The New IBA Self-Shielded Dynamitron Accelerator for Industrial Applications

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Abstract. Radiation Dynamics, Inc. (RDI), currently a wholly-owned subsidiary of Ion Beam Applications (IBA), has supplied particle accelerators for both research and industrial applications worldwide for almost 50 years. The industrial market demands are driving the development of a new Dynamitron® system with a smaller, more compact configuration that may be provided at a lower entry cost. This new system, operating at electron energies up to 1.0 MeV, includes integral shielding, which allows the appropriate material handling system to be installed inside the radiation enclosure. Designed to operate with beam power levels as high as 100 kW, this new system provides a robust base for high-throughput crosslinking of products such as electrical wire, heat-shrinkable plastic tubing and sheet materials. Still retaining the positive aspects of the current Dynamitron system that have established it firmly in the industrial sector, this compact system can be tailored to meet a variety of processing applications.

INTRODUCTION

Industrial electron accelerators have long been used for crosslinking polymeric products, such as insulated wire and cable, heat-shrinkable tubing, encapsulations and food packaging film, plastic foam and automobile tire components. As accelerators have become more reliable and acceptable for industrial processing, the need for integrated, on-line e-beam processing systems has increased. The demand for highly-reliable, high-power, compact equipment has promoted the design of this new Dynamitron electron beam system. Smaller than its robust predecessors [1], this accelerator system delivers comparable beam power and is self-shielded, so that a large, concrete vault is not needed for radiation protection. Currently offered at energies from 300 keV to 1.0 MeV, it is capable of crosslinking a variety of products. Whether installed in-line or off-line in the manufacturing process, this system can provide continuous operation with high throughput rates, high reliability and low operating costs. These are essential features ensuring that commercial processing requirements can be met.

DESCRIPTION

The accelerator itself, with its shielding but without the radio-frequency power supply, stands slightly over 5 m (16.5 ft) tall and occupies about 8.5 sq m (92 sq ft) of floor space. This small foot print provides the ability to install this system within existing process lines with a minimum of equipment relocation. The high-voltage components of this dc accelerator are housed in a pressure vessel filled with sulfur hexafluoride gas as the insulating medium. This allows for very high voltages and high electric fields to be achieved in the limited volume of the enclosure.

The pressure vessel contains both the high-voltage generator and the multiple-gap electron acceleration tube, as shown in Fig. 1. The acceleration tube, usually called the beam tube, is mounted coaxially inside the high-voltage rectifier column. This reduces the physical size of the system and shields the tube inside the linear gradient of the high-voltage column. With the tube placed here in the neutral rf plane, the accelerated electrons are free from any rf electric fields that could adversely affect their flight path.
FIGURE 1. Compact accelerator assembly with lower radiation shield.

FIGURE 2. Top view of high-voltage rectifier column.

FIGURE 4. Completely enclosed accelerator assembly with beam scanning system, upper and lower radiation shields, including product entrance and exit chambers.
The electron gun, mounted at the high-voltage end of the beam tube, is capable of providing up to 160 mA of dc beam current. The lifetime of the cathode, which is a tungsten-wire filament, may reach 25,000 hours and it can easily be replaced. The power for heating the filament is derived from a portion of the rf power coupled to the high-voltage rectifier column. The electron emission is determined by the filament temperature, which is controlled by means of a saturable-core transformer. This device is controlled by an external optically-coupled system.

The nominal 460 volt, three-phase ac line power is converted to 15 kV dc power with a conventional iron-core step-up transformer and a bridge rectifier circuit. This dc power is supplied to an industrial triode tube, which drives a resonant "tank" circuit. The tank circuit consists of an iron-free step-up transformer connected to a pair of semi-cylindrical electrodes, which enclose the high-voltage rectifier assembly. The rf power is coupled to all of the rectifiers in parallel while high-voltage dc power is obtained from the series-connected rectifiers. This Dynamitron system allows for many rectifier stages with minimal coupling capacitance to each stage and very low stored energy in the system (typically less than 100 joules). This essentially eliminates the risk of damage to sensitive components that might occur during adverse operating conditions or internal arcing of the high-voltage components.

The triode tube operates in Class C mode, which provides very good efficiency for converting dc to rf power at a frequency of about 100 kHz. The efficiency for converting input ac line power to electron beam power usually exceeds 60%. A self-tuning and self-biasing grid feedback network compensates for small changes in the resonant frequency and large changes in the beam power. This arrangement ensures stable rf operation over the full range of beam power. The high-voltage potential generated by the rectifier assembly, which determines the electron energy, is controlled by the dc voltage applied to the anode of the triode tube. The electron energy is stabilized by a feed-back signal obtained from a voltage divider, which is a column of resistors mounted alongside the electron beam tube.

**ENHANCEMENTS**

The enhancements realized in this new design are:

- Compact configuration, which reduces the system shielding by about 50%
- Reduced size generally translates to lower discreet component costs
- New solid state rectifiers reducing size and part counts and improving performance
- New rf transformer design improving efficiency and reducing heat loads
- New beam current controls reducing complexity and internal control components
- Elimination of mechanical control devices within the pressure vessel to minimize maintenance
- Compact integrated cooling system
- Parallel rectifier configuration allowing high beam currents in low-voltage applications
- New "Millenium" system controller based on over 25 years of programmable controllers
- User oriented integrated system controls and diagnostics
- Customized integrated radiation shielding and material handling interface

The enhancements that have most contributed to this enhanced accelerator system are the re-design of the solid-state rectifiers and the assembly of the high-voltage column. All components in this column conform to the cylindrical configuration, as shown in Figs. 2 and 3. Challenges in providing an assembly that is as robust as the original Dynamitron design and yet occupies approximately half the space were overcome utilizing state-of-the-art components.

Electron beam delivery is accomplished by a beam scanning system and a thin, air-cooled titanium window. This system can provide a wide variety of scanning patterns and very high beam densities. For some applications, this allows reducing the size of the scanner, the radiation shield and the system footprint. Designed to conform to the user’s needs for product treatment, these features assure high beam utilization, further increasing the throughput capabilities of this compact accelerator system. The completely enclosed accelerator assembly with side chambers for product entrance and exit is shown in Fig. 4.

**REFERENCES**