MAGNETIC SYSTEMS FOR BEAM TRANSPORT AT EXTRACTION CHANNELS OF ILU ACCELERATORS

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ABSTRACT

This paper is devoted to magnetic systems for beam transport at extraction channels of electron industrial accelerators of the ILU type. The extraction systems meant for energy of the accelerated electrons up to 10 MeV and beam power up to 100 kW are described. Special attention is paid to forming of the dose field in a radiation zone. In paper the magnetic system for bending of the nonmonochromatic beams is offered to application. The essence of the described device consists in application of two identical magnetic mirrors in which distribution of magnetic field on depth is formed so that natural rise of magnetic field intensity on an entrance to a mirror is followed by decrease of this field under a certain law [1]. In the issue of impact on charged particles of forces arising in cylindrical lenses of each mirror is possible to compensate angular divergence of strongly nonmonochromatic beams in gaps of magnetic mirrors and to receive after bending a beam with parameters close to phase characteristics of an input beam.

BEAM EXTRACTION SYSTEMS

Radiation 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. Rigid modern requirements to uniformity of dose fields of electronic accelerators demand detailed consideration of the questions connected with operation of extraction devices. The extraction systems of ILU accelerators are meant for energy of the accelerated electrons up to 10 MeV and beam power up to 100 kW. The received nonuniformity of the dose field in radiation zone is up to ±5%. The most optimal for application in radiation technologies are ILU-10 accelerator (5 MEV, 50 kW) and ILU-14 accelerator (10 MEV, 100 kW).

The accelerated beam at ILU is scanned on the required sizes of the irradiated object in the triangular metal vacuum chamber (bell), the scanning electromagnet is located in triangle peak, and an extraction window from a titanic foil 50 microns thick on the opposite side. 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. 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 (see figure 1).

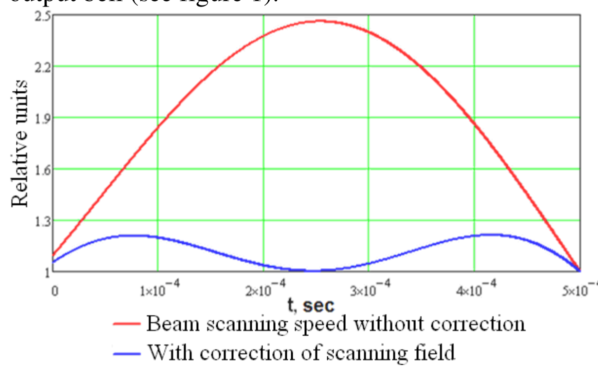

Figure 1: Beam scanning speed along the extraction window during the pulse.

The correction system of the scanning field was tested on the ILU-10 accelerator. For the distribution received without scanning correction, nonuniformity of a dose was ±13%. The optimum form of correction of the scanning magnetic field providing nonuniformity of distribution of a beam current density of ±5% was selected (figure 2).

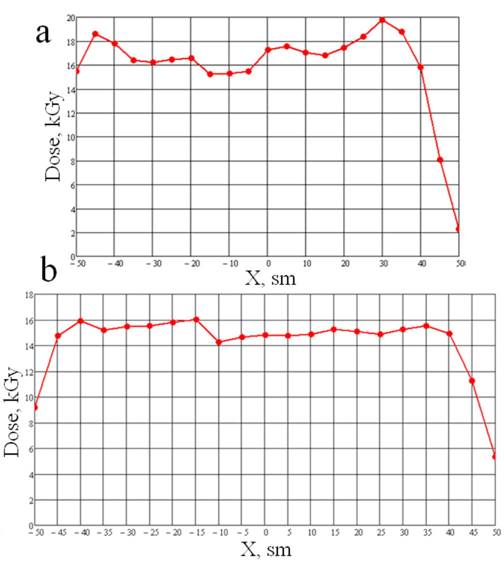

Figure 2: Dose field distribution along extraction window without correction of scanning (a) and with correction (b).

