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Rhodotron: an accelerator for industrial irradiation

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The Rhodotron, a new type of cw electron accelerator, is particularly suitable for applications which need a powerful beam (30–200 kW) in the energy range of 1 to 20 MeV. The prototype built at CEA Saclay has shown the validity of the Rhodotron concept. During the preliminary tests performed in pulsed mode, a 14 kW electron beam at the energy of 3.5 MeV was extracted after a short tuning period. The tests of continuous mode will start shortly with a new gun (chopped at 180 MHz). A bremsstrahlung target has been installed at the output of the accelerator and the measured X-ray spectrum is qualitatively in agreement with the simulated one.

1. Introduction

The use of ionizing radiation is now a well known process in the industrial environment. Electron accelerators are widely used in a lot of applications (cross-linking of polymers, processing of thermoshrinkable products, medical disposals sterilization, food preservation, etc.). When very large volumes of material require radiation treatment, demand is created for an economical, reliable and powerful radiation source. The irradiation of thick pieces of material requires a high-energy beam. The Rhodotron has been developed for such industrial purposes. It is a new type of recirculating electron accelerator under development at CEA Saclay (Commissariat a l'Energie Atomique, Centre des Etudes de Saclay), working in continuous mode (100% duty cycle), that will be shortly industrialized.

2. Description of Rhodotron

The Rhodotron, invented by Pottier [1], is a recirculating electron accelerator with a single accelerating cavity (new coaxial cavity type), in which the beam passes several times along different diameters (figs. 1 and 2) in the median plane. After each pass, the beam is bent by a magnet and then sent back to the accelerating cavity, the trajectories having a rosaceous shape In the Rhodotron cavity (TEM mode), the electric field is radial and the magnetic field is azimuthal having zero value in the median plane. Focusing of the beam is achieved by proper edge shaping of the deflecting magnets.

A continuous mode (100% duty cycle) is the best solution for industrial processes (no modulator, no high peak current, best reliability). The size of the machine is defined by the fundamental resonance frequency of the cavity. The available commercial powerful rf amplifiers are limited in frequency to about 100 MHz ($\lambda = 3$ m).

The number of passes is limited to about 10 by the size of the magnets and the energy gain per pass is limited to about 2 MeV by the power of existing continuous rf amplifiers, and the risk of the electric breakdown inside the cavity. Hence the energy range of the Rhodotron beam is 1 to 20 MeV. For energies beyond this range other accelerator technology is more appropriate.

The power of the electron beam is limited by different factors: the beam current is limited by space charge effects in the injection area, where the energy is very

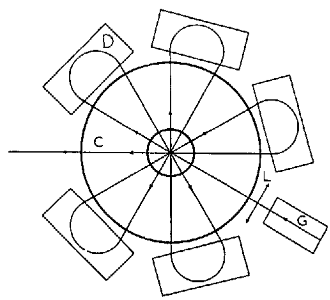

Fig. 1. Median section of Rhodotron, with electron trajectories shown. G: electron gun. L: magnetic lense. C: coaxial accelerating cavity. D: deflecting magnet.

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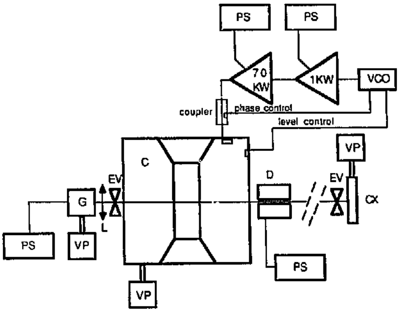

Fig. 2. Rhodotron components: D: magnet. C: accelerating cavity. G: electron gun. L: magnetic lense. VCO: high-frequency oscillator. VP: vacuum pump. PS: power supply. EV: electro-valve. CX: X-ray conversion target.

low; the beam power must not be much higher than the power needed to create a nominal accelerating electric field in order to keep the coupling between rf generator and cavity nearly constant. These limitations depend on the beam energy and can be overcome for any special application.

3. Rhodotron prototype description and experimental results

The prototype system built at Saclay (fig. 3) has shown the feasibility of such a machine [2]. Its design performance is at an energy of 3.3 MeV and a continuous power of 20 kW. The main components of the prototype are as shown in figs. 1 and 2.

The nominal energy was easily reached at a low current (less than 1 mA) [2]. The electron gun, adapted from a TWT tube, is a diode gun with a Wehnelt command electrode and a thermoelectronic dispenser cathode. The 8 keV electron beam is extracted continuously or pulsed by the Wehnelt (1 to 20 μs pulses at 100 to 1000 Hz repetition frequency).

