Chapter 16

Vacuum in Industrial Electron Beam Accelerator

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Industrial electron beam accelerators need a vacuum of the order of 5×10^{-7} mbar or better in the beam line. Good vacuum ensures less beam loss due to scattering. Radiation emission from the beam line also reduce with better vacuum. Vacuum provide the required high voltage insulation in the beam line to sustain the required voltage gradient. A high voltage gradient of 1 MV/meter is required in DC accelerators while for RF accelerators, a voltage gradient of 20 MV/m is needed. Further, critical components such as cathode of the electron gun, accelerator tubes etc have longer life once kept in vacuum. Vacuum serves as the basic diagnostic tool for the beam interaction with surfaces.

16.1 Description of the System

Electron gun, accelerator column, beam transition tube and scan horn constitute the beam line. Extracted beam of few mA is accelerated to the desired energy and transported for few meters before scanned into a sheet of length typically one meter. Beam need to be focused and steered in its long travel to avoid interaction with the surfaces of the beam line. In cargo scanners, the scan horn is replaced by the water cooled tungsten target, which emits X-rays which is collimated to useful size to scan the material effectively. Since the electron gun is thermionic one, the filament temperature goes up to 1700 ℃. So, the chamber walls get heated up during the gun operation and outgassing increases. At the beam exit window or the X-ray target, a portion of the beam is dissipated and hence the temperature goes up. This also rises the outgassing there. So, at these regions the gas load will be more compared to the other regions if the beam optics is good.

16.2 Vacuum Design Considerations

For good beam transmission, a good vacuum gradient is to be maintained in the beam line. Since the accelerator column goes to high voltage, there are limitations in putting pumps in these regions. But vacuum conductance is poor in the accelerator due to the peculiarity in geometry of the structure. So, the effective pumping speed available in the gun will be limited by this conductance. Similarly, for scan horn, the available pumping speed is limited by the conductance of the beam locating aperture. Hence, we put additional pump(s) at the scan horn to improve the vacuum there. The basic pumping equation is,

$$P_u = \frac{Q_T}{S_E} \tag{16.1}$$

Where P_u is the working pressure; Q_T is the gross throughput at the point of measurement, and S_E is the effective pumping speed available at this point. Since the pumping speed is limited by the conductance, we have to reduce the throughput to achieve a better vacuum. We can see the geometry of the individual RF linac cell in the following Fig. 16.1(a). Each cell is of 8.5 cm maximum diameter, approximately 3 cm long Considering the 10 MeV RF linac, it is an assembly of 33 such cells. Central aperture is 1 cm in diameter and 2 cm long. Also, the bean shaped RF ports (2 nos.) are oriented at right angles in consecutive cells. So the conductance of the linac is limited to 0.11 lit/sec. By employing pump of any speed we shall not achieve a speed better than 0.11 lit/sec. In DC accelerator tube, the assembly of 19 numbers of titanium chevrons (8.3 cm ID, 1 mm thick), insulated by 18 nos. of ceramic insulators (143 mm diameter, 3 mm thick, 3 mm long). An effective conductance of 32.5 lit /sec per tube is obtained. So, to obtain a good vacuum we have to reduce the throughput, which requires a good vacuum practice.

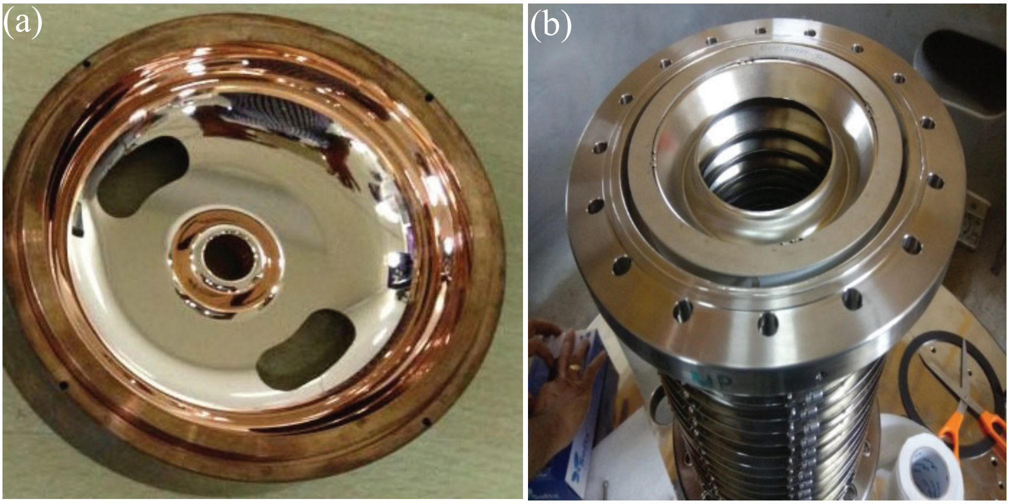

Figure 16.1: (a) Cell of the RF linac, and (b) Accelerator tube of DC accelerator.

16.3 Vacuum Practice Measures

To reduce the throughput the following measures are taken during the construction, establishment and maintenance of vacuum.

