Nuclear Instruments and Methods in Physics Research A 828 (2016) 72–80

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Technical notes

Design study of double-layer beam trajectory accelerator based on the Rhodotron structure

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ARTICLE INFO

Article history:
Received 7 May 2015
Received in revised form
13 April 2016
Accepted 30 April 2016
Available online 3 May 2016

Keywords:
Electron accelerator
Rhodotron
Coaxial cavity
Double layer beam trajectory

ABSTRACT

In this paper, the conceptual design of a new structure of industrial electron accelerator based on the Rhodotron accelerator is presented and its properties are compared with those of Rhodotron-TT200 accelerator. The main goal of this study was to reduce the power of RF system of accelerator at the same output electron beam energy. The main difference between the new accelerator structure with the Rhodotron accelerator is the length of the coaxial cavity that is equal to the wavelength at the resonant frequency. Also two sets of bending magnets were used around the acceleration cavity in two layers. In the new structure, the beam crosses several times in the coaxial cavity by the bending magnets around the cavity at the first layer and then is transferred to the second layer using the central bending magnet. The acceleration process in the second layer is similar to the first layer. Hence, the energy of the electron beam will be doubled. The electrical power consumption of the RF system and magnet system were calculated and simulated for the new accelerator structure and TT200. Comparing the calculated and simulated results of the TT200 with those of experimental results revealed good agreement. The results showed that the overall electrical power consumption of the new accelerator structure was less than that of the TT200 at the same energy and power of the electron beam. As such, the electrical efficiency of the new structure was improved.

1. Introduction

The Rhodotron accelerator is a high power industrial electron accelerator working based on the re-circulation of electron beam within a single coaxial cavity. Initial design of Rhodotron was proposed by Pottier in 1989 [1] but the first prototype with a beam of 3.5 MeV and 14 kW power was built in 1992 by Bassaler et al. [2]. Later, the first industrial Rhodotron was built in 1993 at Ion Beam Applications (IBA) in Belgium [3]. Currently, there are several industrial models of this accelerator including TT100, TT200, TT300 and TT1000 that are manufactured by IBA company [4–7] providing beam power ranging from 35 kW to 700 kW at 10 MeV beam energy. Rhodotron accelerators have found numerous industrial applications [8–10]. In Rhodotron TT200, energy of electrons in each trip across the full diameter of the cavity reaches 1 MeV per pass. So after 10 passes using 9 bending magnets, the final electron energy would be 10 MeV. In Fig. 1(a) and (b) the trajectory of electron beam and the electrical (E) and magnetic (B) fields in the acceleration cavity are shown, respectively.

RF power consumption and its electrical efficiency are considered as the most important parameters for designing RF accelerators [9]. In this paper, a new structure of industrial electron accelerator was designed based on the Rhodotron accelerator and its properties were compared with those of the Rhodotron-TT200 accelerator.

2. Material and methods

In this study, a new double-layer beam trajectory coaxial (DLBTC) cavity was designed. This proposed cavity has similar structure to that of the Rhodotron accelerator but its length is equal to the RF wavelength and bending magnets are arranged in two layers (upper and lower layers). It must be noted that the length of the coaxial acceleration cavity, L, of the Rhodotron accelerator is equal to the half of the wavelength. In addition, RF losses in the DLBTC cavity were calculated and compared to those of Rhodotron-TT200 cavity.

Schematic view of the proposed structure is shown in Fig. 2. In this design, similar to the Rhodotron accelerator, the electrons produced by the electron gun are accelerated by the electric field inside the coaxial cavity and are sent back into the cavity after

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http://dx.doi.org/10.1016/j.nima.2016.04.112
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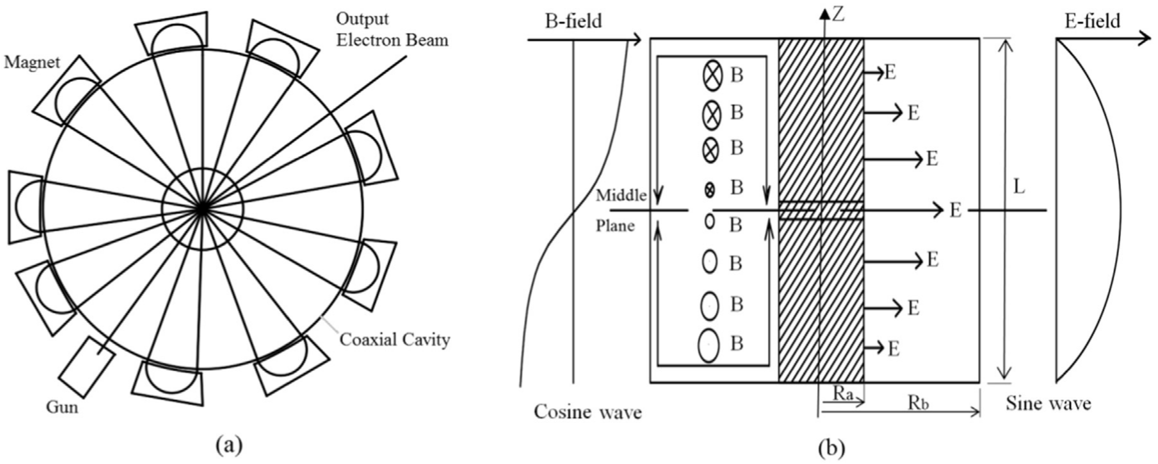

Fig. 1. Rhodotron accelerator: (a) trajectory of the electron beam; and (b) the electrical and magnetic fields inside the acceleration cavity.

