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THE BASIC SUMMARIES OF WORKING OUT OF RECIRCULATOR SALO MAGNETOOPTICAL SYSTEM

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Effects of modelling moving an electron beam in the optimised magnetooptical structure recirculator SALO are in-process resulted. Modelling is spent with the account of agency of nonlinear components of a magnetic field of dipole magnets and quadrupole lenses with use of programs TRANSPORT and MAD-X. The gained effects testify to a possibility of a beam production of the given sizes in points of a leading-out and beam acceleration without essential losses along accelerator.
KEY WORDS: electron, recirculator, dipole magnet, quadrupole lens, SALO.

ОСНОВНЫЕ ИТОГИ РАЗРАБОТКИ МАГНИТООПТИЧЕСКОЙ СИСТЕМЫ РЕЦИРКУЛЯТОРА SALO

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В работе приведены результаты моделирования движения пучка электронов в оптимизированной магнитооптической структуре рециркулятора SALO. Моделирование проведено с учётом влияния нелинейных компонент магнитного поля дипольных магнитов и квадрупольных линз с использованием программ TRANSPORT и MAD-X. Полученные результаты свидетельствуют о возможности получения пучка заданных размеров в точках вывода и ускорения пучка без существенных потерь вдоль всего ускорителя.
КЛЮЧЕВЫЕ СЛОВА: электрон, рециркулятор, дипольный магнит, квадруполь, SALO.

ОСНОВНІ ПІДСУМКИ РОЗРОБКИ МАГНІТООПТИЧНОЇ СИСТЕМИ РЕЦИРКУЛЯТОРА SALO

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У роботі приведені результати моделювання руху пучка електронів в оптимізорованій магнітооптичній структурі рециркулятора SALO. Моделювання проведене з урахуванням впливу нелінійних компонентів магнітного поля дипольних магнітів і квадрупольних лінз із використанням програм TRANSPORT і MAD-X. Отримані результати свідчать про можливості одержання пучка заданих розмірів в точках виводу і прискорення пучка без істотних втрат уздовж усього прискорювача.
КЛЮЧОВІ СЛОВА: електрон, рециркулятор, дипольний магніт, квадруполь, SALO.

Making of major electrophysical facilities usually includes some stages. For developed in NSC KIPT a base accelerating facility on a nuclear physics and a high-energy physics such stages is working out of the perspective program of experiments where the urgency of examinations with electron beams to 1 GeV is displayed, the basic demands to beams are formulated, importance of making on the basis of facility a powerful source of neutrons that will allow to spend a number of applied researches [1, 2] is specified.

On the basis examination of the basic trends in development of the accelerating high technology in the world the select of the plan of the accelerator has been spent, allowing to gain electron beams of the given performances with the account features of its arrangement in existing capital buildings in NSC KIPT [3-7].

At following stage technical requirements to recirculator electromagnetic system basic elements have been formulated and preliminary designs of dipole and quadrupole magnets and all system as a whole [8] are developed. This design has displayed technical possibility embodying of the chosen magnetic structure and has given data for conducting of estimation facility cost. On the other hand, it has determined necessity of the further recirculator structure optimization for unification of magnetic devices and regimes of their operation, and also improvement of performances of output beams.

For support of the continuous regulation of energy on beam lines on an inlet regulating of injection energy has been injected into recirculator accelerating system [9]. Because to the present time the electromagnet with length of poles 100 mm, displayed good performances [10] is designed, made and tested, unification magnets of injection system and magnets of the snake has been spent. For the optimization score it was possible to expel a number of the strong quadrupoles from structure and to diminish fields in quadrupoles of the first and second recycling ring [11]. The General view of modified accelerator magnetic system is presented on Fig. 1.

The main task of this paper is description of the optimized recirculator magnetic system and analysis of beam parameters on an inlet in transportation channels of beams to physical installations. Simulation driving of corpuscles and magnetic structure optimization was carried out by means programs TRANSPORT [12] and MAD X [13] and the methods included in these programs. For deriving of the effects, the most approximate to really implemented in the future facility, used values of effective length of dipole magnets, quadrupole and sextupole field components gained from experimentally measured allocations of fields in magnets, and also models exposition of fields in dipoles and the quadrupoles, widely used in the literature and displayed good coincidence to experimentally measured performances of these magnetic devices [24].

Assuming from features of corpuscles driving at various stages of acceleration and assuming from various designs for the magnetic devices used on these sections, it is convenient to view effects of simulation for system of injection, a gap with accelerating sections, the first turnover of a recycling and the second turnover.

