THE 3 MEV, 200 KW HIGH VOLTAGE ELECTRON ACCELERATOR FOR INDUSTRIAL APPLICATION

N. G. Tolstun, V. S. Kuznetsov, A. S. Ivanov, V. P. Ovchinnikov, M. P. Svinjin
D.V.Efremov Research Institute of Electrophysical Apparatus, 189631, St Petersburg, Russia

Abstract

The high-voltage electron accelerator with an energy of 3 MeV and a beam power up to 200 kW comprising a high-voltage generator based on a single-phase transformer-rectifier without iron core is under development. The accelerator is meant for purification of wasted waters, sterilisation of medical products and ecologically safe treatment of logs before transportation with the aim of suppressing the viability of fungus and pests, etc. The main units and systems of the accelerator are described. Versions of the extracting device with output of the beam into the atmosphere or with conversion of its energy into bremsstrahlung are presented. The accelerator is equipped with the unique electron irradiation field shaping system with an elongated turning magnet allowing an irradiation field up to 6 m in width to be produced.

For many years DC high-voltage electron accelerators for the radiation technology based on a single-phase transformer-rectifier without iron core with a particle accelerating tube arranged on its axis in the energy range from 0.3 to 2.5 MeV and beam current power up to 150 kW have been designed and manufactured at the Efremov Research Institute [1]. We have gained much experience in their operation and the design of accelerators has been sufficiently improved during the last years [2].

The accelerator of this type is placed in a metal vessel, filled with a pressurised electric insulating gas. The conic primary winding provides an alternating magnetic field with a frequency of about 1 kHz and an induction of about 100 G. The sections of the secondary winding form the voltage-doubler scheme and are connected in series, rectified voltage is applied to the metal-ceramic accelerating tube modules made by the diffusion welding method. The production of such accelerating tubes with ceramic insulators 100, 130 and 200 mm in diameters has been organised. The electro-magnetic screening of the tube aperture is used to exclude the effect of alternating magnetic field of the transformer-rectifier on the accelerating electron beam [3]. The electron source with a LaB_6 emitter has a lifetime of several thousand hours. The accelerated electron beam is additionally focused and is scanned over the outlet device in two mutually normal directions. These accelerators are powered by commercial thyristor frequency converters. The total efficiency of conversion of electric power into electron beam power (η_E) exceeds 80%.

The schematic of the accelerator with an energy up to 2 MeV and a beam power up to 150 kW is shown in Fig.1. The high-voltage rectifying column is 0.72 m in diameter and 2.4 m in height. The accelerated electron beam is extracted into an atmosphere through the 220×10 cm outlet window, closed by a 50 mkm titanium foil. This accelerator is under testing now.

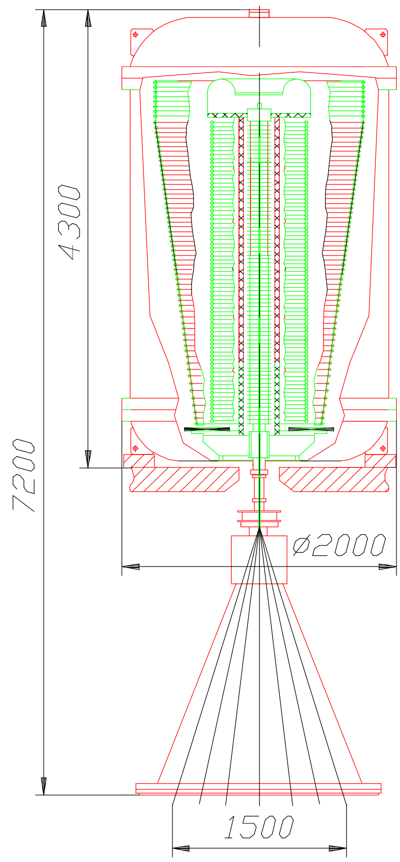

Figure 1. The schematic view of 2 MeV, 150 kW high-voltage electron accelerator based on the single-phased transformer-rectifier with the rectifying column 0.72 m in diameter.

