DEVELOPMENT OF 3 MeV, 30 kW DC ELECTRON ACCELERATOR AT EBC, KHARGHAR

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Abstract

A 3 MeV, 30 kW DC industrial electron accelerator has been designed and is in advanced stage of development at Electron Beam Center, Kharghar, Navi Mumbai. Electron beam at 5 keV is generated in electron gun with LaB_6 cathode and is injected into accelerating column at a vacuum of 10^{-7} torr. After acceleration, the beam is scanned and taken out in air through a 100 cm X 7 cm titanium window for radiation processing applications. The DC high voltage accelerating power supply is based on a capacitive coupled parallel fed voltage multiplier scheme operating at 120 kHz. The electron gun, accelerating column and high voltage multiplier are housed in accelerator tank filled with SF_6 gas insulation at 6 kg/cm^2. This paper describes about the design details and current status of the accelerator and its various subsystems.

INTRODUCTION

Electron beam accelerators are finding wide ranging applications like surface curing of coatings, cross-linking polymeric materials, sterilization of medical products, coloration of diamonds, disinfection and preservation of food products, purification of industrial and biological waste etc. Electron beam energy and dose rate for different application differs widely depending upon the type of product and the desired modification. The beam energy and dose rate requirement for these types of applications ranges between 0.15 MeV to 10 MeV and few kilowatt to hundreds of kilowatts. In view of the growing needs we have taken up indigenous development of industrial accelerators at APPD, BARC. A machine rated for 3 MeV, 30 kW beam power is now under development [1] which being commissioned at Electon Beam Centre, Kharghar, Navi-Mumbai. The 3 MV DC supply for this based on a parallel fed voltage multiplier scheme considering power efficiency, energy stability and reliability [2]. The accelerator is designed to operate with beam energies from 1 MeV to 3 MeV with beam current of 0 -10 mA.

ACCELERATOR DESIGN

Schematic of the accelerator is shown in Fig. 1. The accelerator and its high voltage power supply are housed in a pressure vessel filled with SF_6 gas as the insulation at 6 kg/cm^2. The accelerator is a vertical assembly housed in a concrete building where the accelerator is located in the upper cell and the product irradiation facilities in the lower cell. A triode electron gun using LaB_6 cathode generates the electron beam and injects into the accelerating column at 5 keV. This beam is accelerated through a 3.5 m long accelerating column assembly consisting of 10 numbers high gradient metal-ceramic diffusion bonded tubes made by NEC, USA. Potential grading of the accelerating column is accomplished by a resistive divider chain. Electron beam after acceleration is transported through a beam line, scanned and brought out to atmosphere through titanium window for radiation processing applications.

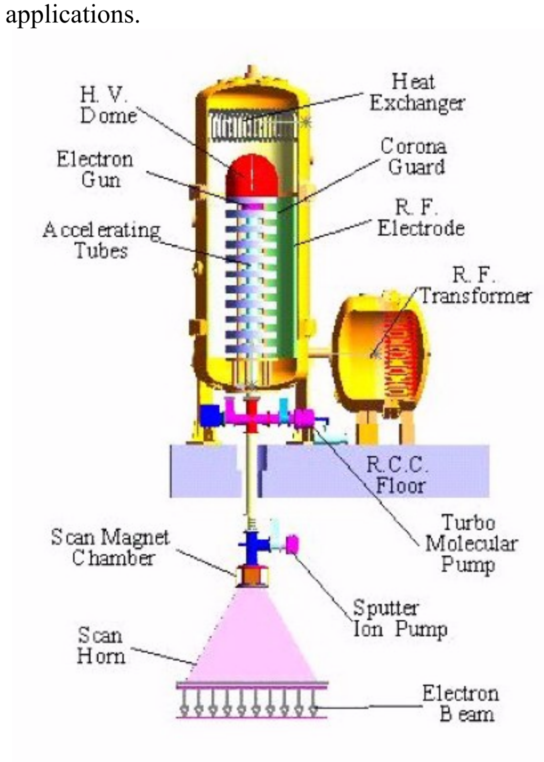

Figure 1: Schematic of 3MeV, 30kW Accelerator

High Voltage Supply System

The 3 MV, 10 mA DC supply for the accelerator is based on a 68 stage, capacitive coupled parallel fed voltage multiplier scheme operating at 120 kHz. The input to the voltage multiplier is 150 kV - 0 -150 kV (peak), 120 kHz which is fed to a pair of semicylindrical feeder electrodes. The feeder electrode assembly supported on the insulators inside the pressure vessel is shown in fig.2. Power from the feeder electrodes is coupled to an array of semi-circular corona guards of the voltage multiplier column through the inter-electrode capacitances between each corona guard and the RF electrode. The coupled voltage between two opposite corona guard is about 50 kV (peak). These stage voltages are rectified using 68 numbers of high frequency rectifier stacks and cascaded to achieve 3 MV DC. Extra corona guard electrodes are provided for extracting auxiliary power at the high voltage terminal and for ripple filter.

Figure 2: Feeder Electrode Assembled inside the Pressure Vessel

Figure 3: 150kV-0-150kV/120kHz transformer

The 150 kV - 0 -150 kV (peak), 120 kHz source is generated [3] by class-C push pull vacuum tube oscillator operating in Colpits configuration and a resonant transformer. The self capacitance between RF electrodes and the secondary inductance of the transformer forms the tank circuit for the oscillator. Feedback for the oscillator is derived by configuring electrodes in between RF feeder electrodes and pressure vessel. The transformer is an air-core in toroidal geometry, made using 2464 strand, 40 AWG Litz wire has 5 mH inductance and no-load Q factor of 1500 at 120 kHz. A photograph of the transformer installed inside the transformer vessel is shown in fig.3.

