New Irradiation Field Shaping Systems of High Voltage Electron Accelerators for Industry

A.S.Ivanov, V.P.Ovchinnikov, M.P.Svinin, N.G.Tolstun
The D.V.Efremov Scientific Research Institute of Electrophysical Apparatus,
189631, P.O.42, St.Petersburg, Russia

The competitiveness of high voltage accelerators for industry is determined by their cost, operational conveniences and sizes, provided their main parameters are equal. These characteristics have been essentially improved in the machines with the extended cathodes that provides their wide usage in such spheres of technologies as for example the treatment of thin coating layers [1]. The accelerators for higher energy range have far more large sizes and high costs that restrains their industrial application, though the electron beam modifications of thicker materials are in high demands. The dimensions of high voltage accelerators in the energy range of 0,3 to 3,0 MeV are determined mainly by their sizes and mutual arrangement of their main systems: an accelerator itself which includes a high voltage generator and an acceleration structure and an irradiation field shaping system (IFSS). The height of a 1 MeV accelerator with an outlet window width of 150-200 cm is about 4,5-6 m, if designed to a traditional schematic and thus requires higher premises to provide service (see Fig.1.). The height of accelerators often is a restricting factor because customers would like to install them in common industrial premises.

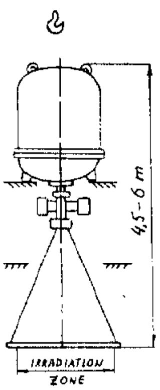

Figure 1.The lay-out of traditional scheme of industrial electron accelerator

The IFSS with an extended bending magnet designed in our institute uses the principles of cylindrical electron optics and allows to decrease the vertical size of accelerator by several times. Such type of IFSS and the projection of electron trajectories in it obtained by numerical simulation are rep-resented in Fig.2. Another merit of such field shaping system is practically normal angles of electron trajectories on the outlet window foil, as shown in Fig.2. It must be emphasized that such IFSS demands higher quality and smaller beam size at the inlet than conventional ones because the bending magnet field enlarges the beam size on the foil plane by several tens. When using a double shaping system of such a type an accelerator beam can be extracted through the two outlet windows facing opposite sides, providing double-sided or staged irradiation of materials (see Fig.2.).

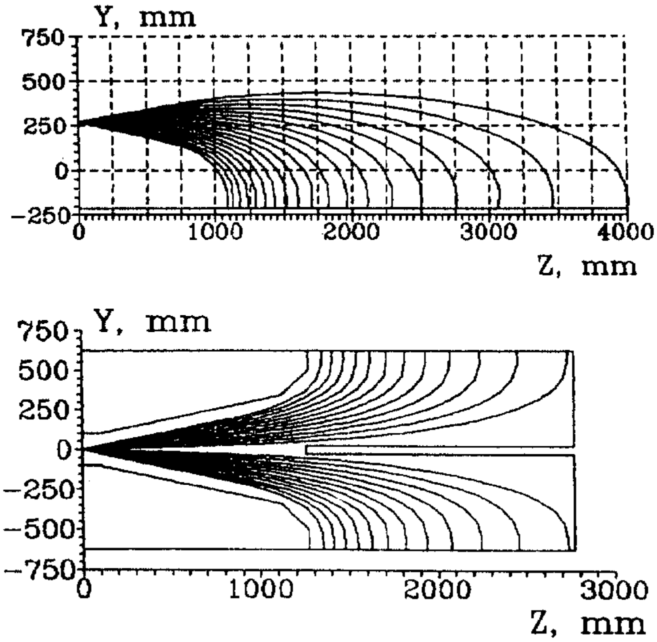

Figure 2. Projection of electron trajectories in the IFSS with bending magnets

On the other hand one of the most compact and convenient in operation type of high voltage electron accelerators is that on the basis of a single-phase transformer-rectifier with the particle accelerating channel situated on its axis [3,4]. The alternating magnetic field of an axially-symmetric primary winding induces the e.m.f. in the sections of a secondary winding. The alternating current in each section is rectified by a voltage-doubler scheme and the separate DC outputs are connected in series. The power supply system of such accelerators is the reliable mass production frequency converters.

These accelerators are designed and successfully operate in industrial and pilot plants at the energies from 0,5 to 2,5 MeV and beam power up to 100 kW.

So we have put the task to design the compact and convenient industrial accelerators by means of combining these two technical decisions in the one machine.

The main problems to be solved in such accelerators are associated with the beam passage through the accelerating tract in the presence of the transformer magnetic field. The value of this field on the system axis is 100-150 G. The tube screening by means of copper rings provides an axial magnetic field decrease from 50 to 60 times on the tube axis, but the main influence on the accelerated electrons, naturally, is from radial and crossed components of the field. The radial component of axial symmetric winding equals zero on the winding axis, but the location of the electron optical axis may not coincide with the magnetic one, moreover the nonsymmetrical elements of primary winding produce a crossed field component on the optical axis.