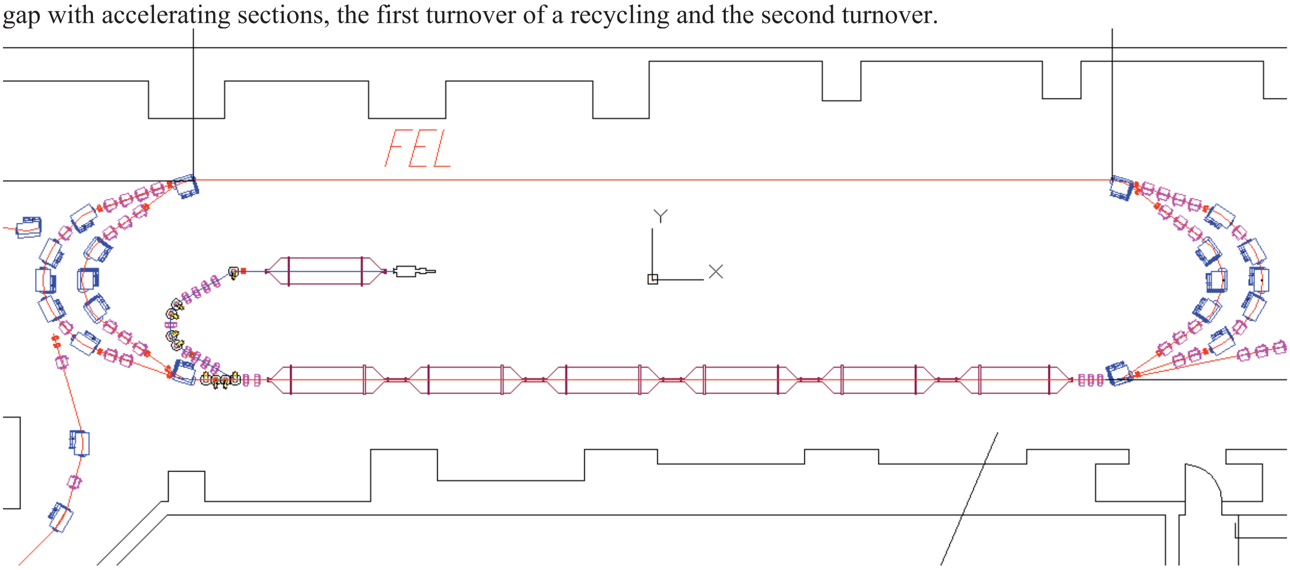

Fig. 1. The General view of recirculator magnetooptical system

RECIRCULATOR ELECTROMAGNETIC SYSTEM DEVICES

As a result of the spent optimization of structure and equipment unification, the recirculator electromagnetic system consists from: dipole magnets system of injection and a snake, quadrupole magnets of system of injection, dipole magnets of the first ring of recirculation, quadrupole magnets of the first ring (they also are used and on the second ring), dipole magnets of the second ring and dipole magnets system of correction.

Dipole magnets (9 copies) injection systems have an s-shaped construction, poles cross-section 100×100 mm, 25 mm distance between poles [10]. Spools windings are executed from a copper wire with heatproof and radioresistance isolation. Cooling of windings is carried out at the expense of air natural circulation. The maximum value of an induction of a field - 0.3 T. The magnet copy is made, the field topography is measured in all effective range of fields. The effective length of a magnet, equal 133, 8 mm, quadrupole and sextupole field components is measured. Maintenance of a pre-production model of a magnet on an exit of technological accelerator "EPOS" within more than one and a half years in the conditions of the strong radiation fields has displayed reliability of a construction and necessary longevity on all prospective expected life.

Quadrupole lenses of injection system [6] (14 copies) are used both on an injection section, and for beam focusing on a section of an arrangement accelerating structures. The maximum value of a field gradient – 6.4 T/m. Diameter of the lens aperture is equal 32 mm. The lens geometrical length is equal 80 mm, settlement effective length - 100 mm. The lens construction is developed on the basis prototype; it is a lot of years operated on electron linacs in NSC KIPT [16]. Cooling of windings air, natural.

10 dipole magnets of electron storage ring EUTERPE [4, 17] are used as dipole magnets of the first ring of recirculation. These magnets have an s-shaped construction with the right-angled poles cross-section 120×480 mm. The positive allowance altitude is equal 25 mm. The magnetic circuit is made of transformer steel leafs, a winding - from the copper tube, chilled by water. The maximum field in a magnet – 1.35 T. Effective length of magnets equal 516 mm. Values of integral sextupole field component along a path of corpuscles [17, 18, 19] which are used in calculations of a path beam driving have been measured also.

28 quadrupole lenses of the first and second turnover of recirculation have been developed and made for ring EUTERPE [4, 17]. The maximum gradient - 15 T/m. The pole length of lens is equal 250 mm, effective length – 274 mm. The radius of the lens aperture is equal 25 mm. The lens yoke is made of a transformer steel. Windings are made of a copper tube and chilled by water.

The design of a dipole magnet of shell-type type is developed for the second ring of recirculation [8]. Cross-section of a pole this magnet equally 120×610 mm, a distance between poles is equal 25 mm. The maximum field of a magnet equally 1.34 T, settlement effective magnet length - 658 mm. The magnet construction guesses manufacture of a yoke from leafs of a transformer steel width 0.35 mm. Windings are supposed to be produced from the copper tube chilled by water. In total it is necessary to make for a ring 10 magnets.

The construction of the corrector is developed on the basis of the prototype operated on NSC KIPT accelerators [8,16]. The maximum field – 0.02 T, settlement effective length - 100 mm. It has a window construction, is made of a steel, the winding has an air cooling. In total for recirculator it is necessary to make not less than 18 correctors.

SYSTEM OF ELECTRONS INJECTION

As it was already noted [4, 6] acceleration of beams of the polarized and not polarized electrons is supposed in recirculator.

On the given time beams of polarized electrons are actively used in physical experiments on recirculator S-DALINAC in Darmstadt, recirculator CEBAF in Jefferson Laboratory, on microtron MAMI and on accelerator SLAC in Stanford Linear Accelerator Center. Build-up of polarized electron sources typically for all these accelerators [4]. It is longitudinal polarized electrons gain on the basis of a photoeffect from a surface of specially prepared monocrystals of arsenide gallium. These electrons are sped up in a constant electric field to energy 100 KeV and carried to a magnet which gives the chance to spend further beams both polarized, and not polarized electrons on one channel. This channel usually contains the Faraday cup for measuring of a current amount, the Wine filter for regulating of an angle of a spin precession of electrons and Mott polarimeter for measuring magnitude of beam polarization. Further electrons get to accelerating structures, magnetic system and are carried in the experimental halls. No special demands for polarized beams transportation on all facilities are present. The Wine filter allows controlling magnitude of an angle of polarization of electron beams in the experimental halls, canceling an angle of rotation of polarization of the beam, linked with a spin precession of a beam in the course of acceleration. On recirculator SALO there is enough place for disposing of the Wine filter and Mott polarimeter which demand about 1.5 m along an injection line in accelerating section.

