BEAM EXTRACTION SYSTEM FOR INDUSTRIAL ELECTRON ACCELERATOR ILU-14

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Abstract

This paper describes beam extraction system for pulse linear electron accelerator ILU-14 with energy range 7.5-10 MeV and beam power up to 100 kW. The main aim of this work was to achieve the uniform dose field in radiation zone. Admissible dose nonuniformity is of no more than ± 5% along the scanning length up to 1m (if necessary, the scanning length may be reduced). Geometrical and electron-optical characteristics of all the beam channel elements were optimized after computer simulation of electron trajectories. To achieve the required nonuniformity of dose field additional electromagnets were installed. These magnets realize beam focusing and centering of the beam endwise of the channel, as well as correction of the scanning field. Control system of magnets power supply allows the online correction of electron beam.

INTRODUCTION

Radiating technologies reached now such wide application in the industry that became its separate branch. And improvement of generators of electron beams occurs at the same time to high-quality improvements of extraction devices. Questions of efficiency of radiation, i.e. efficiency of process of radiation became the main requirements at radiation of production. The nomenclature of irradiated objects considerably increased and diversified. Rigid modern requirements to uniformity of dose fields of electronic accelerators demand detailed consideration of the questions connected with operation of extraction devices. To improve radiation quality (dose uniformity) and obtain competitive advantages the new system of the beam output for the industrial accelerators of the ILU series is developed. The main requirements to this system are nonuniformity of the dose field not worse ±5 %, and also width of the beam scanning of 1 m (at energy of an electron beam up to 10 MEV). In industrial accelerators of ILU type an electron beam with duration 0.5 ms is scanned along the output window from a titanic foil (thickness of 50 microns). Uniformity or the set nonuniformity of distribution of the beam intensity along a foil is one of the most important parameters of radiating and technological complexes on ILU base. The general block diagram of the output path of the accelerator is provided on fig. 1. After accelerating structure 1 beam gets to the electron-optical channel. For control of the beam position of rather central axis of the channel input of the directing magnet 2, representing the two-coordinate corrector of electron trajectories in the range ±5sm is supposed see. For formation of the cross-section size of a beam (at initial adjustment of system without beam scanning) the quadrupole doublet 3 is provided. For control of beam parameters the graphite diaphragm 4 from which the signal will be taken off further will be located. Necessary uniformity of the output current density is offered to be reached by installation before the main beam scanning system 6 of the correction system of the scanning magnetic field 5. Also in extraction system possibility of so-called horizontal beam scanning 7 across the bell is provided. For receiving on the bell foil of a beam with identical angular characteristics, especially at big angles of scanning, it is necessary to install the additional turning devices 8 (Panovsky lenses) which transform trajectories of electrons so that a beam falls on a foil everywhere on its length at right angle. After an exit of an electron beam from a bell possibility of its transformation to bremsstrahlung by means of the converter 9 is provided.

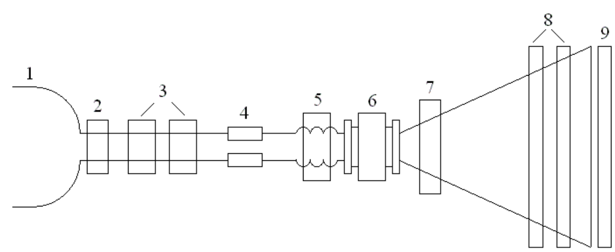

Figure 1: 1 – accelerating structure, 2 – control magnet, 3 – quadrupole doublet, 4 – diaphragm, 5 – bellows unit with correction system of scanning field, 6 – scanning chamber with scanning electromagnet, 7 – transverse beam scanning system, 8 – Panovsky lenses, 9 – converter.

BEAM SCANNING SYSTEM

It is necessary to give special attention to formation of a demanded dose field on an exit from the accelerator. First of all, it is necessary to consider influence on a form of a scanning field of the processes occurring in metal walls of the vacuum chamber of beam scanning (a bell filler).

When giving a pulse magnetic field in a metal not magnetic shield (screen) of scanning system which divides on vacuum space of a beam deviation and the scanning electromagnet which was outside, there is a reaction of the induced currents which distorts a scanning field. From [1] follows that the field inside the screen H0(t) is superposition of the influencing field H1(t) and the field H2(t) raised by currents, induced in the shield thickness by pulse of H1(t). In the same place it is deduced that the field in the screen H0(t) raised by pulse H1 (t), satisfies to the ordinary differential equation:

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$$H1(t)=\frac{L}{R}\cdot\frac{dH0}{dt}+H0(t),\quad H0(0)=0,\quad (1)$$

where L and R are inductance and active resistance of the screen.

From the equation (1) it is obvious that the field form in vacuum depends only on size of a ratio of L and R. For the designs of scanning shields in accelerators of a ILU series, the size of the relation of L/R makes size about 100 microseconds. The technique of definition of this constant is stated in [2].

