Indian Journal of Pure & Applied Physics
Vol. 50, November 2012, pp. 805-807

Safety aspects of a medium energy industrial electron beam accelerator being utilized for technology demonstration and commercial operations

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Received 23 August 2012; accepted 28 September 2012

Bhabha Atomic Research Centre (BARC) has installed a unique high pulse-powered 2 MeV electron beam (EB) accelerator for developing industrial applications. It is capable of delivering powered EB up to 20 W average beam power (1200 kW peak pulse power) at energy 1 to 2 MeV. Safety features have been designed for safe utilization during irradiation of large scale products, safety of users, operation staff, industrial products and several types of material handling equipment. Adequate shielding is made for bremsstrahlung radiation with maximum beam energy and power. Safety for ozone emission, high voltage, RF radiation has been addressed. This paper gives an account of overall safety features incorporated in the facility.

Keywords: Accelerator, Electron beam, Industrial scale, Processing, Safety

1 Introduction

High energy (up to 10 MeV) electron beam (EB) accelerators are being utilized in fields of material modifications, sterilization of health care products, hygienization and preservation of food, cross-linking of wire and cables, etc. These machines are foolproof systems in terms of their safety and continuous operations with minimum man power in order to cut costs and achieve better economics than existing conventional technologies to produce cross-linked wire and cables, heat-shrinkable products, etc. The paper discusses various safety issues in routine processing of the machine.

1.1 Features of the EB accelerator

The industrial EB accelerator is a pulse linear accelerator and can be operated up to energy 2 MeV, 20 kW power. Electrons are accelerated under high frequency EM field generated by RF system coupled to a single toroidal resonator cavity (Fig. 1). Shape of the resonator enables to get an optimum resonant frequency of 100-120 MHz in relatively smaller dimensions. Length of the accelerating gap up to 200 mm ensures full use of accelerator voltage with small energy losses in resonator. The beam is uniformly scanned for an area of 100 cm × 10 cm in air. The accelerator is housed in a shielded cell having a labyrinth with separate entry and exit ports where power roller conveyor system has been installed for the material transport in and out of the irradiation zone (Fig. 2). Other systems of accelerator include beam extraction and scanning, beam control and monitoring, vacuum, air/water cooling, ventilation, search and secure system and product handling conveyors. The estimated values of radiation levels for the designed EB accelerator are: average dose of direct beam near extraction foil with scanning area 900 × 70 mm² is 33 kGy/s, dose of scattered electrons at 1m from steel target is 35 Gy/s, dose of BR with steel target in lateral directions at 1m is 0.05 Gy/s, ozone output within air gap between irradiated object and 0.05 mm thick extraction foil is 60 mg/s.

2 Safety

Radiation hazard can occur only when machine is in operation. Potential hazards associated with it are radiation, RF, high voltage, toxic gases (Ozone, NOX) and fire.

2.1 Radiation Safety

Radiation Shielding: To maintain dose levels and exposure to operating personnel, users, etc. in nearby area within permissible limits, the accelerator has been housed in shielded concrete cell/building confirming to ALARA principle by providing 130 cm thick concrete wall and making provision for material transport in and out of cell. Fig. 2 shows layout of EB accelerator. The output beam is available in air over
an area of $100 \times 10 \text{ cm}^2$ by beam scanning mechanism for industrial scale processing of materials.

Radiation dose due to bremsstrahlung and scattered electrons at various locations inside the cell were measured while beam is being extracted in air for product treatment. Dose mapping studies were carried out to estimate radiation field exposed to various equipment and materials lying inside vault area. EBT $(1-800 \text{ cGy}^2)$ and Gafchromic HD-810 $(1 \text{ Gy to } 1 \text{ kGy})$ films were used for dose mapping studies. Both dosimeters were suspended at 60 locations inside and around irradiation area. Accelerator was operated for 10 min to map exposure profile of X-rays generated as a result of EB interaction with Al target. The films were read using flat-bed scanner for number of pixels per unit area. The result shows that the exposure is higher near beam window.