Beams parameters of chosen for recirculator prototypes sources of the polarized and not polarized electrons essentially do not differ [4, 6]. But that the not polarized electrons source is supposed to be used in much major number of problems, known measuring of an emittance of this source and design values for different operating modes [14,15] are in-process used for calculations. All reduced values of beam parameters are counted for emittance, equal 1.88 10^{-7} m·rad. The traversal beam cross-section after a gun is presented on Fig. 2.

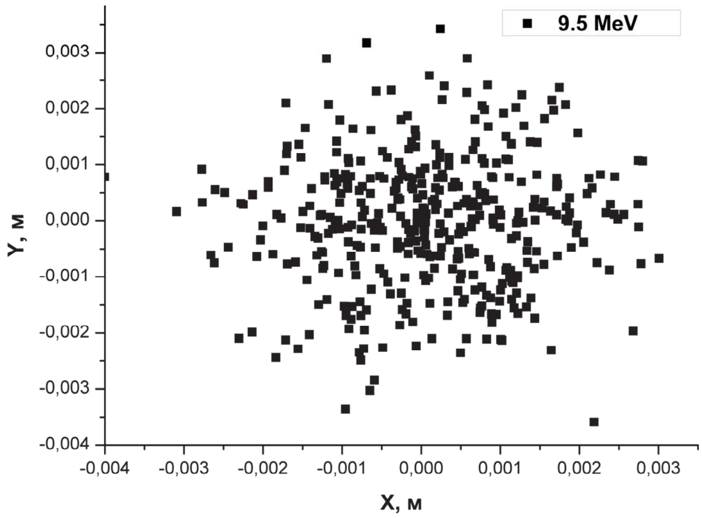

Fig. 2. Traversal cross-section of an injected beam

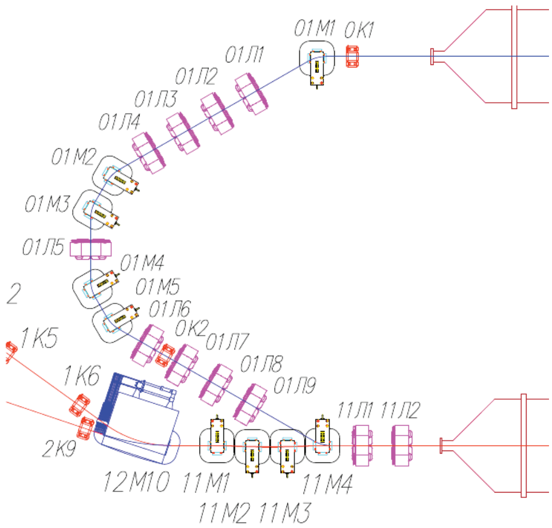

Fig. 3. Structure of the channel beam injection

Electrons are speed up in the accelerating module with superconducting section TESLA to energy 6.66 … 20 MeV after injector and, by means of magnetic system of the transportation presented on Fig. 3, shaped on an entry in the basic accelerating recirculator structure. The traversal cross-section of a beam on an entry in system (a magnet 01M1) is presented on Fig. 4.

The main requirements to the transportation system are isochronism and achromatism. This is achieved by a system consisting of six magnets and 9 quadrupole lenses and the requirement of equality to null elements 1-6, 2-6, 5.6 six-dimensional matrix of transition from the exit of the injection accelerating section up to the entrance to the main accelerating structure [26]. Selection of these requirements was carried out by means of program TRANSPORT [12] and MAD X [13]. Besides, quadrupole lenses of system together with lenses 11Л1, 11Л2 realize traversal focusing of a beam on an entry in the basic accelerator.

Amplitude focusing functions βx, βy and the dispersion function Dx in this area, calculated by the program TRANSPORT [12] and MAD X [13], shown in Fig. 5 and 6.

The envelope of the beam, which represents the maximum deviation from the equilibrium particles orbit, calculated using TRANSPORT [20], is shown in Fig. 7. Obviously, the loss of the beam with dimensions on the path of the injection at the chosen aperture of the magnetic elements will be negligible.