To provide the maximum penetration depth of electrons in material the beam should pass to atmosphere perpendicular to the irradiated production on all length of the accelerator extraction window. For this purpose near extraction window are set two bending electromagnets (Panofsky's lenses). In figure 3 electron trajectories at the extraction channel using the bending electromagnets and without them are given.

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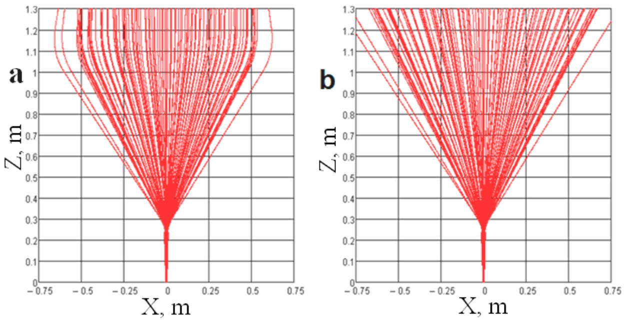

Figure 3: Electron trajectories of scanned beam: a – with using of Panofsky' lenses, b – without additional bending of beam.

In the ILU-14 accelerator along with the described elements of extraction system additional electromagnets for centering and focusing of a beam are used. To control beam position after the exit of accelerating structure with respect to the central axis of the output channel the additional magnet was entered. There is two-coordinate corrector of electron trajectories in the range ± 5 sm. For beam focusing at output channel of the accelerator the quadrupole doublet was installed.

SYSTEM OF BEAM BENDING

Extraction of the electron beam in the atmosphere not vertically, and under a certain corner, in particular, horizontal extraction is in certain cases of material radiation demanded. For bending of the accelerated electron beam it is offered to use system of two magnetic mirrors (M1 and M2). The task of use of a magnetic electron mirror as system for bending of the nonmonochromatic beams was considered for a long time [2]. However, practical implementation of these schemes (with formation by charged particles in a mirror of trajectories in the form of loops and without circumscribing of loops) for various reasons wasn't widely disseminated (complexity of receiving the required distributions of magnetic fields, narrow range of bending angles). At magnetic mirrors with electron trajectories without formation of loops input magnetic field is defocusing. This effect of beam widening on width of a mirror gap has stopped application of such scheme of bending. In connection with this, the subsequent achromatic bending or displacing magnetic systems began to contain flat bending magnets and the focusing systems of the quadrupoles. This scheme allows to reduce angular divergence of a beam after bending [3, 4], but has many permanently controlled variables. Considering the previous experience, authors suggest to use magnetic mirrors with such characteristic of magnetic field distribution on depth with which directly increase of magnetic intensity on the magnet input is followed by its recession under a certain law. Thus, the defocusing action of the growing field on an input to a mirror is compensated by the focusing area of the field recession (because of change of a sign of the first derivative of magnetic field).

The magnetic mirror represents the bending system with two-dimensional magnetic field. There are so-called flat or cylindrical fields. In such fields the method of approximation of this field in the symmetry plane by pieces of curves of the second order is applied to definition of three-dimensional distribution of magnetic field [5]. According to this work components of magnetic field in any point (x, y, z) for M1 and M2 have an appearance:

$$BX(x,y,z) = y \cdot B'(x);$$

$$BY(x,y,z) = B(z) + B(x) - \frac{y^2 \cdot B''(x)}{2} - \frac{y^2 \cdot B''(z)}{2};$$

$$BZ(x,y,z) = y \cdot B'(z).$$

Where BX, BY, BZ – components of a vector of magnetic field induction in any point of a magnet, B(z) and B(x) – the preset distributions of magnetic field in the symmetry plane: for M1 on z, for M2 on x. B' and B'' – respectively the first and second derivative of these distributions of fields in the symmetry plane. System of the equations for the electron movement in the Cartesian coordinates:

$$\frac{d}{dt} vx = \eta \cdot (vy \cdot BZ(x,y,z) - vz \cdot BY(x,y,z));$$

$$\frac{d}{dt} vy = \eta \cdot (-vz \cdot BX(x,y,z) + vx \cdot BZ(x,y,z));$$

$$\frac{d}{dt} vz = \eta \cdot (vx \cdot BY(x,y,z) - vy \cdot BX(x,y,z)).$$

Where η – the electron charge relation to his relativistic mass, vx, vy and vz – a projections of speeds of particles.

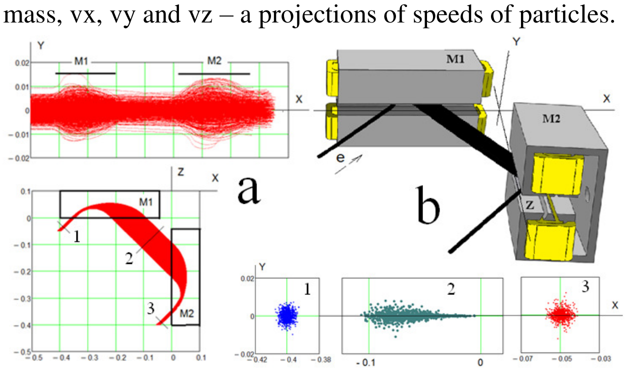

Figure 4: Calculation of beam bending on 180°.

By consideration of the three-dimensional movement of particles in a mirror it is convenient to divide it into two groups of projections of trajectories, as well as it is accepted for dipole magnets. The first group in the radial plane of symmetry (for M1 it is zx) represents bending of a beam on 90 degrees, the second group in the axial plane (xy for M1 magnet gap) describes focusing and defocusing of an electron beam (see figure 4a). For the first time the problem of a beam input taking into account the dispersion field at edges of a magnetic dipole has been considered in Ya. L. Hurgin's paper in 1939 [6].

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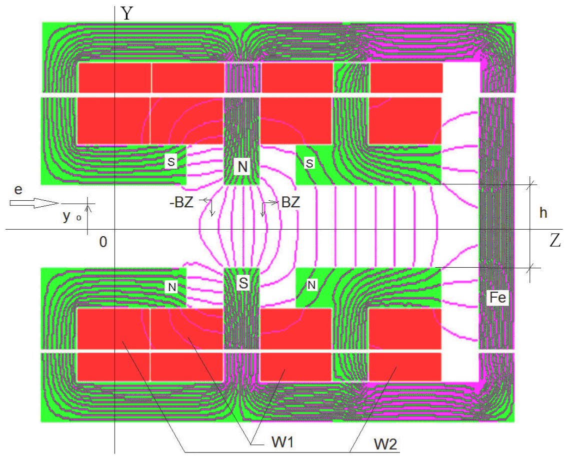

Figure 5: Construction of the magnetic mirror with two pairs of coils.

In this paper dynamics of the movement of particles in the growing flat fields has been for the first time considered. The proof that the growing fields of a magnet edge are cylindrical lenses which depending on the direction of a beam entrance can be collecting or dispersing was the main physical conclusion of this article. In the same place it has been shown that fields near the median plane (for M1 it is the zx plane at y = 0) are equal to the product of a particle coordinate from this plane y at a value of a derivative of magnetic field distribution on depth (for M1 on z).

