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OPTIMIZATION OF THE FOCUSING LATTICE OF THE MAGNETO-OPTICAL STRUCTURE OF THE MULTIFUNCTIONAL ACCELERATOR COMPLEX NSC KIPT

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The results of the further optimization of the focusing lattice of the magneto-optical structure of the multifunctional accelerator complex of the NSC KIPT are presented. The basis of the complex is an electron recirculator with a superconducting accelerating structure. The maximum electron energy of about 600 MeV can be obtained when the beam passes through the accelerator three times. The beam layout into injection area and recirculator arcs are given. Focusing functions and beam sizes along the beam trajectory and at the output azimuths are calculated.

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INTRODUCTION

In order to implement the concept of the state target program for the development of the experimental base of the NSC KIPT for fundamental and applied research in the field of nuclear physics, high-energy physics, and the interaction of radiation with matter in works [2–4], a project of a multifunctional accelerator complex, the main object of which is an electron recirculator at a maximum energy of about 600 MeV. The basis of this conceptual project was the results of a review of the world facilities at which nuclear physics research is conducted in the world [2, 3] and ideas for the development of accelerator technologies laid down in the European Strategy for Particle Physics – Accelerator R&D Roadmap [5]. This strategy is a roadmap for the development of accelerators in Europe in the next 5…10 years. Active participation in these works is taken by world centers in which the latest directions of nuclear physics research are currently concentrated [3].

The general view of the magneto-optical structure of the multifunctional accelerator complex is presented in Fig. 1.

Let us consider in more detail the results of optimizing the magnetic structure of the recirculator project.

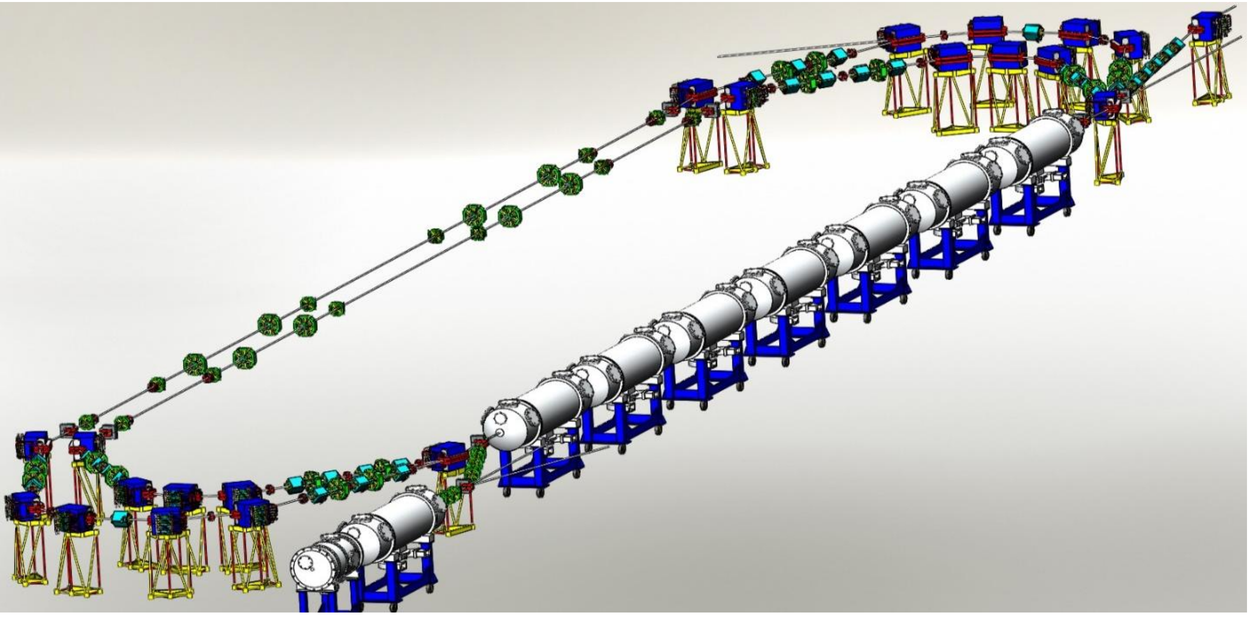

Fig. 1. General view of the recirculator

1. STRUCTURE OF THE COMPLEX

The scheme of injection of electrons into the recirculator is presented in Fig. 2. As a prototype of the electron source in the project, an injector with a superconducting accelerating structure, developed at the HZDR in Dresden, was selected [6, 7]. In one of the modifications of the source, electrons can be accelerated to 9.5 MeV, the average value of the accelerated current reaches 1 mA, the charge in the bunch up to 1 nanocoulomb. Bunch length is 4…15 ps. The accelerator structure of the injector operates at a frequency of 1.3 GHz at a temperature of 1.8 K.