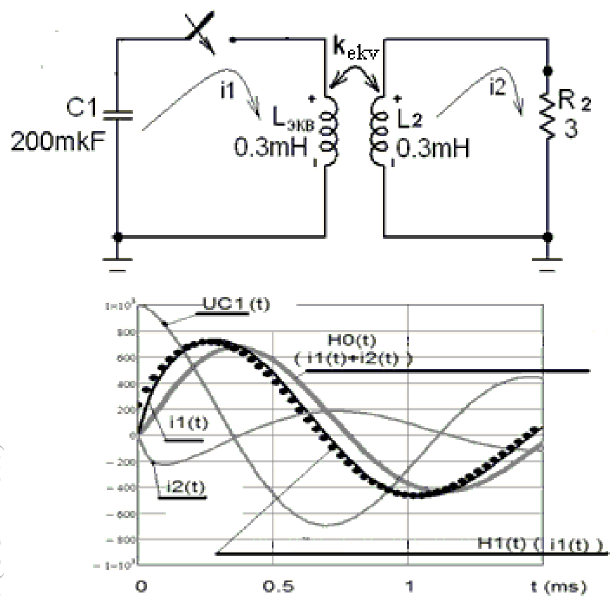

Figure 2: Calculated curves of currents and magnetic fields in the simple generator of scanning.

Let's consider work of an equivalent chain of a scanning electromagnet at the discharge on this chain of capacity. On fig. 2 the scheme of a chain and the main curves of currents, voltages, and also magnetic fields in vacuum are presented. And, continuous lines reflected results of calculation of transients for this scheme, and points showed a curve of the exciting field H1(t) found according to (1). For H0(t) we take i1(t) + i2(t). The main time regularities of influence of the closed turn of a vacuum shield on a working magnetic field are visible. It is necessary to note big attenuation of a field in vacuum H0(t) from brought active resistance of a filler R2.

The sign-variable scanning field during a pulse of a beam current should be symmetric, concerning the middle, not only on absolute amplitudes, but also on their derivatives. This circumstance considerably reduces possibilities of application of schemes of this kind because of a big difference of working amplitudes of a demanded symmetric reverse of this field.

SYSTEM OF THE SCANNING FIELD CORRECTION

For the purpose of elimination of the described effect for the scanning electromagnet supply of the accelerator ILU-14 the following scheme (fig. 3) was offered.

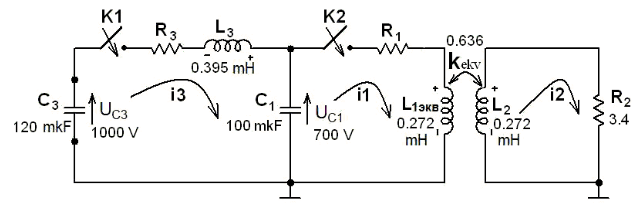

Figure 3: The scheme of a working chain of a scanning electromagnet taking into account a filler. i1, i2 and i3 are currents in contours. Keys K1 and K2 are switched on at the same time.

Presence of a correcting chain of L3 and C3 allows to achieve symmetry of a sign-variable scanning magnetic field during the beam current pulse (see fig. 4). It is necessary to note that given results were received provided that by R1=R3=0. Thus, we consider only influence of the bell filler on a resultant magnetic field in vacuum.

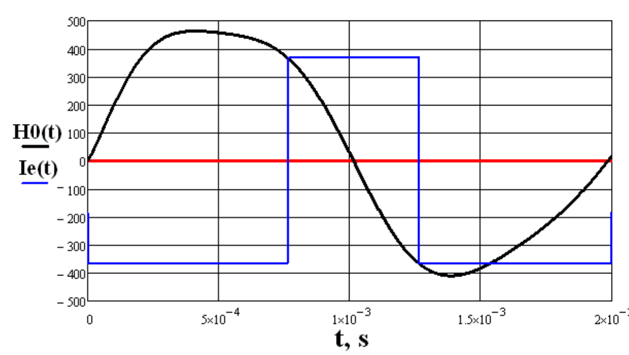

Figure 4: The diagram of a scanning magnetic field with use of a correcting power-supply circuit of a magnet. During a beam pulse (a dark blue meander) the symmetric part on amplitude of this distribution is used.

For computer modeling of electron trajectories the beam on an entrance to the output channel is set or a circle of the points, which gives the evident three-dimensional image of the beam form deformation in the plane of the output foil, or in the form of a round electron spot with really measured distribution of current density that allows to receive values of current density distribution on the exit. Calculation of movement trajectories of electrons in constant magnetic fields was carried out by means of MathCAD software. By results of this calculation the value of amplitude of a magnetic field of the scanning electromagnet necessary for a beam turn on the demanded length along the output window of the accelerator is 0.11T. On fig. 5b calculated trajectories of electrons with energy of 10 MEV are given in a way from scanning electromagnet to the extraction window of the bell. The bell height (axis Z) is 2 m.