Based on the rectifying modules with the above mentioned diameter the accelerator with an energy of 3 MeV and a beam power up to 200 kW is under development.

By increasing the diameter of the high-voltage rectifying column up to 1.2 m and using the two-period rectifying scheme it will be possible to increase the accelerator power up to 500 kW.

As all of the main components of accelerator are studied sufficiently, we do not foresee any serious technical or technological problems in designing such a machine. As seen from Fig.2, the dimensions of this accelerator are increased in comparison with the 2 MeV one, as they are determined in general by accelerating voltage, but they do not differ much from those of a 3 MeV, 200 kW machine.

The accelerators with these parameters can be used for the electron beam processing of materials and articles with a surface density up to 1 g/cm^2 (up to 2.5 g/cm^2 if double-sided irradiation is used), for example, in an installation for sewage purification.

Another possible application of such accelerators is the processing of materials and products by bremsstrahlung generated by the electron beam interacting with heavy metal targets (W, Ta).

Similar installations of a smaller capacity have been used to sterilise medical products, to treat food for increasing its preservation time and for another sterilisation processes. As the experience with the "Dynamitron" accelerators used for this purpose reveals, the cost of irradiation by bremsstrahlung at energies of 4 and 5 MeV does not exceed that of isotope sources [4,5].

The efficiency of the electron beam power conversion into bremsstrahlung (γ) at these energies is 0.15 and 0.18, respectively, the above mentioned accelerators have η_e = 40 ÷50%, thus the ratio of bremsstrahlung power (P_v) to total electric consumed power (P_E) is 0.07÷0.08.

The coefficient of electron energy conversion into bremsstrahlung for 3 MeV electrons is 0.12. With η_e = 0.8 the total efficiency $\eta_e \cdot \nu$ = 0.096 is possible. It allows the accelerators based on the single-phase transformer-rectifier to be considered as the effective source of bremsstrahlung.

Through the conversion of accelerated electrons energy into bremsstrahlung a certain portion of energy is carried away by reflected electrons (about 14% of beam power according to [5]). These losses are minimum when the angle between incident electrons and target surface is normal, and they increase with the angle deviating from the normal. If traditional scheme with beam scanning in the triangular vacuum chamber is chosen, the angles of incident electrons increase from the target centre and reach the maximum on its edges (see Fig.1). This causes also another problem, as the target effective thickness increases with a change in the angle.

These negative effects may be avoided by using the electron irradiation field shaping systems with extended bending magnets, which nowadays are used in our electron accelerators to extract the scanned electron beam through the outlet foil windows [1,3]. The projections of electron trajectories in such a system obtained by the numerical simulation are presented in Fig.3. The angles between the target surface and incident electrons here differ from the normal along its length by not more than 7°.

In spite of directed character of bremsstrahlung, when calculating the production capacity of an irradiating installation, it should be taken into account that not more than 50% of bremsstrahlung is usually used effectively, i.e. η_v = 0.5. For obtaining a sufficiently homogenous dose distribution in the whole volume of irradiated material it is important to determine its optimum thickness and to use double-sided irradiation or, if possible, to rotate the objects

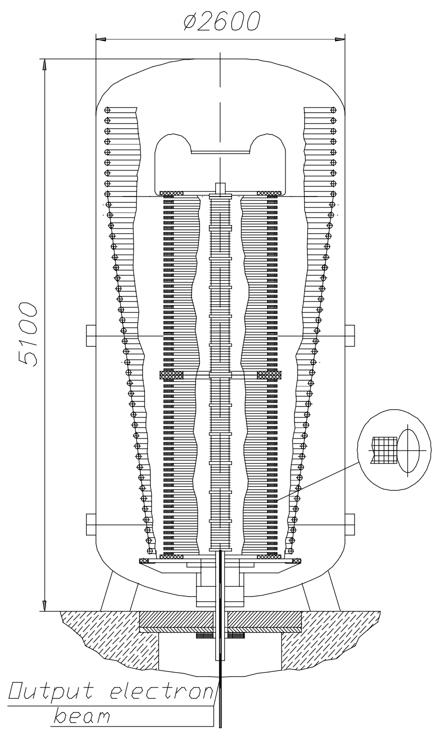

Figure 2. The schematic view of 3 MeV, 500 kW high-voltage electron accelerator based on the single-phased transformer-rectifier with the rectifying column 1.72 m in diameter.