After the injector, the beam will enter the superconducting accelerator module, which contains two 9-resonator structures TESLA made of niobium [8–10]. Energy gain – 25 MeV.

A system of three and five quadrupoles QL2 and two dipoles BM2 creates an achromatic structure that allows the formation of beams with good characteristics at the entrance to the main accelerating structure. The angle of rotation of the beam in dipole magnets is 18.30º.

For injection positron into the recirculator, a converter and a solenoid made on the basis of rare-earth alloys will be installed in front of the first dipole, which will be able to be removed from the beam when working with accelerated electrons.

If the field of the first magnet is turned off, a beam with a maximum energy of 34.5 MeV can be transported to create a source of slow positrons for positron annihilation spectroscopy.

When changing the direction of the magnetic field, a beam with the same energy can be used on the channel for work with radiation technologies, production of isotopes for medicine, etc.

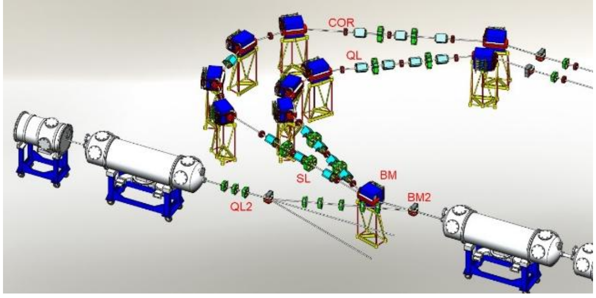

Fig. 2. Injection

In order to reduce the influence of longitudinal harmonics of perturbation of the fields of focusing elements and nonlinear effects in the dynamics of the electron beam, an injection scheme was chosen, which made it possible to create a symmetrical focusing structure in the recirculator rings [4]. This led to the optimization of the phase portraits of the beam. In this structure, the beam undergoes a turn in an arch at an angle $\psi > 180º$; $\psi = 180º + 2\varphi$, where $\varphi = 3º$ (at a beam energy of 210 MeV) is the angle of rotation of the additional magnet on long straight sections. Injection into the recirculator is carried out with the help of this BM2 magnet (see Figs. 1 and 2). The same magnets are introduced on the rectilinear spaces of the first and second recirculation rings, not occupied by the accelerating system (Fig. 2).

After injection, the beam is accelerated in a system of seven superconducting modules [8–10] installed in a long straight span (see Fig. 1). A beam with a maximum electron energy of 209.5 MeV is directed along the first ring of the recirculator with the help of a BM dipole magnet installed at the end of the gap after the accelerator (Fig. 3).

If the rotary magnet is turned off after the accelerator, the beam can be directed to the target of the pulsed neutron source [11].

The magnetic system of the first ring (see Figs. 1–3) ensures the rotation of the beam into the accelerator, where its energy will increase by 175 MeV. After that, the beam completes its rotation through the second ring, passes through the accelerator a third time, and with an energy of 559.5 MeV is output to physical installations. This beam can also be injected into the storage ring – a source of synchrotron radiation and used in a free electron laser.

If you turn off the fourth magnet on the second recirculation ring, as shown in Fig. 3, you can get another channel of the emitted beam with a maximum energy of 384.5 MeV.

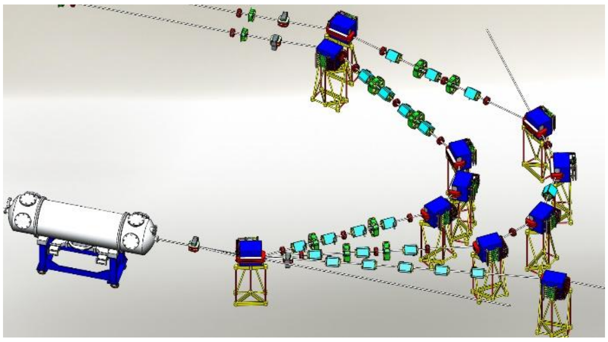

Fig. 3. Output channels

Quadrupoles QL, placed in rectilinear intervals of turning arcs (Fig. 4), should ensure the isochronous motion of the electron beam in the recirculator and achromaticity of long rectilinear intervals, and sextupoles SL – correction of natural chromaticity and dynamic aperture of the rings.