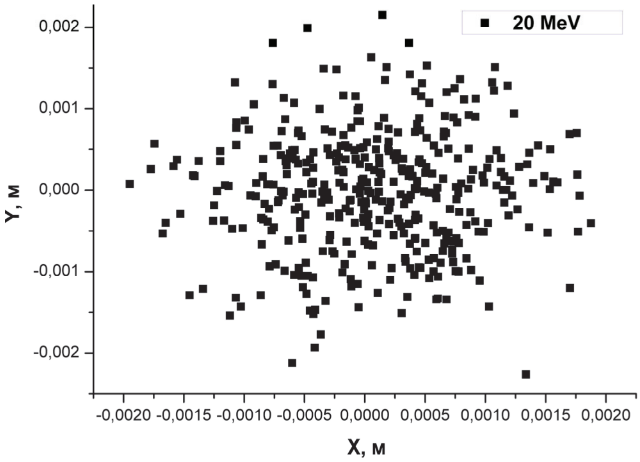

Fig. 4. The cross-section of the injection beam

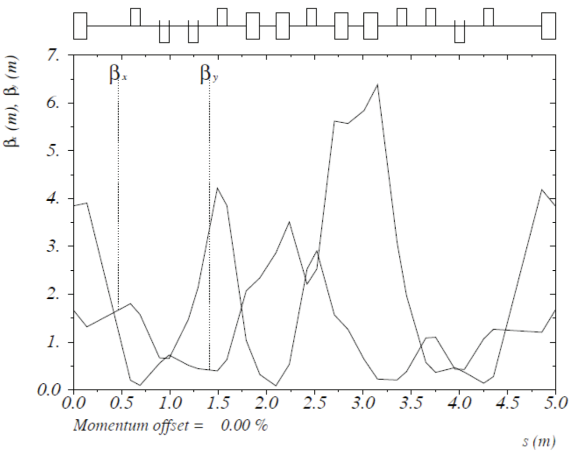

Fig. 5. Focusing functions βx, βy the channel beam injection

The structure of the channel (see Fig. 3) consists of dipole magnets 01M1 - 01M5 and 11M4 dipole magnet, which is part of the snake 11M1 - 11M4. Induction of the field in the magnets in the working range of energies varies from 0.249 to 0.063 T. Quadrupoles 01Л1 – 01Л9 and 11Л1, 11Л2 allow obtaining the necessary achromatism and isochronous system. The maximum value of the gradient in the quadrupole reaches 3.18 T/m. Correctors 0K1, 0K2 can adjust the position of the beam at the entrance of the accelerating section.

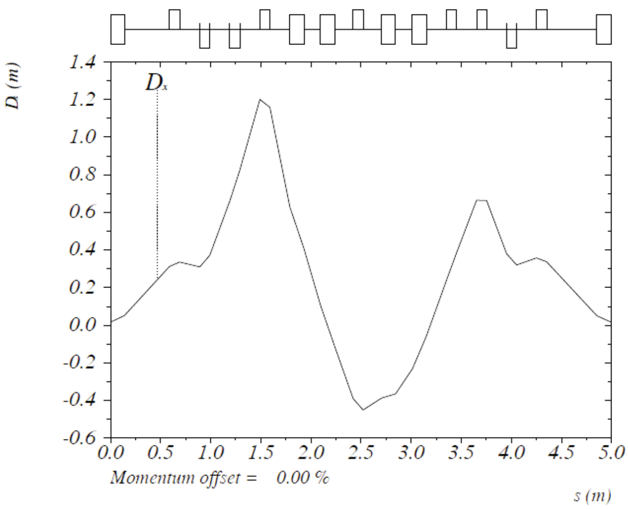

Fig. 6. Dispersion function Dx of the channel of injection

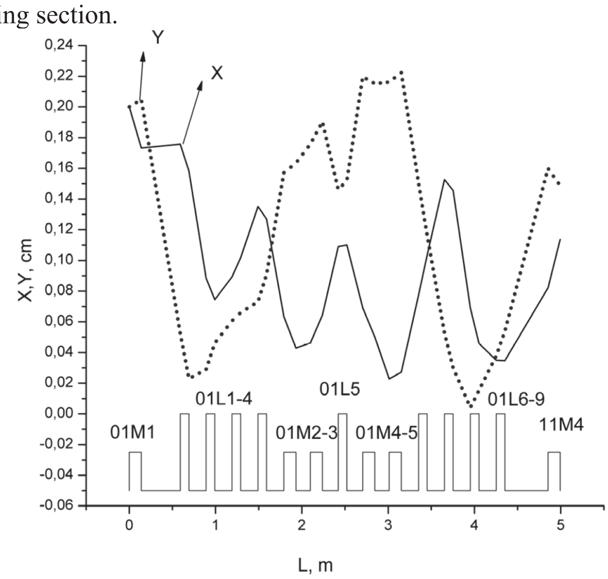

Fig. 7. Beam envelopes on a transportation section

STRAIGHTNESS GAP WITH ACCELERATING STRUCTURE

Snake magnets 11M1 - 11M3 and 11M4 (see Fig. 3, 8), intended to compensate for the effect of the injection field of the 11M4 magnet after the first and the next turns in the first and second ring is located in the straight-line recycling interval length 25.02108 m. Further, in this interval are 6 modules with two superconducting accelerating structures TESLA, allowing to obtain an increase of energy equal to 240 MeV [4]. Calculation of the beam during the passage of the accelerator was carried out under the program MAD-X, which took into account the influence of the transverse defocusing the beam, especially when the injection beam has energy in the energy range 6.67 - 20 MeV. Doublet of quadrupole lenses 11Л1, 11Л2 and triplet-11Л3-11Л5, located before and after the accelerator to compensate defocusing the beam in the accelerating structure and implement its fine-tuning at the entrance to the structure after the first turn without changing modes of magnetic arches of the first and second turn. The maximum gradient is required to perform these procedures does not exceed 4.4 T/m.

The traversal cross-section of a beam on an entry in the accelerator is presented on Fig. 9. On Fig. 10 the cross-section of a beam after acceleration on an entry in the first arch of the first turn of recirculation (a magnet 12M1) is shown.

It is necessary to note, that the specified sizes of a beam correspond to an injector operating mode with average current 1 mA, necessary for implementation operation of the accelerator in the capacity of the driver subcritical assembly [2, 5] and for manufacture isotopes [23]. At this alternative of use of the accelerator it is supposed, that rate of acceleration in superconducting sections equal 10 MeV/m. Really such situation will be already implemented on the accelerating complex ELBE working many years [21, 22] with use of two accelerating modules. At energy spread less than 0.2 % the beam with such parameters and aggregate power about 140 KW can be transported on tens meters lost-free on a target as it is offered in articles [2,4,5,7], or can be used in a hall of the SP-103 hall for manufacture isotopes of medical appointment [23].

