STATUS OF INDUSTRIAL ELECTRON LINAC DEVELOPMENT PROGRAMME AT BARC, INDIA

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Abstract

Electron accelerators from 500 keV to 10MeV energy are employed for surface irradiation, food preservation, medical sterilization, cargo scanning and other industrial products. At EBC, a 10 MeV Linac has been indigenously developed and is operational for radiation processing. This is an on axis coupled cavity standing wave type of RF linac operating with 50-70 keV electron gun having LaB6 cathode and klystron based RF source at 2856 MHz. The linac is currently operating at 10 MeV, 130 mA (peak), 10 μs pulses at a prf of 415 and is employed for various experiments. A similar 9 MeV linac is operational for cargo scanning. A compact 9 MeV linac is under development. A 500 keV. 3 kW DC accelerator based on Cockcroft Walton multiplier has been operational for industrial surface processing. A 3MeV DC accelerator based on parallel coupled multiplier column is operational at 1 MeV, 4.6 kW level. Experiments for pollution control are planned on this accelerator. A 700 keV, 5 kW DC machine for cross linking and graft polymerization is under development. A 100 MeV, 100 kW electron Linac for producing intense neutron source has been proposed for development. Technological developments, operating experiences and utilization for industrial applications will be described.

INTRODUCTION

The extensive use of electron accelerators for industrial applications has spurred the industrial accelerator programme in APPD/BARC. The programme involves building and operating high power electron accelerators in the energy range of 200 keV to 10 MeV to cater to most of the applications. There has been a constant focus to develop the core technologies required for these accelerators indigenously and this effort has yielded successful results, which are evident in the present operation of these accelerators.

10 MeV RF LINAC

An Industrial 10 MeV RF Electron linac [1], shown in Fig.1, has been in operation at Electron Beam Centre, Navi Mumbai, for the past three years. This pulsed linac has an on-axis coupled cavity bi-periodic π/2 structure and operates at frequency of 2856MHz [2]. The injector is an LaB_6-based electron gun [3] in the triode configuration. Klystron-based RF source powers the linac [4]. The 10 MeV output beam is scanned over a length of 1 m with the help of a scan magnet [5]. The electrons emerge into the atmosphere through the 50 micron thick titanium window and are incident on the products to be irradiated, which are placed on the conveyor. This linac can be used in the x-ray mode too, during which the electron beam impinges on a tantalum target to produce Bremmstrahlung.

Fig. 1: 10 MeV linac system

One of the main technological challenges of this linac has been the design and development of the RF cavity which forms the main heart of the system. The cavity, made of OFHC copper, has a complicated geometry and requires dimensional tolerances in the range of 10 - 20 microns and surface finish better than 0.2 microns. Each cell of this cavity is manufactured separately and then the 33 cell assembly is brazed in a vacuum furnace. This challenge has been successfully implemented using indigenous facilities available at CDM/BARC and the private industry in and around Mumbai.

Another technological challenge is the design and development of the electron gun, which produces electrons of 70 keV, 1A (pk). The triode gun uses LaB_6 as the cathode material, which is indirectly heated. Ceramic is used as the insulation between the anode and cathode to withstand voltages up to 70 kV (pulsed). The entire heater assembly and ceramic has been developed indigenously.

The klystron-based RF source, developed in collaboration with SAMEER, Mumbai, produces output power of 6MW (pk), 25 kW (avg) at a frequency of 2856 MHz. This is powered through a line-type modulator (55kV, 280A, 10µs, 415 pps) which uses a thyratron as the switching element.

A distributed turbo-cum-sputter-ion pumping system [6] enables a vacuum level of 10^{-7} in the linac system. Scan magnet made of silicon steel laminations is used to generate a maximum magnetic field of ~1.5 kG. Scan horn, made of SS304, has been designed and developed indigenously. Thermal analysis of the linac cavity [7] has been carried out to assess the temperature distribution and cooling water requirement. A demineralized water system [8] caters to all systems which require cooling. Hard-wired interlocks have been provided for the safe operation of the linac.

RF conditioning of the linac [9] was carried out and the linac tested up to a maximum beam power of 5kW [10] A successful 24-hour continuous run, at 3kW, established the long term stability of all the linac parameters. Dosimetry studies [11] have established dose uniformity in the static and dynamic mode of ±8% and ±5% respectively. The linac is being used for a number of applications [12], both industrial and research, including irradiation of PE gaskets to enhance mechanical properties, coloration of gems, irradiation of food products to increase shelf-life, etc.