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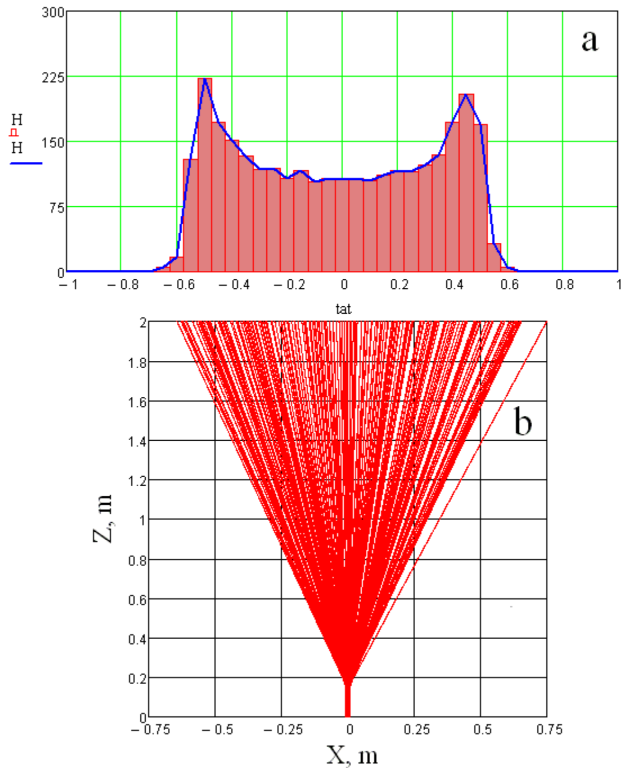

Figure 5: a – the histogram of output current density without correction, b – the scanned electron beam with energy of 10 MEV.

The power supply system of the scanning electromagnet forms a current pulse, in a form reminding piece of a sinusoid with duration of 0.5 ms and adjustable amplitude. Scanning of the beam occurs on a linear site of a sinusoid in the field of transition through zero. Speed of scanning is proportional to a derivative of a magnetic field and there can not be a constant during an acceleration cycle.

On fig. 5a the calculated histogram of the output current density distribution of the scanned beam is provided. It is visible that the current density at edges of a foil increases, and for achievement of the dose uniformity the speed of beam scanning to edges should be raised. Necessary uniformity of output current density is reached by installation before a scanning electromagnet of the system for scanning magnetic field correction. The additional correcting field leads to equalizing of beam scanning speeds along the output bell. The amplitude of the correcting magnetic field is 0.012 T.

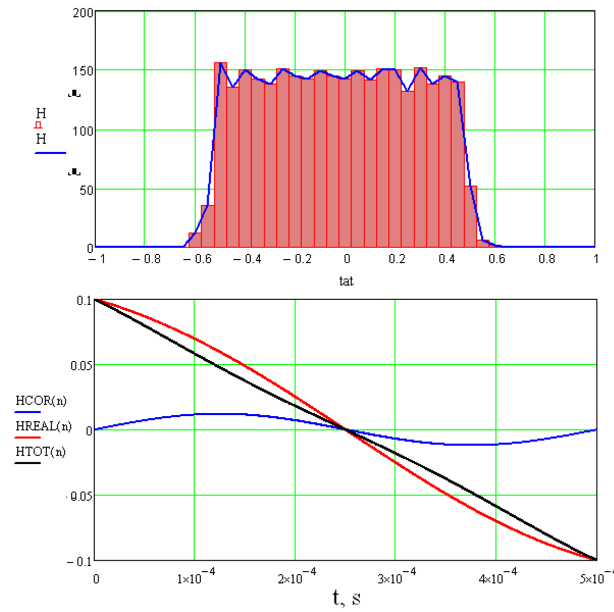

Figure 6: Distribution of output current density with necessary uniformity (at the top) and distributions of the scanning (HREAL), correcting (HKOR) and total (HTOT) magnetic fields (on the bottom).

On fig. 6 the histogram of output beam current density along the bell (the sizes are specified in meters) with use of the system of scanning magnetic field correction, and also forms of scanning and correcting fields during the beam pulse are illustrated.

RESULTS

The scanning system of the beam with energy up to 10 MEV is produced and tested. The received nonuniformity of the dose field in radiation zone was ±10%. To improve radiation quality (dose uniformity) and obtain competitive advantages the correction system of a scanning magnetic field was designed. Consequently, nonuniformity of the surface dose is reduced to ±5 %. This system will be tested within projects of sterilizing complexes at FMBC of A.I.Burnazyan (Moscow) and “Park of Nuclear Technologies” (Kurchatov, Kazakhstan).

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