The high voltage multiplier column is assembled around the accelerating column on an acrylic support structure. Height of the voltage multiplier column is made nearly equal to the accelerating column to minimize radial electric field stress between them. Components dimensions and geometries are designed to limit electric fields less than 160 kV/cm with 6kg/cm^2 SF_6 gas environment. For measurement of 3 MV DC a voltage divider chain made into 4 modules is attached on the high voltage column. A photograph of the voltage divider module is shown in fig.4.

Figure 4: 750kV Voltage Divider Module

Auxiliary Supply on 3 MV Terminal

For powering the devices which are floating at 3 MV terminal is provided by an alternator. The alternator is driven by a motor and an insulator shaft assembly supported on the high voltage column. The ratings of the power supplies at the high voltage terminal are 15V/20A, 5kV/15mA and 3kV/5mA for filament, anode and control electrode respectively of the electron gun, 24V/4A for sputter ion pump and 18V/1A for control electronics. Arrangements are also made for extracting power from the RF source itself at the terminal using a step-down transformer.

Beam Generation and Transport

A triode electron gun using indirectly heated LaB_6 material as cathode is the source of electron. Electrons beam is extracted with anode potential of 5 kV which is injected to in to the accelerating column. Magnitude of the beam current can be adjusted by controlling the heater temperature and the potential on the control electrode. Injected beam is accelerated under the applied potential and further transported through a 3.5 m long, 100 mm diameter beam line to the scan chamber. Vacuum pumping systems are attached on this beam line. Apart from vacuum system there is a thermal based beam locating aperture, a focus coil, and two sets of beam steering coils. Before the beam enters into the scan chamber it can be aligned by adjusting current in these coils. The beam is then scanned at 100 to 200Hz to cover over 1 m width uniformly using a bipolar magnet and brought out to the atmosphere through 120 cm x 7 cm, 50 micron thick titanium window for product irradiation.

Figure 5: High Voltage Assembly

Utility Systems

Other than the core systems described above there are many other sub-systems which are essential for reliable and safe operation of the accelerator. This includes radiation shielding, vacuum system, SF6 storage & transfer system, ozone removal system, product conveyor system and cooling systems. For radiation shielding the accelerator is housed in concrete building. Accelerator is located on the upper floor above the irradiation cell isolated one another with 1 m thick concrete slab to protect the sensitive components from high intensity X-Rays. Irradiation cell having 1.5 m thick concrete walls attenuate the estimated radiation of 4.6×10^8 mR/h at 1 m from source to a safe limit value of 0.1 mR/h in the occupational area. Separate conveyor arrangements are made for handling thick cables and products in trays. Two blowers of 11268 cfm capacity remove the ozone in the irradiation cell. This ensures ozone level in the cell below 0.1 ppm within 5 minutes of switching off the beam. Two chiller type heat exchangers, one at the top of the accelerator and the other in the RF transformer side tank removes heat generated within the accelerator tank. Cooling of scan horn, beam dump, vacuum system and oscillator components are with low conductivity water. Forced air cooling system is incorporated for the beam aperture. A SF_6 handling system consists of two storage tanks and a handling cart that can transfer the gas from accelerator tank to the storage tank and back to accelerator tank during maintenance. This system is also capable of evacuating the tanks up to 0.1 torr in either direction and also can remove dust, breakdown products and moisture through filters built in the handling cart.

Control and Protection Systems

A two level control scheme is adopted for the accelerator in which a centralized control system is for the normal operation and local control for each sub-system. This scheme allows easy testing and maintenance. All signals to and fro from the accelerator are brought on the respective local control. From local controls, the signals which are essential for regular operation is transferred to the control room for computer control. Control instrumentation has a number of interlocks for the personal and system safety. Most of this interlocks are ultimately linked with the high voltage power supply controls which inhibit operation in case of fault. A micro controller based annunciation panel is incorporated in the high voltage system local control which helps in fault identification. For protection of sensitive components hard wired fast acting interlocks are incorporated in the local control level. In order to minimize EMI, signal transmission between the accelerator and control system is through optical isolators.

STATUS AND SUMMARY

Fabrication of all the sub-systems of 3 MeV accelerator is completed. Most of the sub-systems like 50kW/120 kHz oscillator, RF feeders, 150kV – 0 – 150 kV transformer, SF_6 transfer system, cooling system, beam scan assembly, conveyor system, vacuum system are installed and tested. Installation and testing of the high voltage supply is in the advanced stage. It is expected that the accelerator will be commissioned shortly.

REFERENCES

[1] R. Majumder, K.C. Mittal, K.Nanu et al, "Design and Development and Status of 3 MeV, 30 kW DC Industrial Electron Accelerator at Electron Beam Centre, Kharghar", Proc. InPAC-2003, CAT, Indore, Feb. 3–6, 2003, p-241.

[2] K. Nanu, D.K. Sharma, R.N. Rajan et al , "Design of 3MV, 10mA DC Power Source for E-Beam Accelerator", Proc. InPAC-2003, CAT, Indore, Feb. 3–6, 2003, p-246.

[3] R.I.Bakhtsingh, S.K.Srivastava, P.C.Saroj et al, "Design of 50kW, 300kV RF Source for 3MeV, 10mA Industrial Electron Accelerator", Proc. InPAC-2003, RRCAT, Indore, Feb. 3–6, 2003, pp-447.