9 MeV RF linac for cargo-scanning

Cargo scanning systems are based on high energy X-rays generated from accelerated electrons. For this purpose, a 9 MeV RF linac, shown in Fig.2, has been developed and commissioned at the Linac Test Facility (LTF), ECIL, Hyderabad [13]. This linac, similar to the 10 MeV industrial linac, operates at a frequency of 2856 MHz with pulse width of 6µs and 200 Hz repetition rate. A klystron-based RF source powers this linac [14]. Output beam power required is 1 kW (max) with beam diameter of less than 2mm and x-ray dose of ~24 Gy/min/m. In this linac, the output 9 MeV electron beam is focussed by the use of a focussing solenoid to get the required beam size and the x-ray target is placed at the end of the beam tube. A collimator [15] is then used to obtain a fan beam within ±30° in the forward direction. PC-based control systems have been developed for remote operation and data acquisition [16].

In this linac, the most crucial technological challenge is to obtain the required beam size and stability for cargo-scanning. To accomplish this goal, electron beam of ~3-4 mm has been generated using a smaller pellet of LaB6 and adopting the Pierce gun geometry [17]. For stability, grid is energized with dc and used for control. These factors have been considered in the design and development of focussing solenoid and its power supply. Proper mechanical arrangements have been made to ensure alignment within the required tolerances.

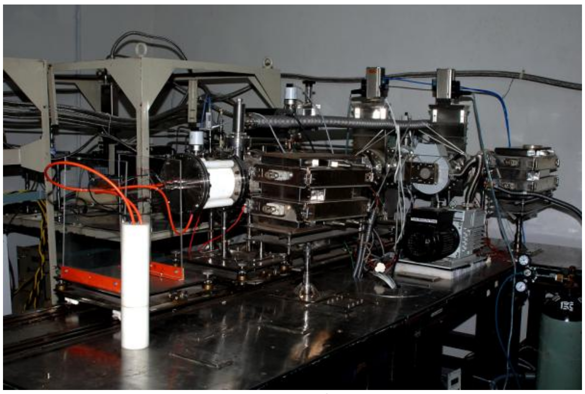

Fig. 2: 9 MeV linac for cargo-scanning

The linac has been RF-conditioned up to a peak power of 2.6 MW. Peak beam current of ~100 mA has been measured at the output of the linac. X-ray dose of ~24 Gy/min/m has been measured on the tantalum target. Beam size of ~2mm has been obtained on the target. Collimator has been assembled. Further experiments are underway.

3 MeV DC Accelerator

A 3MeV, 10mA DC Electron Beam Accelerator [18] based on the parallel-coupled voltage multiplier scheme in SF_6 gas at $6kg/cm^2$ pressure has been developed and is presently undergoing commissioning trials. Fig.2 shows the multiplier column and corona guards of the 3 MeV accelerator.

Fig. 3: Components of 3 MeV DC Accelerator

The voltage multiplier is configured in a cylindrical-geometry around the 3.5 m long accelerating column. The electron gun is situated at 3 MV terminal. Power for the gun has been derived from the last stage of the multiplier column, by using a step down transformer rated for 50kV/600V/100kHz floating at 3MV to extract 500W [19,20] The 3 MV dc required for acceleration of electron beam is developed by a 74-stage parallel-fed capacitance-coupled, cascaded-rectifier system [21] driven by a 300kVp, 103kHz input source. This is achieved by 50kW/120kHz power oscillator [22] in conjunction with a tuned air-core step-up transformer. Vacuum of 10^{-7} torr is maintained in the accelerating column with the help of turbo-cum-sputter-ion pumping system. The entire system is housed in 3 sections of tank or pressure vessel (ID = 2m, overall height = 7m) made up of boiler-grade carbon-steel plates. The beam extraction system, consisting of the titanium window, scan magnet and scan horn, are similar to that of the 10 MeV RF Linac. DM water is used to remove the heat generated (in the dome region and the air-core transformer) through suitable heat exchangers placed in the SF_6 environment inside the tank.

Special efforts are required during the fabrication of the pressure vessel which is required to withstand 6 kg/cm^2 pressure as well as vacuum. Leak tightness should be better than 10^{-8} mbar-l/s to prevent the leakage of SF6 gas, which is both costly and a potent greenhouse gas. Dimensional tolerances for circularity and cylindricity of this tank are difficult to maintain, since they are 5 times lower than ASME permitted levels. All joints should be 100% radiographed, including shell-to-flange joint and shell-to nozzle joint. Pad-type of nozzles have been designed for this purpose.

The fabrication of components of the voltage multiplier presented a technological challenge. These components include the UHV dome (98cm OD, 80cm ht, semi-circular corona-guards (97cm OD, 7cm ht), perspex support sheets of 3.3m height and 64cmx64cm perspex base. These components require mirror finish and surface finish better than 0.4 micron. It is a difficult task to maintain such tolerances in Perspex, as its sizes change after machining. Alignment of these components also plays a crucial part in the performance of this accelerator. Over a length of 5m, the tolerance required is within ±1 mm.