Without a chopper continuous mode operation is not possible: The electrons going through the cavity at the wrong phase are lost in the first turn and produce excessive heating of the vacuum chamber. In pulsed mode, with a 0.1% duty cycle, the heating remains very low during the gun pulses (few microseconds), which

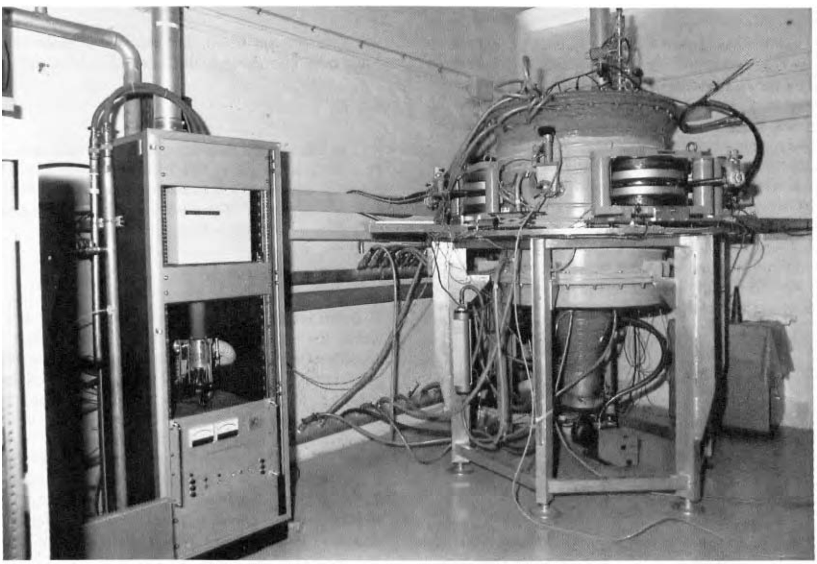

Fig. 3. Rhodotron prototype built at Saclay.

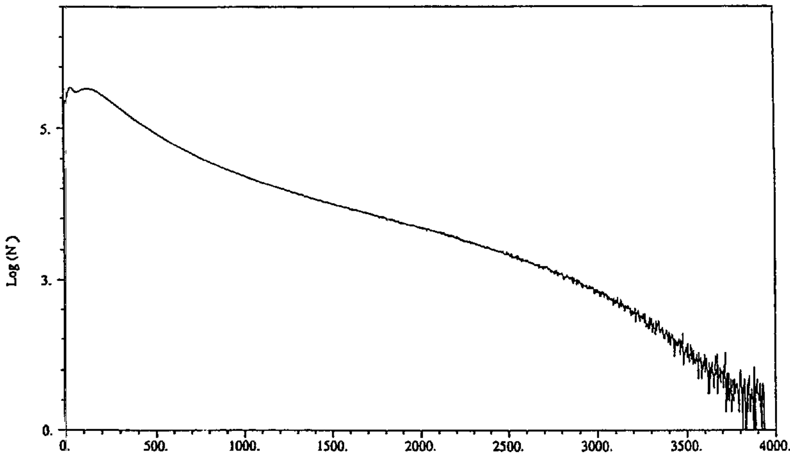

Fig. 4. Experimental bremsstrahlung spectrum.

are long compared to the high-frequency period of 5.4 ns; in these conditions the beam loading is the same as in continuous mode. With such a duty cycle, an output current of 4 mA was extracted at 3.5 MeV (little more than the design energy of 3.3 MeV) corresponding to 14 kW cw equivalent power.

Continuous mode operation will be tested shortly with a new electron gun chopped at the Rhodotron cavity frequency of 180 MHz. This gun is actually under development.

A bremsstrahlung target has been installed at the machine output and an X-ray spectrum was measured (fig. 4). The preliminary results are qualitatively in good agreement with simulations.

4. Industrial development

The following examples show different kinds of irradiation problems which can be solved using the Rhodotron accelerator.

4.1. On-line treatment

The Rhodotron is a compact machine and can be inserted in a production line. For example, the treatment of waste water can be performed with a 10 MeV, 100 kW electron beam. In this case a good solution could be a Rhodotron with 10 passes (1 MeV per pass).

4.2. Test station

The Rhodotron delivers a beam at different energies after each pass. For example, with a 5 MeV, five-pass machine, it is possible to extract the beam at 1, 2, 3, 4 or 5 MeV. The study of an irradiation process at different energies is then possible.

4.3. Multipurpose station

In an industrial irradiation service center, very different materials are treated with various sizes and densities (medical disposals sterilization, colouring of glass bottles, sterilization of spices, cross-linking of polymers, etc.). For very thick material requiring a low dose, X-ray beams are more efficient than electron beams but for high density thin material, a 10 MeV electron beam is better. For food preservation, the X-ray beam energy is limited to 5 MeV by legislation (to avoid bremsstrahlung target activation). An rf linear accelerator cannot deliver a beam at various energies. On the other hand, the Rhodotron allows a lot of operating configurations: an interesting solution could be a two-mode Rhodotron: 10 MeV, 30 kW electron

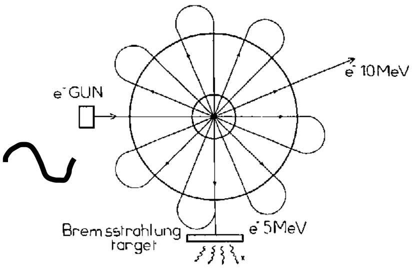

Fig. 5. Two-mode Rhodotron: 10 MeV electron beam and 5 MeV, X-ray converted beam.

beam in the first mode, and 100 kW, 5 MeV electron beam producing an X-ray beam in the second mode (fig. 5).

5. Conclusion

The validity of a new electron accelerator configuration has been proven by computer simulation and by experiment. A high beam power, up to 100 kW or more, can be obtained. This accelerator is well suited for industrial processing by high power electron or X-ray beams, in the energy range between 1 and 20 MeV. An industrial version of Rhodotron (10 MeV, 100 kW) is under development.

References

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