# A 5 TO 20 MEV ELECTRON LINEAR ACCELERATOR FOR METROLOGY

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*Abstract*

The paper outlines design parameters and construction features of an electron linear accelerator to be operated in the Mendeleyev Institute for Metrology (VNIIM). The accelerator system is intended to form bremsstrahlung and electron radiation fields of variable intensity.

## INTRODUCTION

A designed facility should be included into the National standard of units, which is used for metrological assurance of measurements in the nuclear-physical instrumentation, ship and aircraft building, rocket production, radiation processing and in the accelerating equipment for industry and medicine [1].

The accelerating facility consists of an electron source, accelerating structure, magnet–separator, and radiation head with an electrically-operated mechanism used for replacement of bremsstrahlung targets, foils and collimators. Table 1 presents the main design characteristics of the facility designated as follows: $W_B$ is the energy of electrons in the spectrum maximum, $\Delta W$ is the energy spread, $I_0$ is the average electron current, $D_B$ is the beam diameter in the plane of an extraction window. A required range of radiant flux is obtained by changing the pulse-repetition frequency and fine adjustment of the beam current in a pulse. This imparts a high spatial stability to radiation fields.

Table 1: Specification of the Facility

| | |
|---|---|
| **Radiation head input:** | |
| $W_B$, MeV | 5-20 |
| $\Delta W/W_B$, % | ±5 |
| $I_0$, μA | 0.1-10 |
| $D_B$, mm(FWHM) | ≤ 5 |
| **Electron radiation field at the 100 cm SSD:** | |
| Area, cm$^2$ | 10x10 |
| Flatness, % | ≤ 2 |
| Particle flux density (aver.), $c^{-1}\cdot cm^{-2}$ | $6\cdot10^{11}$ - $6\cdot10^{13}$ |
| **Bremsstrahlung field at the 100 cm SSD**: | |
| Area, cm$^2$ | 10x10 |
| Flatness, % | ≤ 2 |
| Energy flux density (aver.), W/cm$^2$ | 0.5-200 |

## ELECTRON SOURCE

The accelerator is equipped with a three-electrode electron source of a typical construction. Electrons are emitted from an oxide-nickel hot cathode 5 mm in diameter. The control electrode is closed with a grid of 0.1 mm-thick wires. The geometric transparency of the grid is 73 %. The grid voltage of 250-300 V provides 70-90 mA current at the gun output. Under these conditions, the electron beam has a minimum emittance well matched with the accelerator acceptance, Fig. 1. The energy of the beam injected into the accelerator is 50 keV. A separate gun modulator specifies the beam pulse duration of 5 μs; the pulses follow with a frequency from 2 up to 200 Hz.

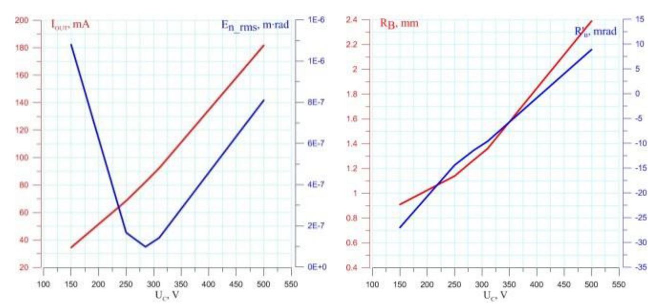


Figure 1: Calculated characteristics of the beam at the electron source output. $I_{OUT}$ is the beam current, $E_{n\_rms}$ is the rms emittance (norm.), $R_B$, $R'_B$ are the envelope size and slope, $U_C$ is the grid voltage.

## ACCELERATING STRUCTURE

A biperiodic electrodynamic structure with internal coupling cells is used for acceleration of electrons. The structure operates in the $\pi/2$ standing wave mode at 2856 MHz and comprises sixty one cells. The first ten bunching cells have cylindrical shape optimized for a minimum of high-energy particle losses over the whole beam line. The rest elements of the structure are standard Ω-shaped accelerating cells alternating with cylindrical coupling cells. The total length of the accelerating structure is 1.5 m.

The electric field of the structure is used both to accelerate particles and to confine transverse dimensions of the beam, consequently there are no external focusing elements. Energy of electrons is varied by changing the accelerating field amplitude (the field excitation power) and is accompanied with some degradation of the electron spectrum [2].



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Design parameters of the structure are given in Table 2 and are designated as follows: $P_{RF}$ is the pulsed RF power consumption; $E_M$ is the maximum field strength on the beam axis; $I_{INP}$ ($I_{OUT}$) is the pulsed beam current at the structure input (output); $I_W$ is the pulsed working current, i.e. the current being in the energy interval ± 5% relative to W and passing through the magnet–separator; $\kappa = I_{OUT} / I_{INP}$ is the beam transmission; $\eta = I_W / I_{OUT}$ is the fraction of the working current in the output one; VSWR is the voltage standing wave ratio in a supplying waveguide.