The air core transformer (150-0-150kV) also needs special fabrication and winding techniques. Deriving power for the anode, grid and cathode of the electron gun is another technological hurdle successfully overcome. The low-level electronics required to generate 15-300V for control and power components are prone to damage due to high voltage arcing and consequent surges. Surge protection systems [23]have been developed and tested rigorously to ensure that these low-voltage components are inherently safe have maintenance-free operation. Control of these power supplies floating at 3 MV and data acquisition from them is another major difficulty which has been overcome with the use of an optically isolated system [24]. A PLC based control system [25] has been designed and developed, to maintain the accelerator voltage at the set value throughout the operation by adjusting the input voltage in close loop to compensate any change in accelerating potential either because of beam-loading or arcing in the accelerator.

The accelerator has been operated [26] up to 7 kW of beam power at 1 MeV, with Nitrogen at 6kg/cm^2. The HVDC to UHVDC (i.e. electron-beam) power-conversion efficiency at 7 kW output was found to be 48.2%. Accelerator has also been operated upto 4.0mA of beam current at 1.5 MeV in SF_6 gas medium. Further commissioning trials are in progress. A pilot project for flue gas treatment has been planned using this accelerator, in collaboration with M/s BHEL.

500 keV DC Accelerator

The 500 keV DC Accelerator, situated at BRIT complex, Vashi, is a Cockroft Walton based DC accelerator [27] designed for 20 mA of electron beam at an energy of 500 keV. A view of this facility is shown in Fig.4 below. The accelerator consists of a LaB_6-based electron gun which delivers a beam of ~20 mA at 5 keV. The gun is of triode type, floating at voltage of 500 kV. The accelerated beam passes through the sweep scanner and the scan horn. It is extracted into air through a 25 μ thick titanium foil. The accelerating column is maintained at a pressure of 6 kg/cm^2 of Nitrogen. The accelerator has been tested up to a maximum of 500 keV, 10 mA. It has been in regular operation for the past few years, at ~350 keV, 3.5 kW. At present, the accelerator is in use for surface modification studies, cross linking of plastic sheets and granules and radiation damage studies of materials including electrical and electronics circuits.

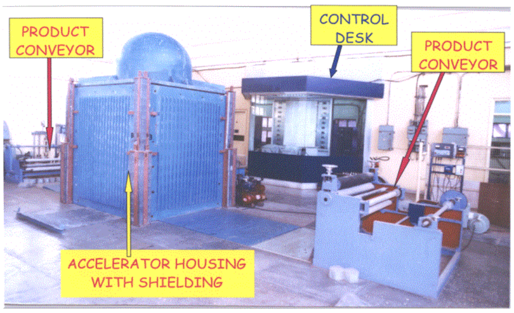

Fig. 4: 500 keV DC Accelerator facility

FUTURE ACCELERATORS

Based on the success in the design, development, testing and operation of the RF linac and DC accelerators, new projects have been taken up. These include the 9 MeV compact linac, which will be powered by a magnetron-based RF source. In this project, the focus is to make the system as compact as possible. Many of the sub-systems of this linac are under fabrication/procurement and the project is scheduled to be completed within a year. Dual energy machines for 6/3 MeV are also being considered for design and development.

Another project under development is a 700 keV, 5 kW DC accelerator, similar to the 500 keV DC accelerator, for cross linking and graft polymerization is under development.

A 100 MeV, 100 kW electron Linac for producing intense neutron source has been proposed for development. This is based on S-band RF structures, similar to the 10 MeV RF industrial linac. This will produce a neutron yield of 2 x 10^{14} per second. The linac will comprise of multiple sections with individual power feeds. The design of this linac is in progress.

CONCLUSION

Design and development of electron accelerators for industrial and other applications has now reached a mature level at BARC. Experience in the successful installation, commissioning and operation of the above high power accelerators will now prove as the major asset for development of various types of electron accelerators for several applications.

In the effort to indigenize the electron accelerator programme, development of core technologies has been taken up in-house. Development of RF power tubes (klystrons and magnetrons) required for this programme has been taken up in collaboration with CEERI, Pilani. Special RF components, such as the circulator, RF ceramic window, directional coupler, power divider, etc. has been jointly developed with SAMEER, Mumbai. Fabrication of accelerating modules with ceramic to metal joints, which are required for the DC accelerators, is being taken up with the private industry in Mumbai. This development will go a long way to have a self-sufficient electron accelerator programme for India.

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