HIGH POWER ELECTRON ACCELERATOR PROGRAMME AT BARC

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Abstract

Bhabha Atomic Research Centre in India has taken up the indigenous design & development of high power electron accelerators for industrial, research and cargo-scanning applications. For this purpose, Electron Beam Centre (EBC) has been set up at Navi Mumbai, India. Pulsed RF Linacs, with on-axis coupled cavity configuration, include the 10 MeV Industrial RF linac, as well as 9 MeV linac and compact 6 MeV linac for cargo-scanning applications. Industrial DC accelerators include a 500 keV Cockroft-Walton machine and 3 MeV Dynamitron. Several radiation processing applications, such as material modification, food preservation, flue-gas treatment, etc. have been demonstrated using these accelerators. Cargo-scanning linacs have been successfully commissioned and are being characterized for the required x-ray output. A 30 MeV RF Linac, for research applications, such as shielding studies and n-ToF experiments, is being designed and developed. For ADS studies, a 100 MeV, 100 kW RF Linac system is proposed. This paper presents the details of the design of these accelerators, their development, current status and utilization for various applications.

INTRODUCTION

Electron beam (EB) irradiation and its applications are increasing day by day. To cater to some of these applications, such as material modifications, food preservation, flue-gas treatment, etc., a programme of indigenous design and development of high power electron beam accelerators has been taken up at BARC in the Accelerator & Pulse Power Division [1]. The Electron Beam Centre, located at Navi Mumbai, houses 2 accelerators, viz. the 10 MeV RF linac and the 3 MeV DC Accelerator. A 9 MeV linac for cargo-scanning applications has been set up at ECIL, Hyderabad. For mobile cargo-scanning applications, a 6 MeV compact linac has been developed. In the field of research, a 30 MeV RF Linac has been designed and is under developed for neutron generation. Flue-gas treatment (FGT) requires megawatt-class of DC Accelerators. A pilot EB-FGT plant with multiple DC accelerators is being configured for treating the flue gas from a captive power plant of 30 MWe. Salient features and status of these accelerators is discussed here.

RF LINACS

RF Linacs operate at 2856 MHz in the pulsed mode and are based on the on-axis coupled cavity geometry. Acceleration gradients of 18 MV/m have been achieved. Three linacs developed in this configuration are successfully operating presently.

RF Industrial Linac

The 10 MeV RF linac, comprising of 17 accelerating cells and 16 coupling cells, is ~1m long. Electron gun has a triode geometry, with indirectly heated LaB_6 cathode and produces pulsed beam of electrons with energy of 85 keV. Klystron-based source provides 6 MW RF power to establish the acceleration gradient in the linac. The 10 MeV electron beam from the linac is scanned over a length of ~800 mm with the help of a magnetic scanner. Electron beam emerges through titanium window for utilization purposes. This linac is in regular operation at 3 kW for various industrial applications [2]. Irradiation of semiconductor has resulted in the reduction of reverse recovery time from 15 to 7 μs. Photofission experiments are also being conducted using this linac facility. Other successful experiments include enhancement of softening temperature of PE, gel formation, cable irradiation, etc.

X-ray Sources Based on RF Linacs for Cargo-scanning

Two linac systems have been configured to operate as x-ray sources for cargo-scanning applications.

Figure 1: View of 6 MeV x-ray source for mobile cargo-scanning applications

These include the 9 MeV RF Linac and the 6 MeV compact linac [3]. Figure 1 gives a view of the 6 MeV linac system, where the linac is only 0.6 m long.

In these systems, the accelerated electron beam is made to impinge on a tungsten/tantalum target to produce x-rays, which are then collimated into a fan-shaped beam. Beam size of <2mm has been achieved. Both linacs have produced the required x-ray dose of 24 Gy/min/m and 3.2 Gy/min/m respectively.

Neutron Generation with RF Linacs

Neutron generation is another frontier area where RF linacs are used. For radiation streaming studies on liquid sodium, a 30 MeV/7 kW RF linac has been planned and is in advanced stages of design and development. As shown in Figure 2, two accelerating sections of 15 MeV each will be used in this linac system, each powered by a separate klystron-based RF source. Water-cooled neutron target of titanium and tungsten gives a neutron yield of 2.1×10^{13} n/s. It is also planned to set up an n-ToF facility, where 100A/1 ns beams will be generated with the use of compression magnet.

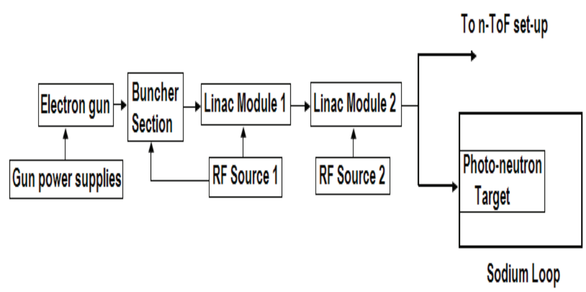

Figure 2: Schematic of 30 MeV RF Linac system for neutron generation

Experience on the 30 MeV RF Linac and modular construction of the linac systems will pave the way for the design and development of 100 MeV/100 kW systems for ADS studies. Establishing technology for the various sub-systems will be the prime focus in this project.