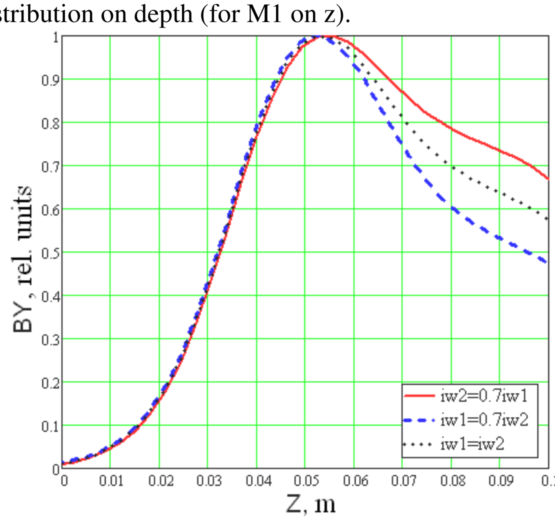

Figure 6: Adjustment of the magnetic field back front at different ratios of ampere-turns of internal (iw1) and external (iw2) coils of a mirror.

Results of calculation of beam bending on 180° are given as an example, the beam enters the first magnet at an angle 45 (see figure 4). Electron energy was 2.5 MeV and beam nonmonochromacity was 50%. The calculated radial projection of a beam to the median plane (xz plane), an arrangement of mirrors of M1 and M2 and an axial projection of path of trajectories to the xy plane are shown in figure 4a.

The scheme of the beam bending, and also beam cross-sections on the way of bending are provided on figure 4b.

The design of a magnetic mirror represents an E-shaped magnetic core with two pairs of coils – internal and external (see figure 5). Distributions of magnetic field in the median plane of this electromagnet for different ampere-turns of coils are provided in figure 6 (h=5sm). The general view of experimental installation for beam bending on 180° is also given in figure 7.

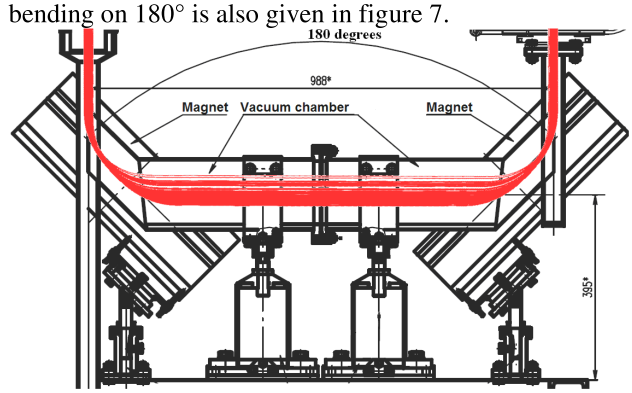

Figure 7: The general view of experimental installation for beam bending on 180° and the scheme of beam motion at the system of two magnetic mirrors.

RESULTS

The system of correction of the scanning magnetic field for electron energy up to 10 MeV providing nonuniformity of the absorbed dose up to ±5% has successfully tested. Calculations of bending of a nonmonochromatic beam with energy of 2.5 MeV on 180º are made, the design of magnetic mirrors and experimental installation for checking of these calculations are developed.

REFERENCES

[1] Bryazgin A.A. et al, “The device for bending of achromatic beams of charged particles”, Patent for the invention No. 2463749, request No. 2011115741, invention priority on April 20, 2011. It is registered in the State register of inventions of the Russian Federation on October 10, 2012.
[2] Kelmam V.M. et al, “Achromatic magnetic mirrors”, JTP, volume 30, issue 2, page 129-137, 1960.
[3] Panofsky Wolfgang K.H., McIntyre J.A., “Achromatic beam translation systems for use with the linear accelerator”, The review of scientific instruments, vol. 25, num. 3, p. 287-290, 1954.
[4] Vladimirskiy V.V., Koshkarev D.G., “Achromatic bending magnetic system”, IET, №6, 1958.
[5] Bleyvas I. M. et al, “The program for the decision on ECVM BESM-6 of three-dimensional problems of electronics”, Works of the third All-Union seminar, Novosibirsk, 1970.
[6] Hurgin Ya. L., “About vertical focusing of a beam of charged particles at its deviation in magnetic field”, JETP, volume 9, issue 7, p. 824-825, 1939.

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