Table 2: Design Parameters of the Accelerating Structure

| $W_B$, MeV | $P_{RF}$, MW | $E_M$, MV/m | $I_{INP}$, mA | κ | η | $I_W$, mA | VSWR |
|---|---|---|---|---|---|---|---|
| 5 | 1.59 | 17.7 | 86 | 0.65 | 0.36 | 20 | 1.50 |
| 8 | 1.86 | 18.7 | 80 | 0.69 | 0.65 | 36 | 1.38 |
| 11 | 2.31 | 20.4 | 80 | 0.73 | 0.71 | 41 | 1.28 |
| 14 | 2.95 | 22.7 | 80 | 0.78 | 0.77 | 48 | 1.18 |
| 17 | 3.95 | 26.2 | 80 | 0.84 | 0.84 | 57 | 1.08 |
| 20 | 5.00 | 29.8 | 80 | 0.88 | 0.87 | 61 | 1.01 |

Computational distribution of the accelerating field on the structure axis is shown in Fig. 2. The maximum average lost power in resonator walls is 1.3 kW, the pulsed power loss is 3.7 MW.

An amplifying klystron KIU-168 is planned to be used for excitation of the accelerating structure. The RF line of the facility also comprises a circulator, 2 waveguide loads and 2 dielectric RF windows; the RF power pulse duration is 6 µs.

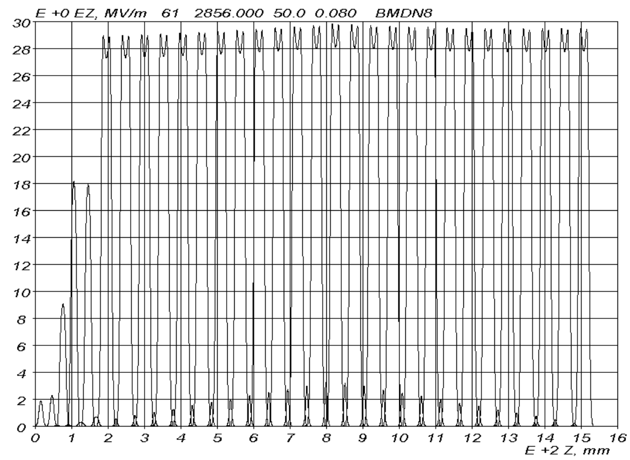
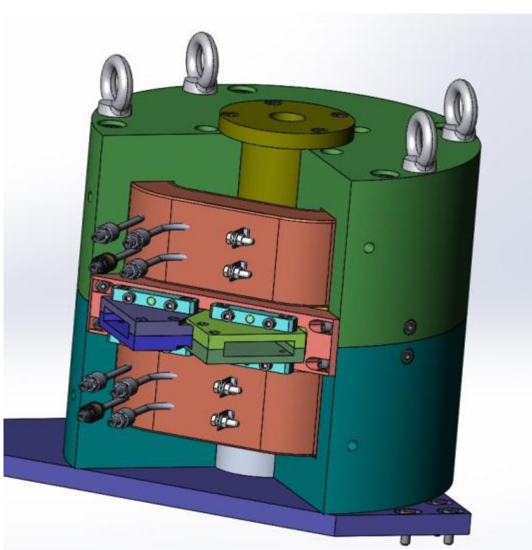



Figure 2: Accelerating field on the structure axis.

## MAGNET-SEPARATOR

The beam-bending magnet-separator (MS), Fig. 3, is intended to change the travel direction of electrons (horizontal instead of vertical) and to remove the non-working part of the spectrum from the beam. The magnet-separator is installed between the accelerating structure and the radiation head. The distance from the structure to the MS input is 700 mm; that from the MS output to the extraction window, behind which the radiation head will be placed, is 525 mm.



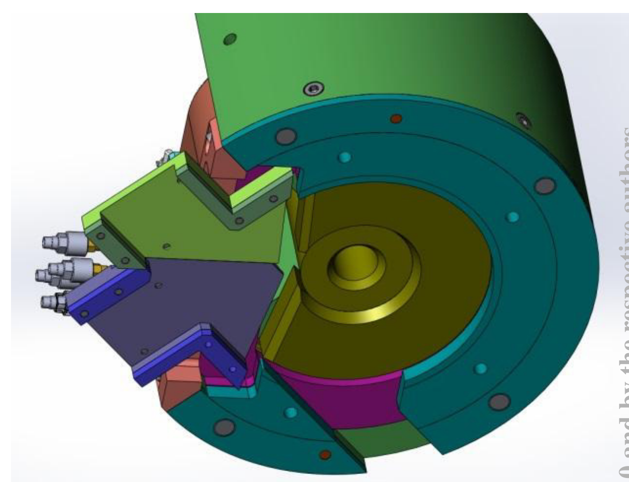


Figure 3: 3D model of the magnet-separator.