16.3.1 Material Selection

In RF linac, OFHC copper is used for the construction of the accelerator structure. The material itself is very pure and bulk outgassing of the material will happen at the brazing process. So, the throughput out of the linac is minimal. In DC accelerators, the accelerator tubes are made of ceramic and titanium. The tubes are pre-conditioned to use directly. Aluminum ring is used to seal the tubes flanged coupling. Electron gun is made of refractory metals like Tantalum, Tungsten, molybdenum etc. The chamber is of SS304 L. For plumbing lines SS 304 L is used. In beam line, the bellows used is made up of SS316 LN, micro-plasma edge welded. For beam window, annealed titanium foil is used. For all the flanged couplings, except that for foil holder assembly, metal gaskets are used. CF flanged fitting is mostly used. Annealed OFHC copper gaskets are used for sealing.For the foil holder assembly, Viton gaskets are used since the temperature is expected to rise due to the beam. All the gauges are radiation resistant of metal and ceramic construction. The gauge and pump supply cables are radiation resistant. The insulation material at the high voltage connector to SIPs is switched to ceramic from Teflon to improve the radiation resistance. Cold forged nut and bolts are use as fasteners for flanged couplings.

16.3.2 Manufacturing Process

The vacuum components are machined with specific grade coolants. Finishing of the internal surfaces is very important. Good finishing will reduce the effective surface area, hence the outgassing throughput. All the welds are TIG grade fuse welds done internal to the vacuum to avoid the entrapment of gases.

16.3.3 Cleaning and Pre-conditioning of the Vacuum Components

After the fabrication, the components are cleaned thoroughly and electro-polished. At site, the components are cleaned with isopropyl alcohol. Smaller components are cleaned in an ultrasonic bath at hot water-citronox added- for an hour. Dried and cleaned in isopropyl alcohol for half an hour in cold condition. Larger components such as scan horn are cleaned internally with isopropyl alcohol, and later air baked at 150 ℃, for one hour.

16.3.4 Leak-testing

Individual components are leak-tested for a leak-tightness up to 5×10^{-10} mbar.lit/sec or better. At the site, components are assembled one by one, and each joint is leak-tested after the assembly. Leak-tightness of 5×10^{-10} mbar.lit/sec is desired. An RGA is included in the accelerator to detect the leakage of SF_6 gas or its byproducts or components into the beam line. This testing is done offline when the accelerator is off. This RGA is also used leak detection in general.

16.3.5 Baking

The throughput has to be reduced to obtain good vacuum in accelerator. After the assembly and leak-testing, the accelerator is pumped down to the ultimate base vacuum level. To improve the base vacuum, the accelerator needs to be degassed by heating it up. All the parts are to be heated to 150 ℃, for 24 hours. Sensitive parts like gauges; bellows etc are baked up to 80 ℃. Heating tapes are employed for this purpose. Previously 10 MeV linac was pumped down differentially. But the plumbing lines for the pumps were long. This adds a load to the linac throughput. So, we removed the plumbing lines and brought the pumps near to the accelerator, which reduced the pump down time drastically.

16.4 Operational Experiences

Even though the pumping is hampered by the conductance of the accelerator for pump down, vacuum got improved with continuous pump down. The out gassing rates fall two orders down by 100 hours of vacuum exposure. On keeping on the SIPs, the vacuum improved drastically. Desorption from the surfaces increase with beam incidence even after thorough baking. So, after beam extraction, the base as well as the working vacuum levels is found to be better. We have to protect the nascence of the surfaces exposed to vacuum, during a service break. Dry nitrogen monolayer is deposited on the surfaces prior to the exposure to atmosphere. This will prevent a moisture deposition on the surfaces. Also, we have to minimize the time of exposure. The total throughput can be evaluated by conducting a pressure rise experiment. We have seen that the actual throughput of an established vacuum system is lower to the design value by an order or two. In the 72 hours run of the DCA at 1.5 MeV, 10 kW, we can see that the vacuum is remaining (Fig. 16.2) in the 10^{-7} mbar range.

16.5 Conclusion

Since the effective pumping speed of the accelerator is limited due to the conductance, stress is given to reduce the throughput by following good vacuum practices. Modification in the beam lines improved the vacuum scenario of accelerators. Unwanted loads are to be avoided. Every component seeing vacuum need to be characterized for its behavior especially outgassing in the operational condition is to be done to properly assess the throughput.

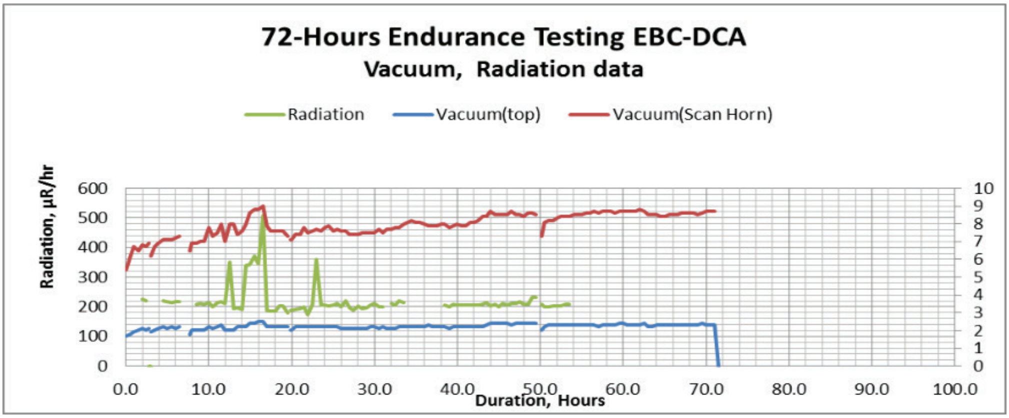

Figure 16.2: Vacuum level and radiation dose with time while operation of accelerator (right hand side y-coordinates are for vacuum in 10^{-7} mbar range).

Suggestions for Further Reading

a) [81–85]