It was necessary to conduct a special study to get at the accelerating tube outlet an electron beam suitable for utilization in the IFSS with the extended turning magnet. All the beam experiments and the magnetic field measurements were accomplished on the 1 MeV accelerator. The magnetic field amplitude was 110 G on the axis of the transformer-rectifier with the frequency from 500 to 800 Hz.

The measurements of the crossed magnetic field distribution along the accelerating tube axis were carried out to study the possibility of combining the magnetic and electron optical axes. The crossed magnetic field minimization was done by the primary winding movement and inclination with respect to the accelerating tube. The results of measurements of the primary winding crossed magnetic fields after their optimization on the tube axis are shown in Fig.3. The corresponding beam axis trajectories and their deflection angles, that have been calculated according to the crossed magnetic field distribution, are represented in the same figure. It was necessary to reduce this deflection by several times within the acceptable limits for the beam usage in IFSS with extended bending magnets.

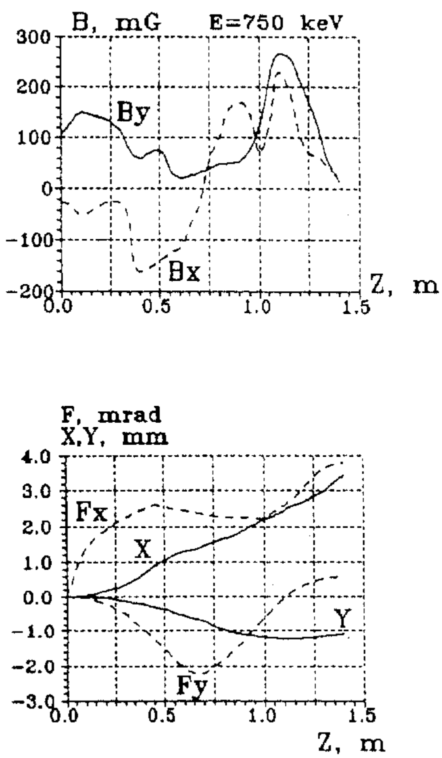

Figure 3. Crossed magnetic field distribution on the tube axis, deflection and angles of electron trajectories in the accelerating tube

The possibilities to screen a tube aperture with the electrodes having high magnetic permeability were considered to decrease the crossed field as well as the copper rings to decrease the axial component.

To determine the screen coefficient (Cs) dependence on different factors, the magnetic field measurements within the aperture of the ferro-magnetic electrodes have been made. The electrodes were put in a special device which permitted to fasten them at different distances. As a source of magnetic field the primary winding of the accelerator was used that gave sufficient magnetic field distribution homogeneity.

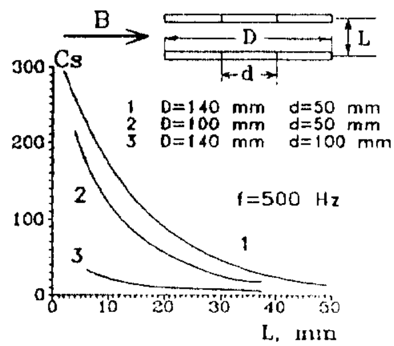

Figure 4. Dependence of screen coefficient (Cs) on the distance between flat electrodes

The dependence of Cs on the distance between the flat electrodes is represented in Fig. 4. As these measurements show, the use of ferro-magnetic electrodes decreases the alternating crossed magnetic field by several tens at the typical for high voltage accelerator correlations of the electrode sizes and the space between them. The experiments on electron beam passing through the accelerating tube thus screened confirmed the high effect of such solution. The beam track photographs, which have been done on the outlet window foil at the various energies, showed the absence of beam swing. Another experiment with a 2° inclination of primary winding, as referred to the accelerating tube, showed the full coincidence of beam track on the window foil and the beam track from primary winding fixed at the right angle.

Thus, this way of the accelerating channel screening permits to exclude the influence of winding magnetic field on the beam dynamics in the accelerator with a single-phase transformer-rectifier.

When this task has been solved there was designed a series of accelerators embodying these technical principles. The height of all the machines is less then 2.2 m thus permitting their location in the standard industrial premises and there is no need of any special lifting devices for theirs technical service.

The accelerator for the energy of 1 MeV, beam current 80 mA and 150 cm width outlet window is represented in Fig.5. Thanks to the horizontal lay-out of its main parts it might be easy integrated in the production lines.