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The separator consists of 1 electromagnet with an angular length of 270° and a constant pole gap of 14 mm. To make the system stigmatic and non-dispersive, which is necessary to keep the azimuthal symmetry of the radiation field, pole face angles are chosen to match with the working position of the bremsstrahlung target. The electromagnet bends the beam with energies 5-20 MeV along the circumference with a radius of 70 mm and consequently provides a change in the guiding magnetic field in the range of 0.26-0.97 T.

To restrict the extent of stray fields around the beam path, the MS is equipped with two field clamps. The clamp is a split-type thick-walled magnetic shielding jacket put on the vacuum chamber. The construction allows the gap between the clamp and poles to be adjusted within the limits of 5-20 mm.

A maximum power consumed by the magnet is 2×500 W, the excitation coil voltage amounts to 20 V and current is equal to 45-50 A. A required stability of the coil power supply is $1 \cdot 10^{-3}$ ($\Delta I / I$).

A prescribed momentum acceptance determines a minimum width of the MS working area and the distance between the walls of the vacuum chamber, onto which the non-working part of the beam will be dumped [2]. The power of the heat released in the walls depends on the current flow and spectrum of accelerated electrons. In the nominal operating mode of the accelerator the power is lower than 140 W. The distance between the walls is 16 mm, and it is the same over the whole bend length.

The vacuum chamber walls are made of tinless bronze, Fig. 4. Both the walls and the magnet excitation coils are cooled with water. The beam is extracted into the atmosphere though a titanium foil.

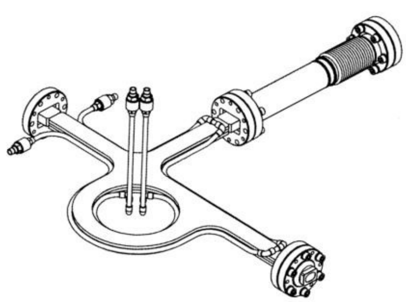

Figure 4: Vacuum chamber with cooling channels.

## COMPONENTS OF LOCAL RADIATION SHIELDING

The non-working part of the beam dumped on the vacuum chamber walls is a source of high-energy background ionizing radiation. The magnet yoke, excitation coils, clamps and vacuum chamber walls attenuate the radiation in part. For this reason, special absorbers made of non-magnetic material were provided in the magnet-separator. Lead absorbers meet the customer requirements for the maximum level of the induced (residual) radioactivity, which is 2-6 µSv/h on the magnet-separator surface, Fig. 5.

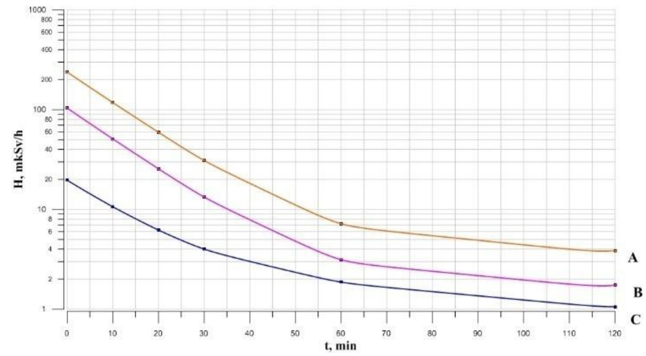


Figure 5: Calculated data on the induced activity of the magnet-separator. A – magnet separator without special radiation shielding. B – magnet separator with added Al absorbers. C – magnet separator with added Pb absorbers.

## RADIATION HEAD

To form bremsstrahlung fields, a system of replaceable units is installed in the radiation head. It consists of a tungsten-rhenium target, cone-shaped collimator made of W-Ni-Cu alloy and copper flattening filter. To form electron radiation fields, the radiation head houses replaceable units comprising a primary collimator made of aluminium, and a pair of foils: tantalum scattering foil and aluminium compensating foil. To define the shape of flattening filters and compensating foils, we used the GEANT4 code.

## STATUS OF THE PROJECT

The electron source has passed testing, and design parameters were confirmed. The accelerating structure has been manufactured (see Fig. 6) and RF-tuned. All the main systems of the facility are ready for delivery to the customer.

Figure 6: Accelerating structure with cooling jacket.

## REFERENCES

[1] I.A. Kharitonov, I.I. Tsvetkov, Proc. X-th Int. Conf. on Appl. Charged Particle Accelerators, Saint-Petersburg, 2001, pp.257-261.

[2] The adopted engineering solution has resulted from the financial resources of the customer.



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