross-section $(n,\gamma)$, $(n, xn)$ and $(n, f)$ reactions at different energies for various materials. Material irradiation studies for the nuclear power programme, Production of Medical Radioisotopes, Neutron rich Radioactive Nuclei.

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## INTRODUCTION

Electron beams have played a key role in the field of basic sciences, applied sciences, medicine, agriculture and Industry. Upto the beam energy of 10 MeV, 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. Accelerator and Pulse Power Division (APPD), BARC has initiated the design and development of various types of electron accelerators. The project for Prototype Development of 100 MeV, 100 kW electron accelerator has been proposed based on the experience gained from 10 MeV RF Linac commissioned at EBC[2], Kharghar, Navi Mumbai. This Accelerator will be used for Nuclear Physics studies, Neutron rich Radioactive Nuclei, Production of Medical Radioisotopes, measurements of Neutron cross-sections for $(n,\gamma)$, $(n, xn)$ and $(n, f)$ reactions at different energies for various materials. Material irradiation studies for the nuclear power programme, etc.

## 1. RF STRUCTURE

An Electron beam of ~ 85 keV will be will be generated in the electron gun and will be injected in the linac, to have optimum transmission. The linac is intended to deliver a beam of 100 MeV with an average beam power of ~ 100 kW. The total linac will consists of 10 modules, each of ~ 900 mm length and will add ~ 10 MeV energy at each stage. Each linac module will be powered by an individual klystron operated at S-band, a frequency of ~ 2856 MHz. It is proposed to use klystrons with power rating of 5 MW(pk), 35 kW(avg) ie., the duty cycle is chosen to be ~ 0.7 %, with a pulse width ~ 25 µs and repetition rate (RR) of 250. Hence, the of peak output beam current from the last Linac module will be ~ 160 mA corresponds to Av. beam power of ~ 100 kW. The schematic of the complete linac is shown in Fig. 1.

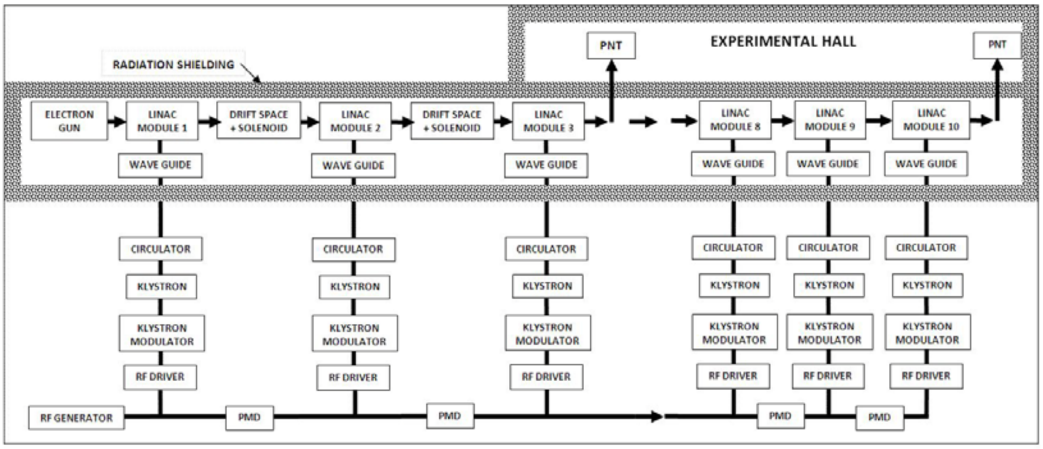


**FIG. 1.** Schematics of 100 MeV, 100 kW RF Electron Linac

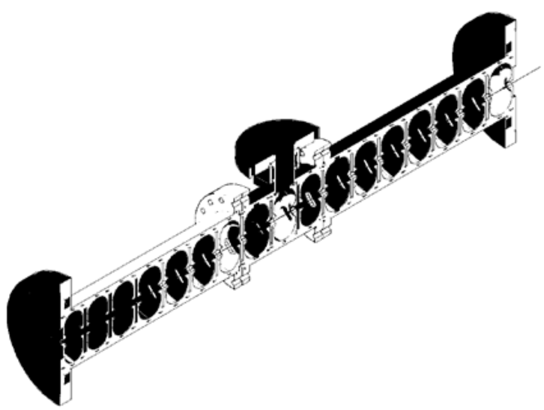

**FIG.2 :** 10 MeV RF Electron Linac Module

For the sake of simplicity of fabrication, constant impedance, bi-periodic on-axis coupled cavity linac operates in π/2 mode configuration has been selected. The first module will be similar to the 10 MeV linac operating at EBC, Kharghar, Navi Mumbai and deliver an electron beam of ~ 10 MeV, will consist of 33 cells, 3 Buncher cells, 14 Accelerating and 16 coupling cells. The length of the acceleration cavity is 52 mm, whereas the buncher cavities are 45, 48 and 50 mm respectively. An acceleration field gradient in the first three buncher cells will be ~ 15 MV/m, ~16 MV/m , ~17 MV/m resp. and ~18 MV/m in the accelerating cells 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 Module 36.072 kA/m. The outer and inner nose radii have been optimised to be 3 mm and 1 mm respectively to obtain the effective shunt impedance for the buncher cavities ~ 80 MΩ/m, while for the accelerating cavities, it is ~ 90 MΩ /m. Most of the design features of the linac have been worked out using SUPERFISH [3]. The total RF power dissipated into the structure at the operating frequency of 2856 MHz is estimated to be 2.0 MW (peak). The remaining 9 modules will consist of 17 accelerating and 16 coupling cells. The annular aperture of size 10 mm width and $30^0$ 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 one linac module made of 33 cells .