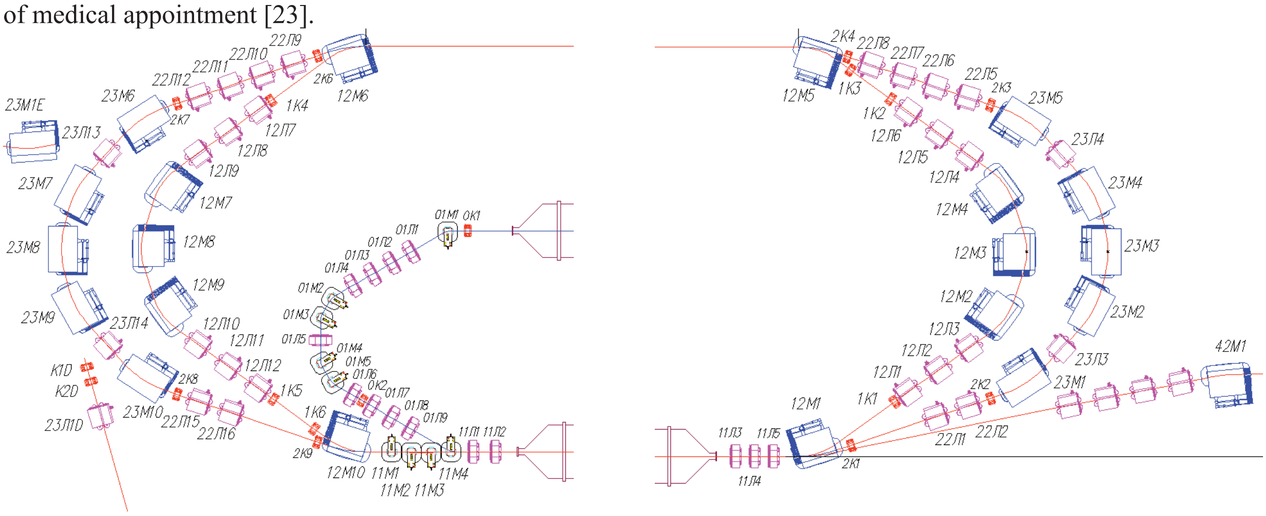

Fig. 8. Structure arches of beam recirculation

We have not detected essential change magnitude of beam losses at emittance magnification in the chosen structure twice.

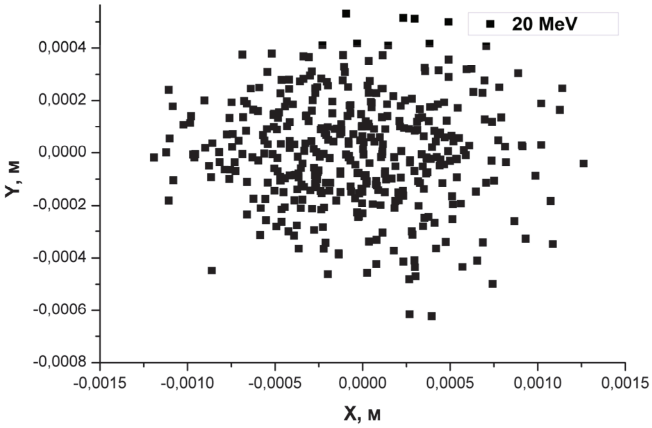

Fig. 9. Beam sizes on an entry in the basic accelerating structure

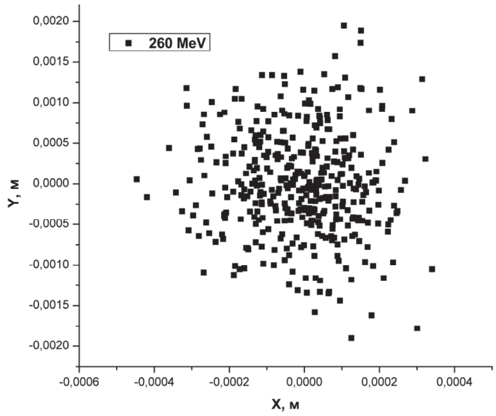

Fig. 10. Beam sizes on an entry in the first arch

The beam current will not exceed 30 µA by recirculator operation on nuclear physics program [25], therefore both the emittance and energies spread of a beam will be less than in a high-current regime. The voltage gradient in the accelerator thus is supposed there will be equal 20 MeV/m.

THE FIRST RING OF RECIRCULATION

The point on an entry in a magnet 12M1 is initial for implementation the first extraction channels of particles from recirculator. First of all, as it has been mentioned above, in a SP-103 hall the direct beam with energy to 260 MeV (140 MeV in a high-current regime) can be received. Besides, at magnet 12M1 turning on, in a hall it is possible to receive the turned beam in the same interval of energies. At partial use of magnets and lenses of the first and second ring of recirculation the beam can be extracted in channels N1-N3 and E, D [25].

The basic demands to sampling of structure and operating modes magnetic devices of arcs the first ring is achromatism, the isochronism and a beam dynamic stability in structure. The length of an equilibrium orbit of a beam was chosen to the multiple wave length of an accelerating field for maintenance of arrival electron bunch in accelerating structure synchronously with an injected beam. The change of path length which is brought in by presence snake of magnets 11M1-11M4 was thus considered. Beam turning angles are equal in all magnets 36°. As a part of the first ring used 10 dipole magnets of storage ring EUTERPE - 12M1-12M10 and 12 quadrupole lenses made for this storage ring - 12Л1-12Л12 (Fig. 1, 8). The maximum field in magnets – 1.02 T, the maximum gradient in lenses – 9.2 T/m.

The rectilinear gap of a ring can be used for free electron laser installation [4]. Studying influence magnetic structure of the laser on beam dynamics in recirculator should become a theme of separate analysis as in magnetic structure of the laser there can be beams the second turn of recirculation with it is essential other energy. The gap does not contain focalizing devices.

Focusing and dispersion functions for the first turn are presented on Fig. 11 and 12.