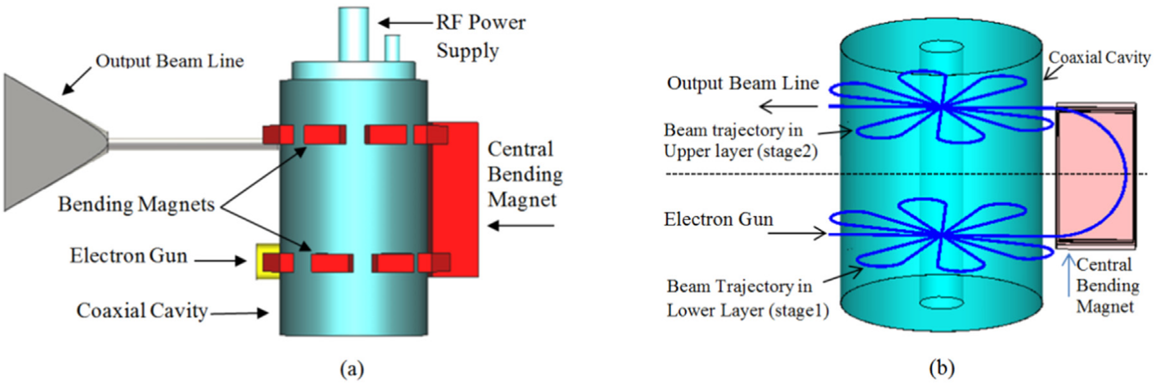

Fig. 2. Schematic sketch of the new designed accelerator with DLBTC cavity: (a) 3-D view; and (b) electron beam trajectory.

each diameter crossing by the bending magnets in order to undergo another accelerating cycle. The bending magnets also contribute to the focusing of the beam. In this process, the total beam energy depends on the electrical field inside the cavity and the number of bending magnets around the cavity. In the TT200 model, total energy of electrons after ten entries reaches 10 MeV.

In the DLBTC cavity, electron beam trajectory has been separated in two layers in one cavity as shown in Fig. 2(b). The length of cavity used for each layer is equal to half of the RF wavelength at the resonant frequency. Electrons are first accelerated in the lower half of the cavity and then are passed through the upper one using central bending magnet. To synchronize RF phase with electron beam passed to the upper layer, the length of beam trajectory inside the central bending magnet should be adjusted properly. To calculate the dimensions of the DLBTC cavity, the length of cavity was fixed to the one-wavelength, λ, and then the radii of the cavity were calculated. For these calculations, several factors were considered including electrical field, voltage breakdown, the number of bending magnets and the RF phase synchronization. For the RF phase synchronization, the required stability is achieved when the total path taken by the electrons passing through the cavity and the bending magnets follow Eq. (1) [11].

$$2R + D = \lambda \tag{1}$$

where R is the distance between the center of cavity and entrance or exit side of bending magnet and D is the length of path taken by the electrons outside the cavity including bending magnets.

The angle between two paths equals $\phi = \pi/N$, therefore, following relations can be obtained.

$$R_c = R\ \tan(\phi/2) \tag{2}$$

$$D = R_c \frac{N+1}{N}\pi \tag{3}$$

R_c is the bending radius. R could be simply obtained from Eq. (1) as below [11]:

$$R = \frac{\lambda}{\left[2 + \frac{N+1}{N}\pi\ \tan\left(\frac{\phi}{2}\right)\right]} \tag{4}$$

The most important parameters for designing an electron accelerator based on the Rhodotron accelerator structure are the number of bending magnets, the RF frequency and the dimensional geometry of the acceleration cavity. In Fig. 3 transactional cross section view of the DLBTC cavity, vertical cross section view of the cavity and the central bending magnet, the beam trajectory in one of the bending magnet around the cavity and central bending magnet and RF synchronization diagram of this cavity are shown.

To synchronize the RF phase with electron beam, the appropriate bending radius, R_c, and the maximum outer radius of the cavity, R, were calculated for various frequencies using Eqs. (2) and (4). To achieve the specified electron beam energy by increasing the number of passes, N, the electrical fields and the RF power required in the cavity could be reduced. However, the number of passes is limited by the size of the bending magnets and outer radius of the cavity. In addition, the energy gain per pass is limited by the RF power and the risk of the voltage breakdown inside the cavity. Other important design parameters are the dimensions of the cavity including inner and outer radii of cavity, R_a and R_b. In