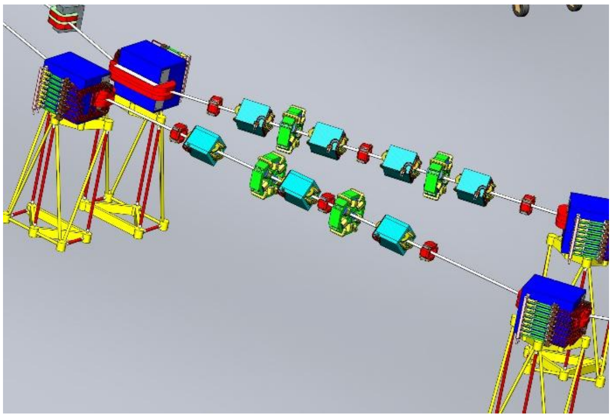

Fig. 4. Structure of short intervals

The system of COR correctors is placed in the structure in such a way as to provide the most effective correction of the beam trajectory.

2. BEAM PARAMETERS

The main features of recirculator focusing structures are:

- the requirement of isochronity of each of the rings, which ensures obtaining the maximum energy of accelerated particles (at each passage of the accelerating structures, bunches of the beam fall into the accelerating field with minimal phase dispersion);
- the minimum requirement of m_{12} (m_{34}) elements of the ring transmission matrices, which ensures the suppression of BBU – beam instability.

These requirements are satisfied by the appropriate selection of the parameters of the quadrupole lenses of the QL and QL2 rings. Focusing is quite tight and the natural chromaticity of both rings is high. To correct the chromaticity and dynamic aperture in the arches of the rings and on long rectilinear spaces opposite to the space with accelerating structures, SL sextupole lenses are installed (see Figs. 1–4).

The minimization of the elements of the matrices m_{12} (m_{34}) leads to the fact that the frequencies of betatron oscillations in the rings are close to integer (halfinteger) values. At the same time, distortions of the equilibrium orbit (EO) in the rings can exceed the aperture values of the vacuum chambers. To correct these distortions, correctors have been introduced into the structure of the rings, which allow compensating for EO deviations along the entire perimeter of the recirculator.

The parameters of the injected beam were calculated as follows:

- beam energy E_i = 34.5 MeV;
- normalized transverse emittance $\varepsilon_x = \varepsilon_y = 2\cdot10^{-6}$;
- electron bunch length (rms) l_b=1.2 mm;
- energy spread (rms) $\delta = 1\cdot10^{-3}$.

The amplitude and dispersion functions of the recirculator rings in the range of injection azimuth – exit azimuth of the accelerating structure after the third pass of the beam are shown in Figs. 5 and 6.

