THE MAGNETIC ENERGY ANALYZER FOR ELECTRON BEAM OF LUE-200 LINAC OF IREN FACILITY

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Abstract

Theses for a base substantiation, results of the calculation for the electron optical parameters and design features of the magnetic energy analyzer for the beam of the LUE-200 electron linac are presented. The static dipole magnet with homogeneous transverse field and with a combined function (the function of a spectrometer and of a spectrograph) established after the second accelerating section, allows to spend measurements in a wide energy range of the analyzed particles up to 224 MeV with the instrumentation resolution not worse ±7 %.

INTRODUCTION

IREN Facility [1,2] of the Joint Institute for nuclear research as a particle energy analyzer uses the static analyzer with magnetic spectrometer and functions as a spectrograph. Feature LUE-200 is the vertical axis of the accelerator and beam transport channel to the target, so convenient for hosting and maintenance analyzer configuration is in the form of a dipole magnet with rotation sector beam at an angle of close to $\Phi = \pi/2$, set so that the longitudinal axis of the accelerator tract passes through the magnet median plane. The energy of the accelerated electrons can vary from 15 to 100 MeV, with the one accelerating sections, and up to 100 - 200 MeV when accelerator is operating in full. When you select the main axis provide turning radius analysing magnet $R_0 = 0.5$ m its magnetic rigidity BR [Tm] = E [MeV]/300 should vary within 0.05 – 0.66 Tm.

ANALYZER DESIGN

The analyzer consists of an electromagnet, the vacuum chamber and the detector - registrar. The principle circuit of the analyzer is presented at Fig. 1. The analyzer electromagnet is made in the "Ш" shape. The yoke of the magnet is mounted on one of the "racks", "beams" of the yoke form the side walls and the median plane of the poles is aligned with the axis of the accelerator. The analyzer is installed in the channel of beam transportation between the second accelerating section and a target (Fig. 2). The magnet is mounted on the rails on which the magnet can be rolled horizontally away from the accelerator (Fig. 3). When the beam is transported to the target, the analyzer is disabled, and the residual magnetization of the yoke is removed by the powering of the magnet from the low current power supply. The current value is selected by the absence of deflection of the beam passing through the analyzer.

To control the position of the beam at the input and output of the vacuum chamber of the analyzer using a "beamviewers". The analyzer can operate in two modes. When changing beam energy analyzer mode of the spectrometer, the changing of the level of the magnetic field is adjusted for accepting of particles with energies E_0 from 10 MeV to 200 MeV. In the mode of the spectrograph at a fixed level of the field corresponding to the electron energy E_0, the analyzer has ability to simultaneously register particles in the energy range $E_0 \pm 0.5E_0$.

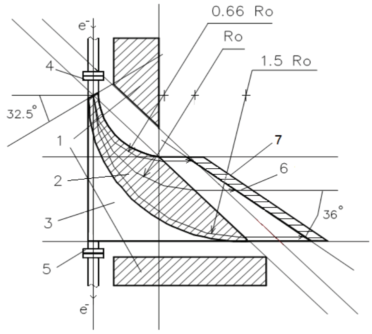

Figure 1: The principle circuit of the analyzer - axial section on median magnet plane. 1 – yoke of the electromagnet, 2 - electromagnet pole, 3 - the vacuum chamber, 4 and 5 - entrance and target branch pipes, 6 - detector window, 7 - the detector - registrar.

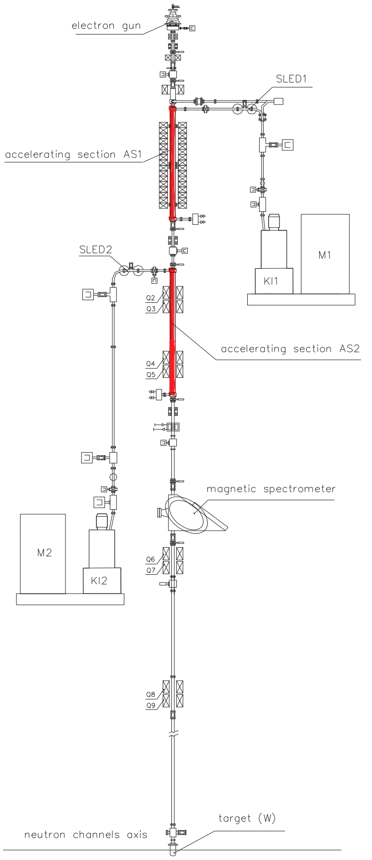

Figure 2: Scheme of the accelerator.

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Figure 3: Layout of the magnet.