The $Q_0$ measured to be ~ 12000. The field flatness measured to be within ± 3.0 %. The above parameters will be improved by surface cleaning of the cavities.

The drift space of ~ 33 cm between two accelerator modules can be used to place a solenoid magnets to focus the electron beam and minimize beam losses at the entrance of the next Linac module, Beam diagnostic Devices for measurement of beam, as well as at the intermediate stage ie., after five accelerator modules a bending dipole magnet can be placed, so that beam at the intermediate energies can be bent in $90^0$ to the beam axis on the Photoneutron target.

In order to maintain the resonant frequency shift within permissible limits, each linac structure is provided with a cooling jacket, through which low-conductivity water (LCW) is passes, to take care of thermal loading.

## 2. BEM DYNAMICS IN THE LINAC

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 5 keV and emittance of 22.5 $\pi$ mm-mrad with $x_{max}$ = 2.5 mm. A phase width of $180^o$ has been considered for the beam pulse. About 1000 particles are scanned. Optimum transmission of the beam is obtained at an injection phase of $-35^o$.

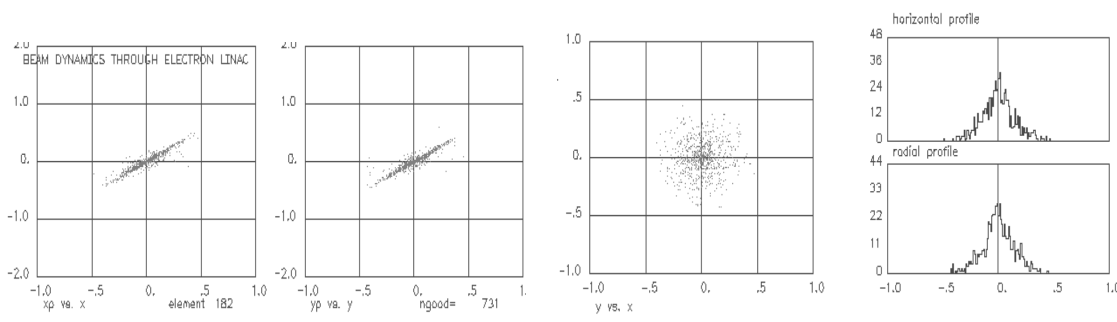


**FIG. 3:** Phase Space, Intensity Distribution of the beam at the end of the Linac

Solenoids with length ~ 20 cm and $B_z$ of ~ 1.5 kG will be enough to focus the beam after module 1 and module 2 to minimize the beam losses in the beam line. The total beam transmission without and with solenoid found to be ~ 73.1 and 69 % resp. The beam losses in the first five acc. cavities of the module 1 is found to be 9.2 %, 1.5%, 4.4%, 1.8%, 1.5%, 1.1 % resp. ie., total 16.9 % . In the remaining cavities, the beam loss is found to be negligible. The total transmission through the linac is 73.1 % with an average energy of 100 MeV and a beam power of ~ 100 kW. The output phase space and beam profile with intensity is shown in fig.3.

# 3. INJECTOR

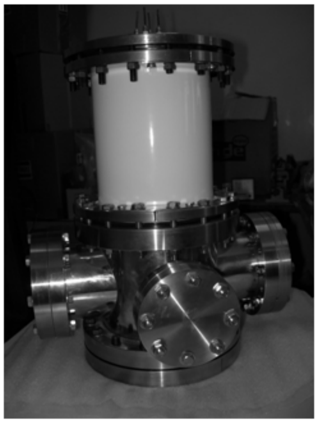

FIG. 4 : Electron Gun

The electron gun (EG), will be directly coupled to the linac system. The electron gun, with a Diode/triode geometry, will deliver a pulsed 500 mA, 85 keV electron beam, with a pulse width of ~ 25 μsec, at a RR of 250 Hz. The power for the injector will be derived from 230V, 50Hz AC mains. A solid-state modulator switching at ~ 1 kV 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)$^{o}$C will be used. The typical rise and fall time of these IGBT's is 100 ns and 40 ns resp. [4].

# 4. RF SYSTEM

A pressurized rectangular waveguide at ~ 1.5 bar with SF6 , operating in $TE_{10}$ mode will be used to transfer rf power of ~ 5 MW (peak), with duty cycle of 0.7 %, from klystron source to Each module of the linac. The total rf plumbing module will consists of RF Driver ~ 100 W, Klystron Modulator, Klystron , Circulator , Water Load , Waveguides and Phase matching Devices between all the RF Modules , so correct phase between the all Linac modules can be maintained to accelerate the electron beam to 100 MeV.

# 5. TARGET

water-cooled W-Cu alloy (75% W and 25% Cu) aligned $90^0$ horizontally in line with the electron beam will be used as neutrons generator. 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 ~ 100 kW, the face of the target which is inside the vacuum port, will heat up to several hundred $^{o}$C, will be conducted throughout the massive target (> 6kg.) and dissipated from its much lower temperature surface by circulation of water. The system will produce ~ $1x10^{14}$ n/s for 100 Mev/100 kW $e^-$ Beam. other targets will also be studied to have optimum neutron Source.

# 6. REFERENCES


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