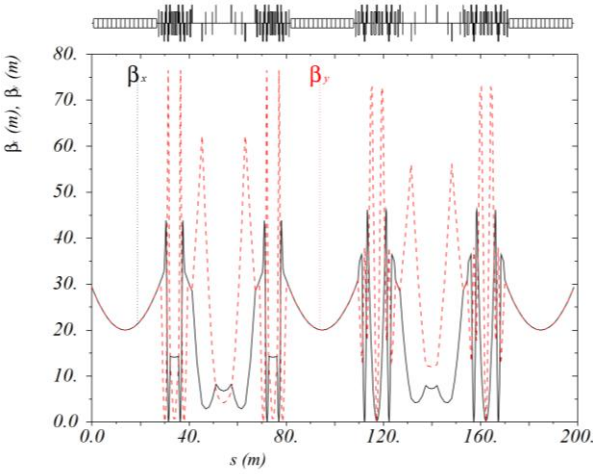

Fig. 5. Amplitude functions of two recirculator rings

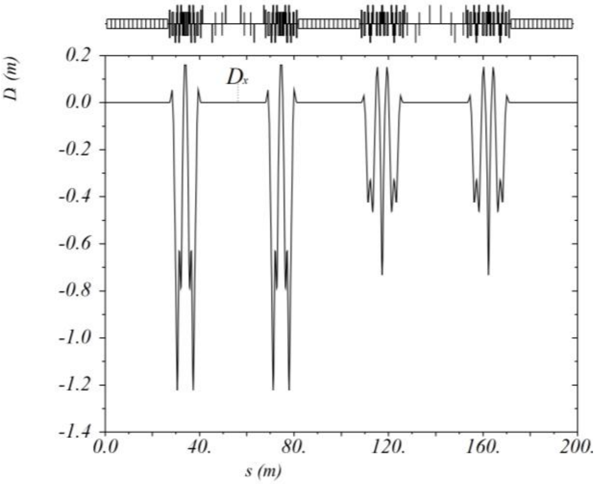

Fig. 6. Dispersion function of the recirculator

To develop the requirements for the vacuum chamber, it is important to know the dimensions of the bundle in the recirculator rings. Fig. 7 shows the root mean square dimensions of the beam in the first ring. Geometric emittance of the beam ε_{xy}=$4.8\cdot10^{-8}$, energy spread of the beam δ=0.167%.

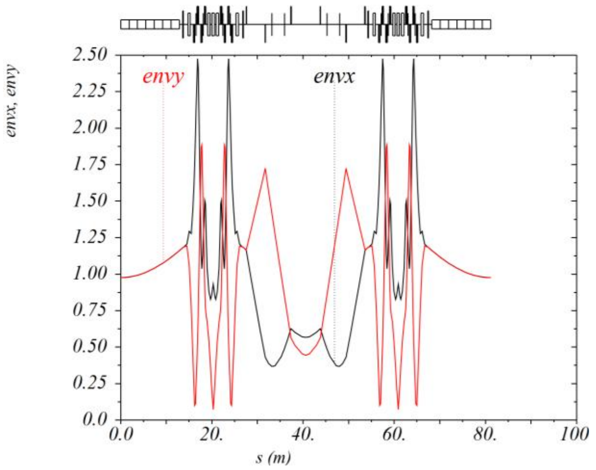

Fig. 7. Dimensions of the beam on the first ring (mm)

Fig. 8 shows the rms dimensions of the beam in the second ring. Geometric beam emittances $\varepsilon_{x,y}$=$2.6\cdot10^{-8}$, beam energy spread δ=0.167%.

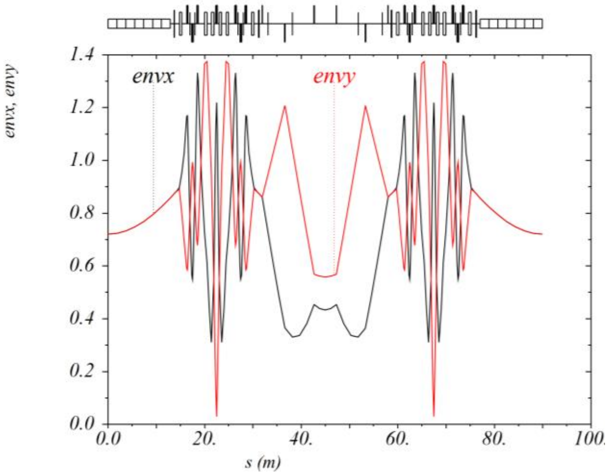

Fig. 8. Dimensions of the beam on the second ring (mm)

The cross-section of the beam after the first pass through the accelerating interval is shown in Fig. 9 (beam energy E = 210 MeV, blue symbols). For comparison, the injection beam at the entrance to the accelerator represented by red symbols.

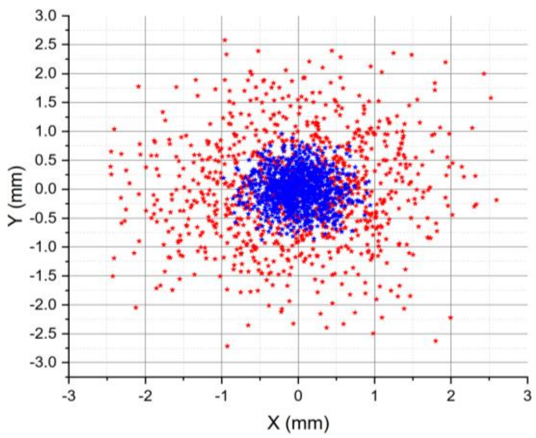

Fig. 9. The dimensions of the beam with an energy of 210 MeV

The cross-section of the beam after the second passage through the accelerating gap (beam energy E=385 MeV) is shown in Fig. 10.

