The UHV System of the 10 MeV RF Electron Linac

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Abstract. A 10 MeV, 10 kW RF Electron Linac, for Industrial applications, is installed and commissioned at Electron Beam Centre (EBC), Kharghar, Navi Mumbai. The accelerator consists of the electron gun, RF Linac, Vacuum system, Beam diagnostics system, Magnetic sweep scanning system and Scan horn. The accelerator is divided into three sections with gate valves to isolate them, to enable servicing of pumps and modifications. The vacuum requirement in the accelerator is \( 10^{-7} \) mbar considering the breakdown parameters of the RF field within the linac. Total length of the accelerator from electron gun to the scan horn is about 5.0 meters. Vacuum plumb lines are of SS 304 pipes of nominal bores of 100 mm and 150 mm, machined internally to a surface finish of 0.8 \( \mu \)m. It encloses a volume of 156 litres. Total surface area exposed to vacuum is 57,500 cm\(^2\). It consists of 5250 cm\(^2\) of OFHC Copper, 51300 cm\(^2\) of SS 304 and 940 cm\(^2\) of ceramic sections. Leak-tightness of the order of \( 1 \times 10^{-9} \) mbar.l/s is ensured for the whole system, after eliminating the leaks at every stage of the assembly. Baking the plumb line and pumps at 150\(^0\)C, for eight hours an ultimate vacuum of \( 2 \times 10^{-7} \) mbar is achieved in the accelerator.

Modifications of the vacuum system is undertaken to suit the design changes in the gun and the diagnostic systems.

1. Introduction
Electron beams have played a key role in the field of basic sciences, applied sciences, industries, medicines and agriculture. Over the last decade or so, the trend and focus has shifted to industry. The electron beams have made significant contributions in the field of food preservation, radiation therapy, medical sterilization, sewage treatment, plastic modifications, diamond colouration etc. The RF linacs, being the most compact and capable of delivering very high beam power, have served as the major source of electron beams. Accelerators have the advantage that they do not pose any environmental threat when not in operation and hence provide better operational safety. Keeping in mind the enormous potential of electron beams, a 10 MeV, 10 kW RF Electron Linac has been developed for industrial applications.

2. 10 MeV Accelerator System
A schematic of the accelerator system is given in fig. 1. 50 keV electrons emitted from the thermionic triode-type LaB\(_6\) cathode electron gun are accelerated by a 33- cell on-axis standing wave coupled cavity linac (OA-SW-CCL) to energy of 10 MeV. The linac structure consisting of 33 cavities operates at 2856 MHz in the \( \pi/2 \) mode and is made from OFHC Copper. The RF power from the klystron is fed to the central power feed of the linac through the RF plumb line consisting of directional couplers, circulator with matched load, E and H-bends with arc detectors and RF window.
The RF plumbline from the klystron up to the RF window is under SF6 gas at pressure of 2 bar. After exiting the linac, the electron beam travels a distance of approximately 3.5 m before it is scanned by a magnetic sweep scanner and taken out through the Titanium window of the scan horn.

Fig. 1: Schematic layout of 10 MeV Accelerator system.

The accelerator is spread over two floors at EBC. Fig. 2 and fig. 3 show the assembly of the linac at the first and ground floors, at EBC, respectively.

Fig. 2: RF Electron linac assembly at first floor, EBC.

Fig. 3: Scan horn and scan magnet assembly at ground floor, EBC.
3. Requirement of UHV

The beam quality is better, if the vacuum is better. From the view of energy losses of the beam when interacting with the residual gas molecules, any pressure lower than $10^{-2}$ torr is acceptable \[1\][2]. At a pressure of $10^{-3}$ torr or lower, multiscattering effect doesn’t contribute to the beam size and hence can be neglected \[1\][2]. Considering the beam neutralization by the ions, a curve of beam radius versus length of the accelerator shows that the beam diameter remains more or less constant for a pressure lower than $10^{-5}$ torr \[1\][2]. The electron linac will accelerate the electron beam to the energy of 10 MeV over a length of 877 mm. For this, the electric field of 18 MV/m is required along the beam axis of the linac structure. To maintain this field on the beam axis at the operation frequency of 2856 MHz, the Kilpactrick limit comes out to be 1.4. This gives a maximum surface electric field of 60 MV/m. Such a high field in the cavity is prevalent in the nose gap region and has to be sustained in the presence of the beam. Due to this high electric field, field emission occurs. The electric field is enhanced due to factors like geometry and the microscopic surface protrusions, which leads to increase in field emission current. The pressure in the region of $10^{-7}$ to $10^{-8}$ torr is capable of sustaining a breakdown field of 60 MV/m and hence has been chosen as the base pressure for the RF linac \[1\][2]. The vacuum requirement at the electron gun is better than $\sim 1 \times 10^{-3}$ torr.