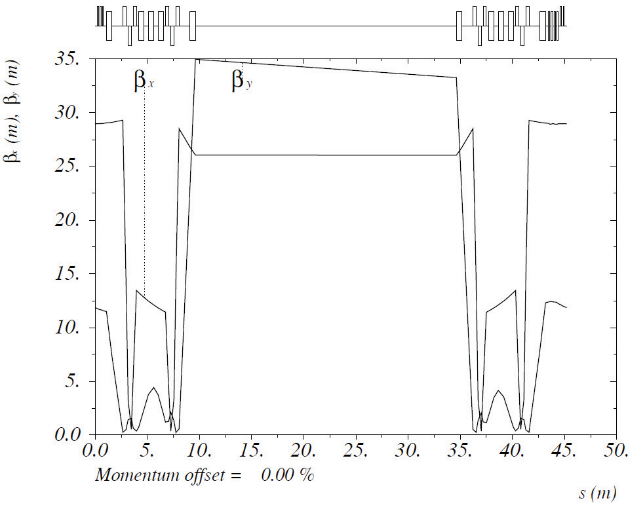

Fig. 11. Focusing functions βx, βy the first ring

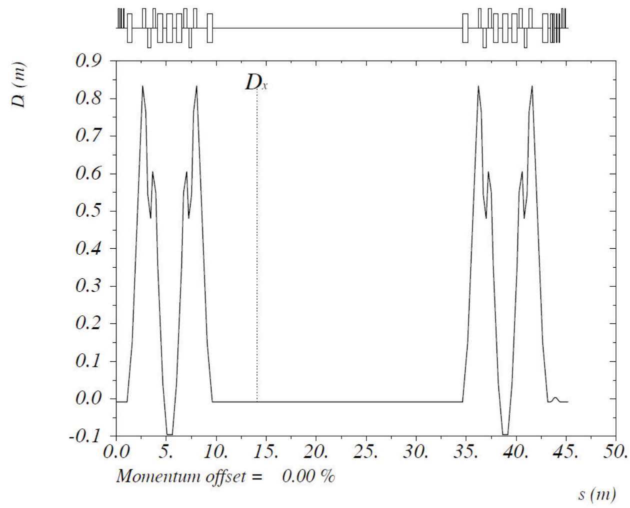

Fig. 12. Dispersion function Dx of the first ring

From the presented data it is visible, that the chosen optimized structure answers the installed measure, and traversal sizes of a beam on all sections of a path equal $\sigma(s)=\sqrt{\varepsilon\beta(s)}$, do not exceed presented on Fig. 10, 13-15.

The traversal beam cross-section on an exit first and on an entry of the second arch is presented on Fig. 13 and 14.

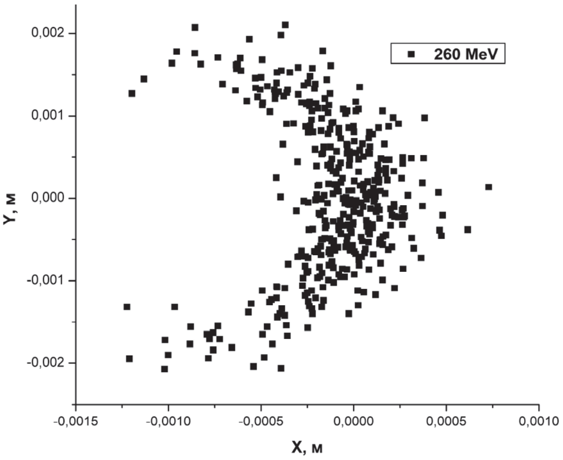

Fig. 13. Beam sizes on 12M5 magnet exit

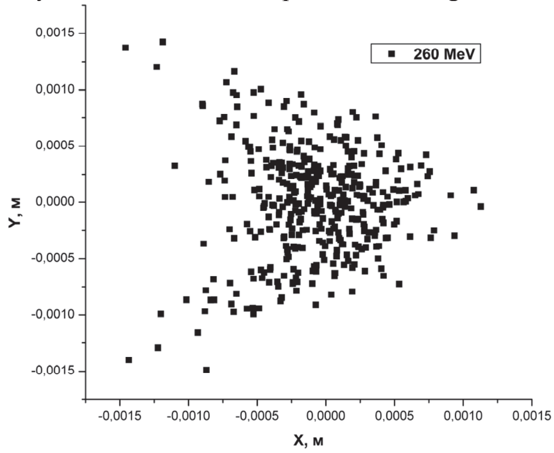

Fig. 14. Beam sizes on an entry in 12M6 magnet

The traversal beam cross-section on an exit of the second arch of the first turn is presented on Fig. 15. Sizes of a beam after double passage of the accelerator (on an entry in a magnet 12M1) are presented on Fig. 16.

The deformation of traversal cross-section of a beam is called by essential change of phase motion of a beam under the influence of nonlinear field component of dipole and quadrupole magnets [24].

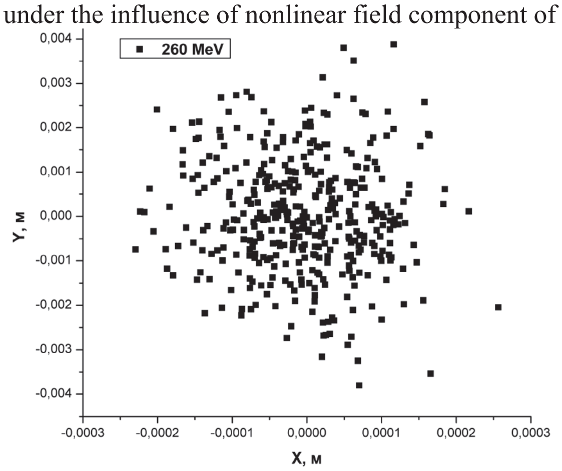

Fig. 15. Beam sizes on 12M10 magnet exit

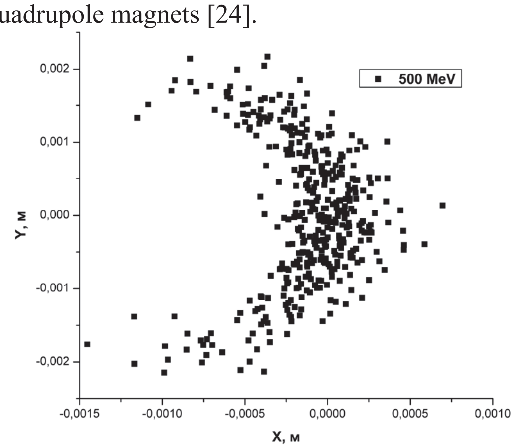

Fig. 16. Beam sizes on an entry in 12M1 magnet

The particles with the maximum energy 500 MeV can be utilize after the first ring of recirculation in SP-103 hall and, with use of dipoles and quadrupoles of the second ring, in channels E and D [25].