DC ACCELERATORS

High Power DC accelerators form the workhorse for high throughput applications. Both Cockroft-Walton and Dynamitron configurations have been designed and developed at BARC.

Industrial DC Accelerators

A 500 keV DC Accelerator has been developed based on Cockroft-Walton circuit. This accelerator, located in the BRIT complex at Navi Mumbai, is used for surface modification applications.

The 3 MeV Accelerator at Navi Mumbai, uses the Dynamitron principle for generation of high voltage. Electron gun operates at 5 kV anode-cathode potential and generates 10 mA beam current. Accelerating gradient of 1 MV/m has been achieved, with SF_6 gas as insulator. This accelerator is in operation at 1 MeV, 10 kW.

Demonstration of flue-gas treatment has been successfully carried out with this accelerator facility. Flue-gas has been simulated using SO_x and NO_x from cylinders. Water spray is introduced and ammonia is injected. Under the influence of e-beam irradiation at 5-12 kGy, SO_x/NO_x is converted to their respective acids and react with ammonia gas to form ammonium sulphate and ammonium nitrate respectively. These by-products, useful as fertilizers, are collected in the bag filter and the flue gas is then vented to the atmosphere through a stack. Figure 3 shows a view of the reaction vessel under the electron beam. Figure 4 depicts the simulated plant for flue-gas treatment.

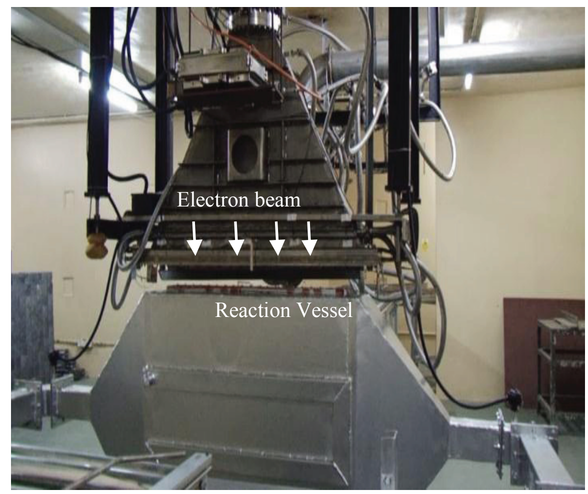

Figure 3: View of Reaction vessel below the electron beam

Figure 4: View of simulated plant for flue gas treatment

The significant reduction in the SO_x/NO_x by >50% with e-beam irradiation has been demonstrated in the 3 MeV accelerator facility and results are shown in Figure 5.

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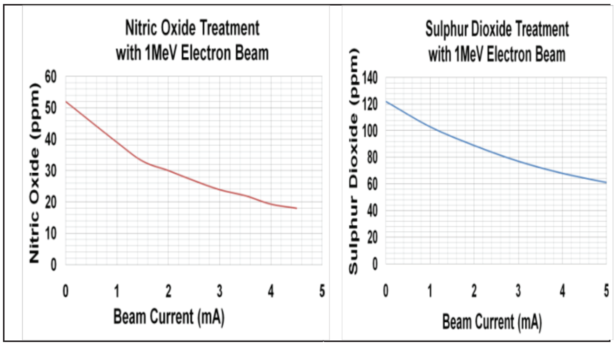

Figure 5: Reduction in SO_x/NO_x with electron beam

Megawatt Class DC Accelerators

Results obtained in the demonstration of flue-gas treatment are very encouraging and it is proposed to set up a pilot plant for EB-FGT in a captive power plant, in one of the 30 MWe streams.

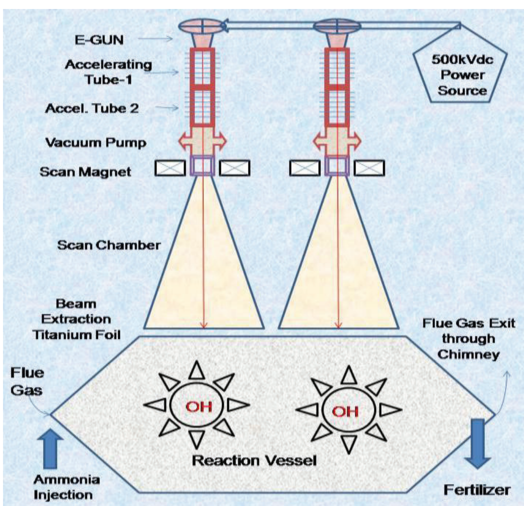

Figure 6: Conceptual design of EBFGT system

Figure 6 shows a conceptual design of 2 accelerator heads powered by HVDC line through a bus-duct. These accelerators are designed for 500 keV/1.2A beam. The reaction vessel will hold the flue gas and ammonia with water under the electron beam. Windows, used as interface between vacuum inside the accelerator and atmosphere are made of Titanium alloy,. These are designed for proper heat dissipation and mechanical strength. Modular construction of accelerators has been considered in order to make it convenient to accommodate additional accelerating structures.

CONCLUSION

The high power electron accelerator programme at BARC has been successfully implemented. Future proposed projects are in advanced stages of design and development. Productionization of various sub-systems of RF linac and DC accelerators is in progress to cater to the increasing demand for industrial, research and security applications.

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