4. The vacuum system

The schematic of the UHV system is given in fig. 4.

![Diagram of the UHV system](image)

Fig. 4: Schematic of the UHV system of 10 MeV RF electron linac.

The UHV system is divided into three sections, the electron gun section, the linac section and the scan horn section \[3\][4]. These sections are isolated with the help of seven numbers of electro-pneumatic UHV Gate Valves (GVs). In order to minimize the vacuum gradient between different sections, distributive pumping is planned. The gun section is pumped by a 70 l/s Triode Sputter Ion Pump (TSIP). The other two sections are pumped by two 140 l/s TSIPs respectively.

To achieve high vacuum of $\sim 10^{-8}$ torr, the materials used are mainly metallic, having low outgassing rates of the order of $\sim 3.0 \times 10^{-12}$ torr-l/cm²-s. The accelerator system is mainly made of OFHC copper, SS 304 and ceramic for the electron gun. The total volume of the vacuum system is 156 litres and the total surface area exposed to vacuum is 57500 cm², which consists of 5250 cm² OFHC
copper, 51300 cm² SS 304 and 940 cm² ceramic. All the vacuum pipelines were electropolished to achieve a surface finish of 0.2 µm and leak tested up to a leak tightness of 5 x 10⁻¹⁰ mbar-l/s using MSLD. The total assembly, as it was building up at EBC, was vacuum leak tested in stages and the entire linac system was found to be leak tight up to 1 x 10⁻⁹ mbar-l/s. OFHC copper gaskets are used for the conflat flanges. Viton gaskets are used in the foil holder assembly.

Keeping all the gate valves open, initial evacuation and baking (upto 150°C) are carried out by a 400 l/s Turbo Molecular Pump (TMP) backed by a 200 l/min 2-stage Rotary pump. Auxiliary lines are provided so that each section can be independently pumped by the TMP-Rotary combination, i.e., opening GV7 and GV4, GV5 and GV6 will independently pump the scan horn section, the linac section and the gun section respectively. After baking, the TSIPs are switched on and the TMP-Rotary pumps are isolated by closing gate valves GV4, GV5, GV6 and GV7. Vacuum is measured with the help of 3 number of dual Pirani - cold-cathode magnetron gauges (G1, G2 & G3), one at each section, and one Pirani gauge (G4).

The entire vacuum system has been provided with interlocks and is operated remotely and manually both from the power supply room and the 10 MeV control room. The scan horn has provision for holding a 50 µm thick Titanium foil, which separates the atmosphere from the UHV. Currently we have used a SS foil of 100 µm thickness. This foil is vulnerable to puncture and can cause an air rush in to the accelerator, spoiling the electron gun, accelerator structure, sputter ion pumps. Pressure rise due to the foil rupture will be sensed and the power to electron gun, the klystron will be put off and the gate valves closed simultaneously by interlocking the system.

The UHV system has been commissioned and a vacuum of 3 x 10⁻⁷ mbar is achieved in the entire linac system [5].

5. RF commissioning and modifications in the system

The RF commissioning of the linac was commenced with low RF power (300 kW) at low PRF. Initially there were heavy arcing inside the linac, which was indicated by the deterioration of the vacuum in the linac region. The vacuum improved immediately after an arc. With time the arcs reduced and the fluctuations in the vacuum reduced, thereby indicating proper RF conditioning. The linac was RF commissioned up to 4 MW forward RF power with PRF of 100 Hz. This was followed by the commissioning trials with beam. The linac was commissioned with an electron beam current of ~1 mA. The energy of the beam was ~10 MeV. The electron gun chamber was modified and the anode-linac distance reduced to 45 mm. The TSIPs are brought close to the main beam line and the auxiliary line is removed. There are three gate valves and three gauge heads in the entire system. The maximum beam of 88 mA is achieved. The vacuum in the gun region is 8 x 10⁻⁶ mbar during operation.

6. Conclusion

The 10 MeV linac vacuum system has been commissioned without and with the beam. Modifications made in the system have improved its performance.

References
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