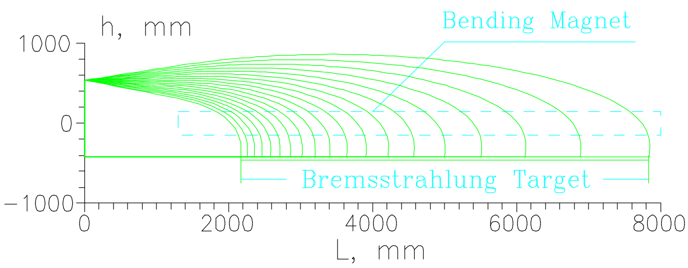

Figure 3. Electron trajectories projections in the irradiation field shaping system with an elongated bending magnet.

during single-sided irradiation. The depth doze distribution under double-sided irradiation in material 0.6 m in thickness and $0.7\, g/cm^3$ in density is shown in Fig.4.

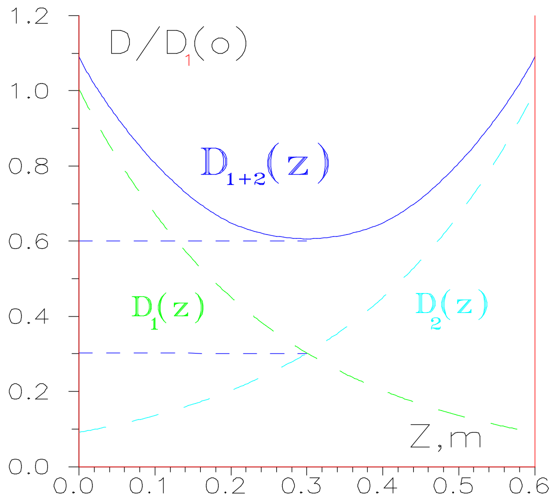

Figure 4. Doze distribution in material 0.7 g/cm^3 in density and 60 cm in thickness for single- and double-sided irradiation under 3 MeV electron bremsstrahlung.

The capacity of installation for bremsstrahlung treatment can be estimated as (considering the year as 7000 working hours of accelerator):

$$G = 25.4 \frac{P_E \eta_e \eta_v \nu}{\rho D_c} \cdot \frac{\mu a}{\exp(\mu a/2)} \left[\frac{T \cdot m^3}{year} \right],$$

where:

P_E is electric power consumed by the accelerator, kW;
D_c is the central doze, kGy;
a is the material thickness, m;
μ is the average coefficient of irradiation flow reduction corresponding to an average energy of bremsstrahlung (1.5 MeV for electrons with energy of 3 MeV), m^{-1};
ρ is a density of treated material, g/cm^3.

As an example of the installation with electron accelerators the process of timber sterilisation aiming at suppressing the vital functions of funguses and their spores on the wood surface and vermin and bacteria inside logs can be considered. The diameter of logs to be treated is 0.2÷0.6 m, the required dose in the log centre is 4 kGy and on the surface - not more than 10 kGy. The installation with double-sided irradiation including 2 electron accelerators 200 kW of beam power each (what equals to a total output of 48 kW of bremsstrahlung) will provide a capacity of about 160.000 m^3 per year with 7000 working hours pear year. As the calculations show, the cost of irradiation in this case will not be more than $10 per 1 m^3, being approximately twice less than the cost of irradiation by isotope Co^{60}, whose irradiation penetrability is practically equal to 3 MeV electron bremsstrahlung. The sterilising installation with high-voltage electron accelerators is absolutely safe, when switched off, as there are no radioactivity in the installation components and in the treated material.

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