REALIGNMENT OF A DIVERGING ELECTRON BEAM: A NEW BEAM DELIVERY SYSTEM FOR RHODOTRONS

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Abstract

Industrially useful electron beams produced at 300 keV or more are typically generated by introducing an oscillating magnetic field near the apex of a triangular scanning horn, thus creating a diverging treatment field. Product dosing is then accomplished by conveying target material through this field. For many irradiation applications this diverging beam introduces inefficiencies in beam power utilization and dosing non-uniformity. This paper presents beam delivery systems developed by IBA for Rhodotron accelerators and, in particular, a new scan horn for delivery of a non-diverging beam.

I INTRODUCTION

Rhodotrons are electron accelerators based on the principle of "re-circulating" a beam through successive diameters of a single coaxial cavity resonating in metric waves. The principle of operation of the Rhodotron has already been described in length in previous articles [1-6].

Three industrial Rhodotron models ranging from 35 kW to 200 kW beam power at 10 MeV are routinely manufactured at IBA's facilities in Louvain-la-Neuve, Belgium. The Rhodotron model "TT100" (10 MeV/35 kW) was especially developed by IBA in order to answer the market demand for a very compact accelerator system operating at 10 MeV and adapted to the sterilization of medical devices. In order to fulfil such industrial needs, a specific scan horn was recently developed, which allows to install both the accelerator cavity and the beam delivery system at the same level although the beam delivered to the product is non-diverging and oriented vertically. This paper focuses on the development of this new scan horn, which was tested at IBA and now is being installed at our customer's site in Italy.

II STANDARD BEAM DELIVERY SYSTEM FOR RHODOTRONS

The Rhodotron technology offers two significant advantages that simplify the design of the beam delivery system:

- Since electrons are deflected many times during the acceleration process, the numerous bending magnets that are placed in serial act as a very selective energy filter. Therefore, energy distribution at the exit of the accelerator is extremely peaked around 10 MeV, which minimizes beam losses in the transport system (in particular, in the 90° bending magnet).
- Since the beam delivered by Rhodotrons is C.W. and not pulsed, dose distribution at the surface of the products can be insured even at high scan frequencies. This is of particular interest for low doses applications (such as food irradiation, or for the treatment of semi-conductors, etc.) where speed of the products conveyed under the beam is high. For such applications, pulsed accelerators show strong limitations or require sophisticated and energy consuming electronics in order to sweep rapidly the beam back and forth during each pulse.

Figure 1 is a schematic of the standard beam delivery system for Rhodotrons. This standard system is designed to deliver a vertical beam to a room located one floor below the accelerating cavity. The following components are installed successively along the beam line: a 90° bending magnet, a quadrupole for adjusting the dimensions of the beam trace, and a scanning magnet allowing the beam to be scanned across a 1 meter wide band. Associated scanning electronics drives the magnet in such a way that the beam trace moves at constant speed whatever the selected scan length (which is adjustable from 30% to 100% of the nominal value). Therefore, scan frequency increases as scan length decreases. A beam delivery horn with a metal (titanium) vacuum-to-atmosphere window is also part of the standard scope of supply. The complete beam delivery system can be connected to any exit around the cavity, typically for beam transport at energies between 3 MeV and 10 MeV.

This standard delivery system is currently used at very high power level (up to 190 kW at 10 MeV). It has proven excellent performances since uniformity of the dose delivered by the horn is better than 95% over 90% of the nominal scan length.

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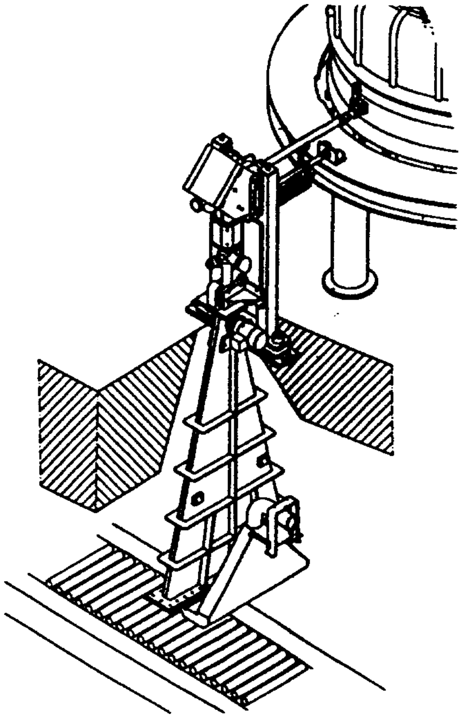

Figure 1: schematic of the standard beam delivery system for Rhodotrons

III NON DIVERGING BEAM DELIVERY SYSTEMS FOR RHODOTRONS

Two new beam delivery configurations were recently developed by IBA in order to fulfil specific demands from our respectable customers.

The first configuration aims at providing a very high scan length. It uses a 2 meters horn placed horizontally and equipped with a non-diverging system. As this new concept is now being patented, it will not be presented in the present paper.