The installation on the basis of the electron

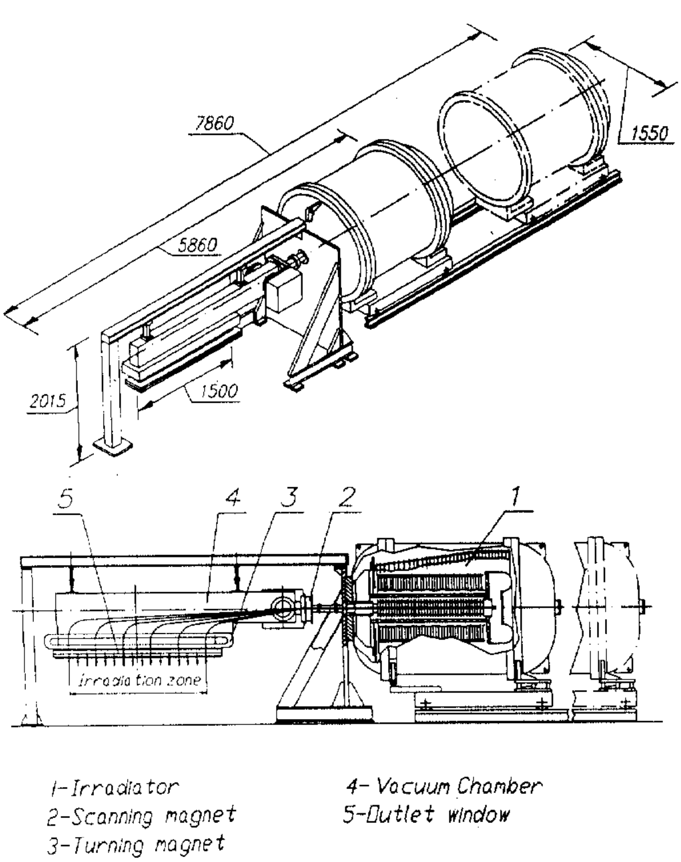

Figure 5. The electron accelerator for the energy 1 MeV

accelerator for the energy of 300 keV and a 200 cm width outlet window is placed inside an iron-lead radiation shielding and is presented in Fig.6.

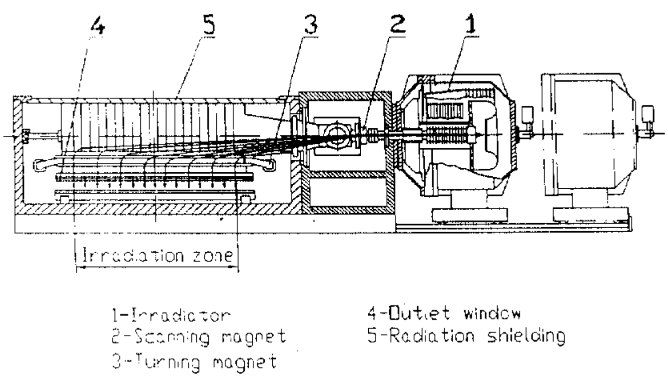

Figure 6. The installation on the basis of the electron accelerator for the energy of 300 keV

The accelerator for the energy of 750 keV and 100 mA beam current with two windows facing opposite sides 150 cm in width each is shown in Fig.7. The accelerator is placed inside a metal radiation shielding and meant for the double-sided irradiation of flexible materials. The electron beam is scanned in each window with frequency about 500 Hz and transferred from window to window with frequency of 40 Hz. The homogeneity of distribution of beam current in each window is better then +/- 5%. Double-sided irradiation allows to increase the thickness of treated material from two to four times in comparison with the one-side irradiation at the same energy and besides provides a complete absorption of accelerated electrons in the material.

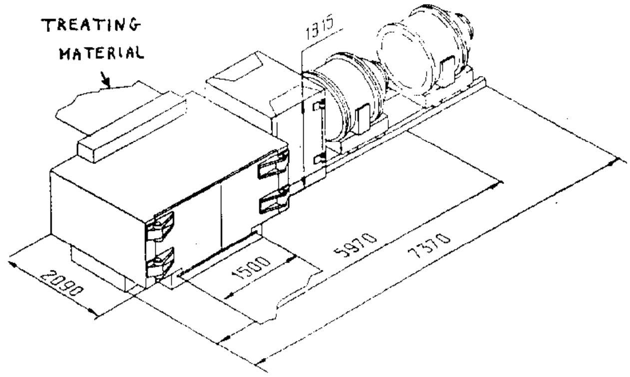

Figure 7. The installation on the basis of the electron accelerator for the energy of 750 keV for double-sided irradiation of flexible materials

Thus, the solution of the problem of combining the two most compact main systems of high voltage accelerator in one unit permits to decrease considerably the sizes of industrial electron accelerators and fully adapt these machines to the demands of industrial production.

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