CALCULATION OF THE ANALYZER PARAMETRES

Calculation of parameters of magnetic analyzer is performed using the method of matching the initial and final parts of the trajectories of charged particles [3,4]. For numerical simulations, the following beam parameters are used: the beam radius r_1 = 6 mm, beam divergency $\Delta\alpha_1=1.7 \times 10^{-3}$. The subscript "1" means input parameter value, and the i subscript "2" means the value of the parameter at the output of the analyzer. According to the Liouville theorem, the magnitude of the emittance of the beam when the dispersion is stored by the analyzer, eliminating the dependence of the size of the focused beam from the largest component of its initial emittance. In this case, "the relative transverse size" of the electron beam $\Delta y_1 = 2r_1/R_0 = 2.4 \times 10^{-2}$ is substantially more deflection of the particle from the "ideal trajectory" due to the angular divergence of the beam $\Delta\alpha_1$, so of the two types of conversion of the beam magnetic field analyzer "point in point" and "parallels in point" dealt with the latter providing a narrower radial "image" of the beam at the output boundary of the analyzer in its median section and consequently a higher energy resolution. The deflection angle of the optical axis defined by place of the analyzer placement on the beam and placing the device, registering the analyzed electrons is assumed to be π/2. In this case, the axial defocusing effect of the exit boundary of the magnet does not take place and the electrons, crossing the exit border, continue to move in straight lines with no additional discrepancies.

The terms linear radial type conversion "parallels in point" in the magnetic sector analyzer in accordance with [3,4] are of the form

$$\mathrm{tg}\, p\Phi_1 = \mathrm{tg}\, \varepsilon_1/p \text{ and } \mathrm{tg}\, p\Phi_2=\mathrm{tg}(\varepsilon_2 + L_2/R_0)/p, \quad (1)$$

where ε_1 and ε_2 - the angles of the input and output boundaries of the analyser, L_2 - distance from the exit boundary of the analyzer to the radial focal surfaces, Φ_1 and Φ_2 - auxiliary angles that define the plane of matching of the input and output parts of the trajectories in the analyzer, $\Phi_1 + \Phi_1 = \Phi$ - a full deflection angle of the main optical axis of the analyzer, p is the index of the radial decline of the magnetic field. In our case, the analyzing magnetic field made homogeneous (i.e., the simplest formation) with index p = 1.

From (1) follows that the input field of the analyzer will provide an axial type conversion "parallels in point" when the deviation of the electrons in the median plane at an angle of $\Phi = 90^{O}$, if the angle of inclination of the entrance boundary of the analyser is $\varepsilon_1 = + 32.5^{O}$.

A similar situation holds for the auxiliary optical axes of the analyzer, which illustrate two extreme trajectories with radii of curvature $R_{max} = 1.5R_0$ and $R_{min} = R_0 /1.5=0.67\ R_0$. In this case, the exit of the magnetic analyzer boundary is a straight line inclined to the main optical axis and to the auxiliary optical axis at an angle $\varepsilon_2 = -45.0^{O}$. The auxiliary optical axis parallel to the main optical axis at $\Phi = 90^{O}$. Local angular dispersion analyzer at the exit boundary is zero on the main and auxiliary optical axis [3,4]:

$$A_\delta = (1/p)\ [(1\text{-}\cos p\Phi)\ \mathrm{tg}\ \varepsilon_2 + p \sin p\Phi] = 0.$$

From the condition of the radial transform with $\varepsilon_1 = +32.5^{O}$ should $\Phi_1 = +32.5^{O}$, $\Phi_2 = +57.5^{O}$ and $L_2/R = 0.39$, where R takes the values R_0, R_{max} and R_{min}. In this case the focal surface is a plane inclined in the radial cross-section to the main and auxiliary optical axes at an angle $\gamma = -54.0^{O}$. The length of the focal plane between the outermost auxiliary optical axes is equal to 0.70 m. The coefficient of linear radial dispersion is equal, according to [3, 4],

$$Y_\delta = L_2(\sin p\Phi_1+\sin p\Phi_2)/pR\ \ \cos p\Phi_2 = 1.0\ R \quad (2)$$

normal to the optical axis, and

$$Y_{\delta.}/\cos\gamma = 1.70\ R \quad (3)$$

along the focal plane. This means that the absolute value of the dispersion along the focal plane are Y_δ = 12.8, 8.5 и 5.7 mm for 1% relative change in the pulse of electrons, respectively for the three electron - optical axes of R_{max}, R_0, and R_{min}. If the value of the magnetic induction = 1.0 T energy values of electrons moving along the three optical axes are equal to 224.4, 149.4 и 98.4 MeV, respectively. While reducing the magnetic induction up to B = 0.447 T the maximum energy of the electrons coming to a focal plane is reduced to 100 MeV, the minimum energy of the electrons is 44.2 MeV. Thus, for two successive cycles of measurements can be analyzed a full range of electron energies from 44 MeV to 224 MeV.

The size of the focal spot along the focal plane is determined by the conversion factor [3,4]

$$Y_\alpha=L_2 \cos\Phi_1/R\cdot\cos\Phi_2 \cdot \cos\gamma \quad (4)$$

and the value of the initial angular divergence of the beam $\Delta\alpha_1$. These two values determine the specific sizes of the spots on the focal plane 1.17, 0.71 and 0.48 mm for the three axes R_{max}, R_0 and R_{min}.