The second development offers some similarities with the IFSSM (Irradiation Field Shaping System with bending Magnet) that was presented at PAC93 by A.S. Ivanov [7] and applied to low and medium energy electron beams. The new development aimed at answering the industrial demand for a compact, high energy (10MeV) processing unit dedicated to the sterilization of medical devices. For high compactness, our choice consisted in developing a new beam delivery system that could be installed at the same level as the TT100 Rhodotron accelerator, although delivering a vertical beam to the product. A very compact scan horn was developed, that scans the beam before bending it downwards to the product. Scan length requirement was 800 ±10 mm, and trace width 30 ±10 mm. Another important parameter for designing this horn was the beam orthogonality with respect to the conveyor : 90 degrees ± 6 degrees, in order to insure uniformity of the dose across the whole scan length.

The magnet was designed and optimized taking into account limitations in geometrical dimensions, in weight, and in power consumption. OPERA-3D [8] was used to design the magnet and to determine the excitation current density - the latter was reduced in possible limits, while producing sufficient magnetic field for bending 10 MeV electrons. Poles of the selected magnet consist of two circular bars. The section of return yokes passing by the bending plane of the magnet is rectangular. These are encircled by coils of a racetrack shape. A part of the return yoke (between poles and coils) has a complex shape, which was necessary to the passage of the magnetic flux between lateral sides of the return yoke. Figure 2 presents trajectories of 10 MeV electrons in the scan horn. In the selected co-ordinate system the bending magnet is symmetrical with respect to the x-z plane.

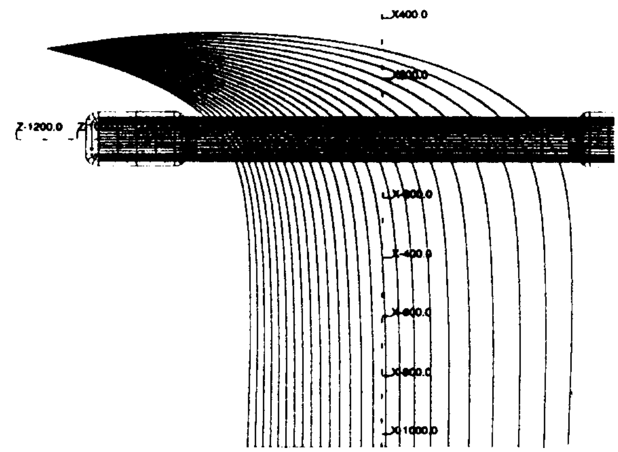

Figure 2: Trajectories of 10 MeV electrons in the non-diverging scan horn

Origin of the co-ordinate system is placed at the centre of the pole i.e. outer pole edges, coil and return yokes are at the same distance from the x-z plane. The starting point (x=300 mm, z=-1100 mm) corresponds to different scanning angles that vary between -14 degree and +10 degree with respect to the plane defined by equation x=300 mm. Positive sweeping angles are measured in the counter-clockwise direction from this plane. It is worth to notice that different trajectories are not equidistant, and their distance increases as scanning angle increases. This means that a complex function has to be generated in order to drive the scanning system in such a way that the beam is scanned uniformly onto the products. Our choice consisted in developing a function generator that uses the measured excitation current as a parameter that limits the scan length. A beam trace of 800 mm is obtained for sweeping angles between -11 degree and +8 degree. Figure 3 is the mechanical drawing of the scan horn now installed at our customer's site in Italy. The bending magnet is placed at the lower part of the horn, above the beam exit window. One can see the two excitation coils that are installed at both extremities of the magnet.

IV CONCLUSION

Preliminary tests performed at IBA indicate an excellent correlation between theoretical simulations and experimental results obtained with this new scan horn.

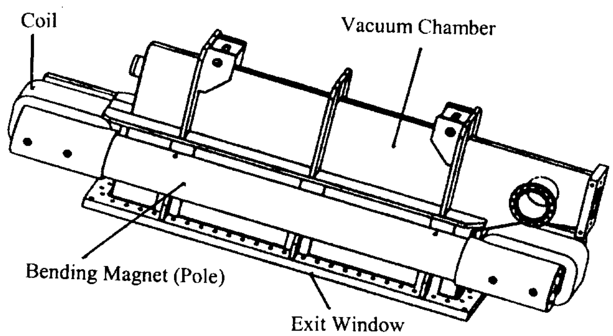

Figure 3 : mechanical drawing of the non-diverging scan horn

The new horn fulfills the initial requirements of designing a simple and compact beam delivery system that can be installed at the same level as the accelerator, and that delivers a non-diverging beam to the products, therefore maximizing beam utilization efficiency. Optimization of the function generated to supply the scanning magnet recently permitted to deliver a 95% homogeneous dose across 93% of the maximum scan length (which is 86 cm). As a next step, complementary dosimetric measurements have to be performed to better evaluate dose uniformity at various scan lengths (variable from 30 cm to 80 cm).

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