THE SECOND RING OF RECIRCULATION

The same demands were made to sampling parameters magnetic system of the second ring of recirculation, as for first, both on geometry, and on optimization of regimes. Characteristic of this ring is lack of a place for disposing quadrupole lenses on a section which is bordering on to the channel of an extraction of particles in SP-103 hall. Such problem has originated that magnets 12M1, 12M5, 12M6 and 12M10 are used as rotary and as parting rings of recirculation and an extraction of particles on the maximum energy. Focusing and dispersion functions for the second turn are presented on Fig. 17, 18.

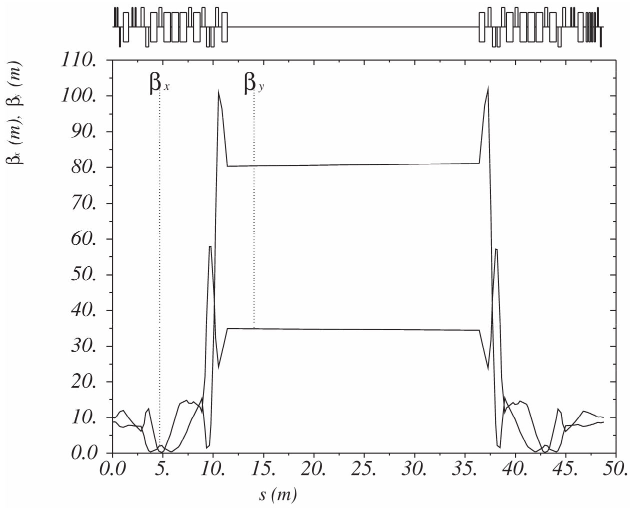

Fig. 17. Focusing functions βx, βy the second ring

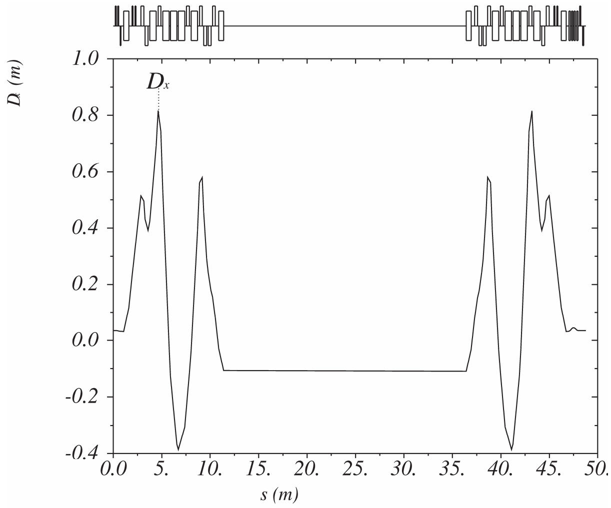

Fig. 18. Dispersion function Dx of the second ring

Traversal beam sizes on 12M5magnet exit, on an entry in magnet 12M6 and on 12M10 magnet exit are presented on Fig. 19-21.

At calculations the sextupole component field of magnets 23M1-23M10 was accepted to the equal magnitude measured for magnets EUTERPE. This magnitude a priori is oversized for the construction of a shell-type dipole magnet, however real magnitude it is impossible to gain because the magnet is not made yet. At sextupole component, equal 0, traversal sizes of a beam in the points figured on Fig. 20, 21 are resulted on Fig. 22, 23. As it is possible to see, it does not lead to an essential dimensional change of a beam size because corpuscles energy essentially major, and the gain is less, than at the first passage of the accelerator.

The beam angle rotation in magnets 23M1-23M10 is equal 28.516º. The maximum value field induction in dipole magnets of this ring attains magnitude 1.25 T and maximum gradient of quadrupole lenses – 15.6 T/m.

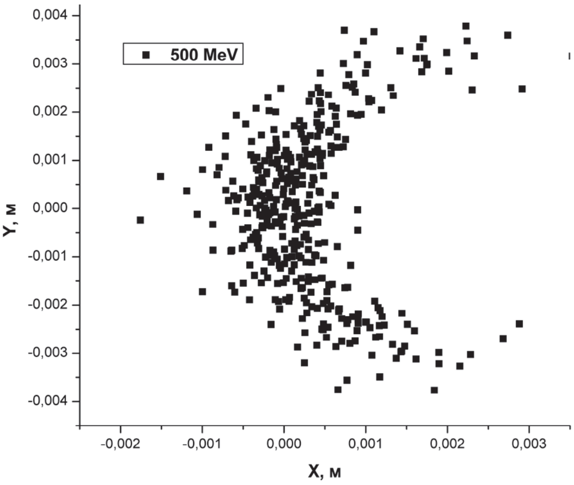

Fig. 19. Beam sizes on the second ring of recirculation (on magnet 12M5 exit)