The resolution of the magnetic field of the analyzer, determined by the ratio of the coefficient of dispersion (3) to the size of the image (4),

$$\text{R.P.} = Y_\delta / Y_\alpha \cos\gamma \, \Delta\alpha_1, \quad (5)$$

is 1190 in the entire focal plane. The reciprocal of the relative energy resolution is $\Delta E/E = 8 \times 10^{-4}$.

Technical characteristics of the electromagnet:

- relative magnetic permittivity of μ=1000,
- maximum magnetic induction of 1.0 T,
- the turning radius along the central axis, R_o = 0.5 m,
- inside turning radius R_{min} = 0.66 R_o, = 0.33 m,
- outside turning radius R_{max} = 1.5, R_o = 0.75 m,
- the sector angle along the central axis is $\pi/2$,
- interpolar gap of 43 mm,
- the weight of the magnet ~ 1.5 t.

The winding of the electromagnet is made of copper tube with square cross section of 12.5 x 12.5 mm with hole Ø 7.5 mm. Winding parameters:

- number of coils - 2,
- the number of turns in the coil - 49 (7 x 7),
- the average length of the turn - 1.5 m,
- single coil resistance (at 200 C) - 0.03 Ohm,
- the current density in the winding ≤ 5.5 A/mm^2,
- adjustment range current - 0 ÷ 700 A.

THE VACUUM CHAMBER OF THE ANALYZER

Analyser vacuum chamber (Fig. 4) is made of stainless steel flat vacuum cavity, covering the trajectories of particles with energies in the range of $E_0 \pm 0.5\ E_0$. Chamber is installed in the interpolar gap of the electromagnet. Chamber has the input flange (1) and output flange (2), the output window to release the beam detector (3), tube for the pumping (4) and detector window (5). The detector window has a rectangular cross section and closes the stainless steel foil with a thickness of 50 µm.

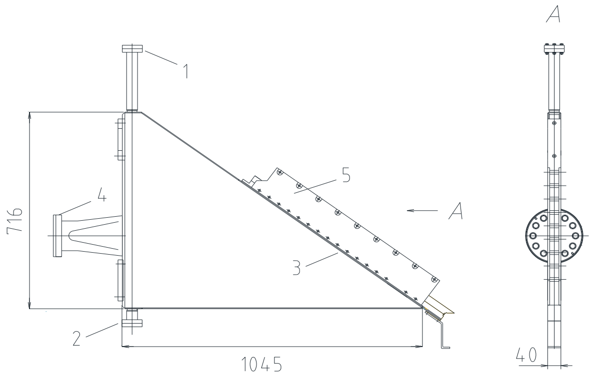

Figure 4: The sketch of the vacuum chamber of the analyser.

THE ANALYZER DETECTOR

The detector is a lamella collector is composed of 37 lead lamellas with dimensions 10 x 40 x 40 mm eacch, installed in the line close to the output window of the vacuum chamber. The lamellas are separated from each other by an insulating plate with a thickness of 1.66 mm. Thus, the step sequence of the lamellas 10 mm + 1.66 mm = 11.66 mm. The input of the detector is set on the "focal plane" of the analyzer magnet at a distance of 0.39R from the edge of the poles of the magnet. The angle of inclination of the plane of the entrance of the detector to the axis of the central trajectory of particles equal 36°. Full size range of the lamellas covers the trajectories of electrons having a radius of 0.33 m to 0.75 m. The amplitude of the electrical signal with separate lamella is proportional to the proportional to the number of particles with energy $E_L[\text{MeV}] = 300 \cdot B \cdot R_L$ where R_L is the position of the lamella along the radius. The electrical signals of the lamellas are measured in every cycle and processed in mode "off line".

Design features of the analyzer detector allow to measure energy spectra with a relative accuracy of $\Delta E/E$ is not worse than ± 7% with a frequency of cycles not more than 5 Hz. If necessary, the lamellas can be combined in groups of 2, 3 or 4 lamellas. Energy spectrum of an electron beam, when lamellas are combined in groups of 4 is presented at Fig. 5.

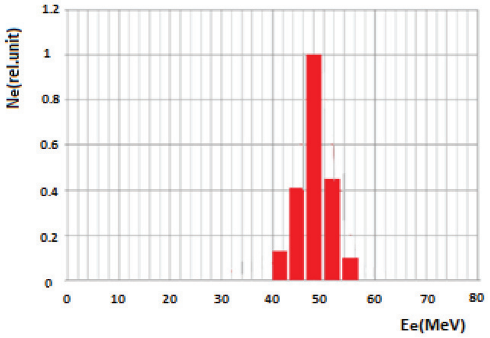

Figure 5: Energy spectrum of an electron beam, measured in process of adjustment of the LUE-200 linac.

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