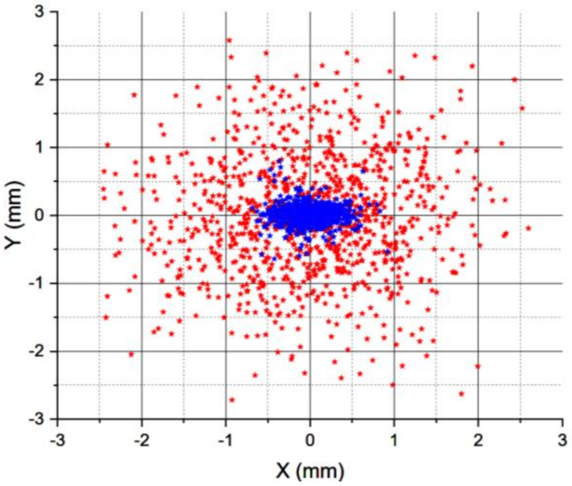

Fig. 10. Dimensions of the beam before entering the second ring recirculator

The cross-section of the beam at the exit of the second magnet of the exit channel (beam energy E = 560 MeV) is presented in Fig. 11.

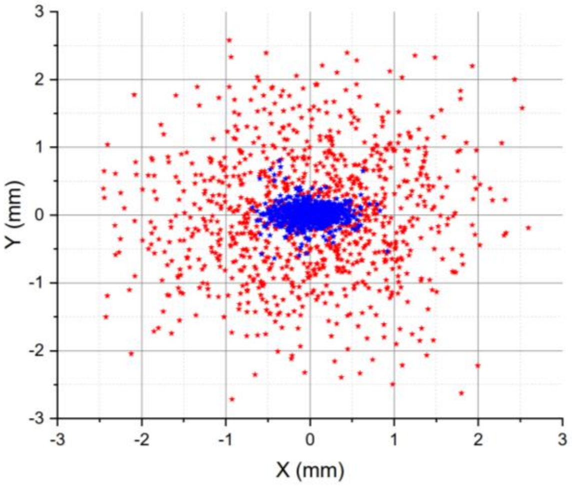

Fig. 11. The beam with the highest energy at the exit output channel

The energy spectrum of the beam after the second magnet of the beam output channel with the maximum energy presented in Fig. 12.

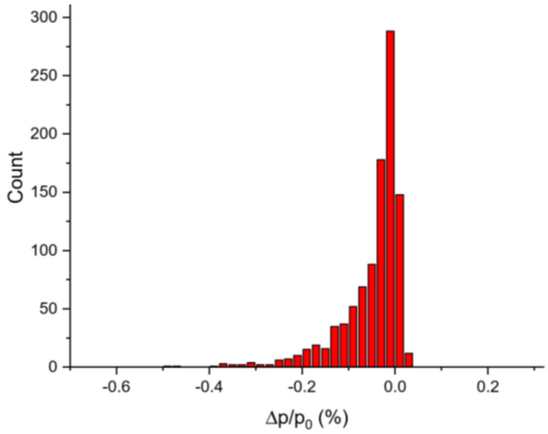

Fig. 12. The spectrum of the beam with the highest energy

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ОПТИМІЗАЦІЯ МАГНІТООПТИЧНОЇ СТРУКТУРИ БАГАТОФУНКЦІОНАЛЬНОГО ПРИСКОРЮВАЛЬНОГО КОМПЛЕКСУ ННЦ ХФТІ

***М.Ф. Шульга*, Г.Д. Коваленко, І.С. Гук, П.І. Гладких, Д.Ю. Шахов**

Представлено результати подальшої оптимізації магнітооптичної структури багатофункціонального прискорювального комплексу ННЦ ХФТІ. Основою комплексу є рециркулятор електронів з надпровідною прискорювальною структурою. Максимальна енергія електронів біля 600 МеВ може бути одержана при трикратному проходженні пучка через прискорювач. Наведено дані про розміщення магнітного обладнання на ділянці інжекції і арках рециркулятора. Розраховано функції фокусування та розміри пучка вздовж траєкторії руху пучка і в точках виводу.