### 2.2 RF and Safety Interlocks

An interlock system with fail-safe mechanism has been provided to ensure safety of personnel working therein. The interlock system includes cabinet door lock switches for high voltage power supplies. Entry of personnel to the radiation cell is restricted when $RF$ is ON. This is achieved by a sequential "Search Operation" that has to be successfully completed in a specified predetermined time interval. The cell entry-exit points of product containers at maze on the load/unload conveyors are cordoned with a wire mesh to avoid any incidence of forced entry to the irradiation cell. Safety interlocks and product container position limit switches are interlinked with "RF" and "Beam ON" operations. All operations in safety procedure have been supplemented with adequate audio-video alarm signals. In emergency conditions, both the Beam and the $RF$ will be automatically switched off. A pull card SS rope runs along labyrinth for emergency switching off the machine.

### 2.3 High Voltage

High voltage is present in power supply cabinets in the cell and on accelerator tank at some terminals only when door interlock and search procedure are successfully completed. This includes HV cabinet doors safety switches and a rotary lock (with a common key) which does the mechanical grounding. This key switch prohibits access to high voltage areas and eliminates possibility of applying HV to installation unless doors of power supply cabinets and accelerator cell are closed and locked.

### 2.4 Toxic, Obnoxious gases and Fire

Toxic gases (Ozone, NO$_x$) are produced when radiation passes through air between extraction windows foil and target materials. Ventilation is provided for 30 air changes per hour inside cell, maintaining negative pressure to avoid any Ozone leakage to nearby rooms and control within permissible limits in all accessible areas. Door lock actuator is given to avoid door opening during high ozone concentration. Adequate care is taken to prevent fire.

(a) If HV insulators are not maintained sufficiently clean, electrical breakdown may occur. Routine...
maintenance schedule is prepared to keep the surfaces of the HV insulators and ceramic capacitors clean and tidy to avoid the possible fire hazards.

(b) If the conveyor system fails and product delivery container stops under beam extraction window during irradiation, temperature of material being irradiated is likely to increase to its ignition point and consequently may lead to fire hazard. This not only damages the equipment, also give rise to irreparable damage to material being treated which is much valued product like diamonds, polymer formulations etc. To eliminate this, product delivery/conveyor system is provided with interlock linked with ‘Beam On’ operation, which in case of system failure, will switch off the beam.

Safety of industrial accelerators with high energetic beams (up to 10 MeV) and large beam powers (as high as 400 kW) are not only limited to radiological safety but also is extended to the various equipment, products and different activities carried out in utilizing the machine for wide ranging applications. During irradiation, due to conveyor stuck up or product tray jam, many times the material under the beam was damaged because of overdose. To overcome this problem, a unit ‘material over exposure prevention unit (MOPU)’ was designed consisting of photoelectric sensors, limit switches, delay timer and relays incorporated in the control circuit. If the product trays stop moving due to any reason, the unit shall come into action tripping the accelerator with the hooter and over exposure indicator ON. Press the acknowledge push button to make the hooter in silence mode and attend the problem, after rectifying the problem press the reset push button for keeping the unit ready for next operation.

2.5 Machine Safety

During industrial processing, EB accelerators should be reliably operating on 24 h basis with minimum shut down time and man-power involvement. There are many warning and shut down controls incorporated in machine which comes into effect in case of any failure. These are vacuum deterioration, failure of cooling mechanism, beam scanning failures, high voltage breakdowns in the cavity etc.

3 Conclusions

With effective troubleshooting, proper and relevant incorporation of safety features in accelerator facility, a totally accident-free operations (both in terms of radiological or high voltage/RF field) could be achieved for a decade long of operation which is rigorously utilized for several applications, industrial demonstration and commercial operations.

Acknowledgement

The authors wish to thank Head, RTDD; Associate Director, RC&I and CE, BRIT for their constant encouragement. We thank Dr S D Sharma, RP & AD for providing facility for dose mapping in the accelerator facility

References

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