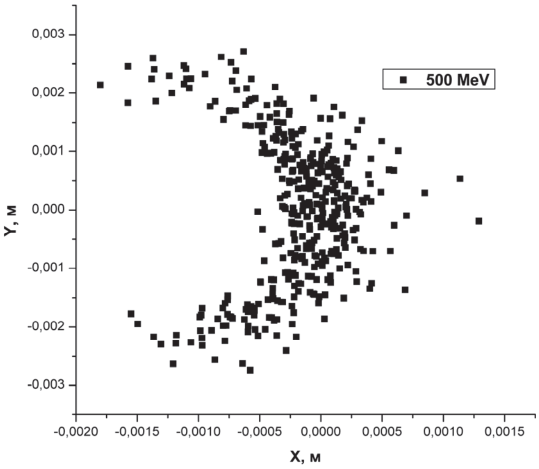

Fig. 20. Beam sizes on the second ring of recirculation (on an entry in 12M6 magnet)

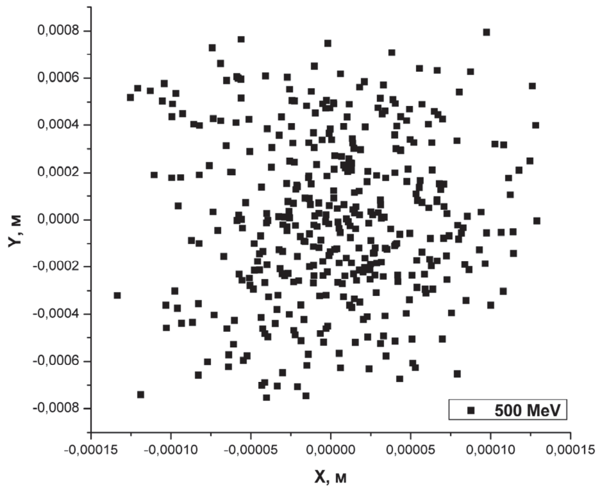

Fig. 21. Beam sizes on the second ring of recirculation (on magnet 12M10 exit)

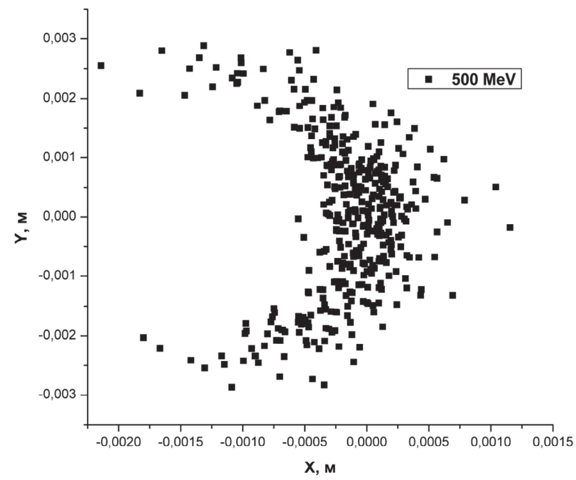

Fig. 22. Beam sizes on the second ring of recirculation (on an entry in 12M6 magnet) with sextupole component equal 0

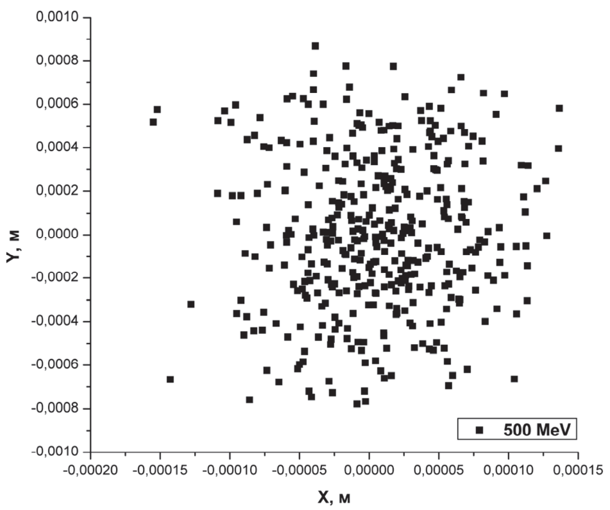

Fig. 23. Beam sizes on the second ring of recirculation (on magnet 12M10 exit) with sextupole component equal 0

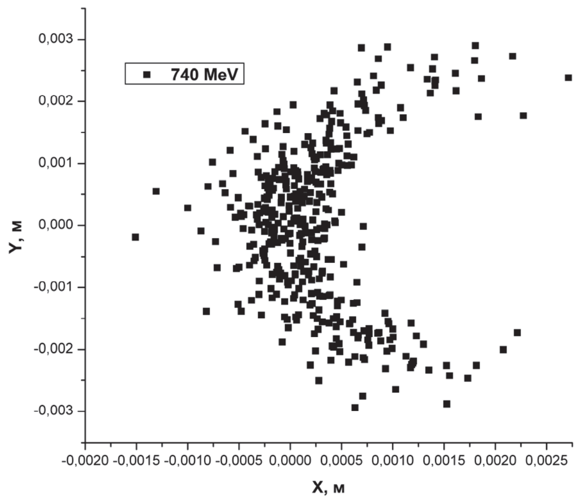

Fig. 24. Beam sizes at the maximum energy on an entry in 12M1 magnet

Traversal beam sizes on an entry in the transportation channel in SP-103 hall are presented on Fig. 24.

CONCLUSION

Optimization of structure and operating modes magnetic devices of recirculator magnetooptical system has allowed gaining the required parameters of electron beam in points leading-out to physical facilities by means of three types of dipole magnets and two types of quadrupole lenses. Nonlinear component fields of dipole and quadrupole lenses work upon traversal beam cross-section, however at shut down sextupole field component of dipole magnets on the second ring of recirculation an essential dimensional change and the beam shape does not occur. The maximum beam sizes along accelerator do not exceed 6 mm; therefore losses of corpuscles at the chosen aperture of magnetic devices will be very small.

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