RECIRCULATOR SALO DESIGN-WORK EXECUTED IN 2006

I.S. Guk[*]
National Science Center "Kharkov Institute of Physics and Technology", 61108, Kharkov, Ukraine
(Received April 17, 2007)

In 2006 development of the recirculator design was carried out within the limits of three programs. With the purpose to decrease of a beam traversal emittance and energy straggling the new system of injection allowing smoothly to control energy of a beam is offered and optimized. The magnetooptical recirculator system structure was optimized also. The basic aspects of recirculator operation in structure of the driver of subcritical assembly are in detail viewed. Alternatives embodying of beam transportation channels on a target are offered. Draft designs of all recirculator magnetic devices and the draft design of magnetic system as a whole are developed.

PACS: 28.50.Dr;29.25.-t

1. INTRODUCTION

In compliance with the decision handed down by the Scientific Council of the Institute of High Energy and Nuclear Physics (IHENP) in 2002 had been created working group on development of new base accelerator of institute. Work was completed in 2003 on selecting the promising directions for creating a baseline accelerator facility at NSC-KFTI to meet the demands of nuclear and high-energy physics research [1]. The agreement with Eindhoven University of Technology (Kingdom Netherlands) about teamwork above the future facility design has been the same year signed. Results of operations 2004 and 2005 have been published in two monographs [2, 3]. Main routes and results of project development are approved by Academic council SDC "Accelerator", report N.7 from April, 11, 2005, Academic council IHENP NSC KIPT, report N.4 from May, 18th, 2005 and report N.2 from February, 23rd, 2007, Academic council NSC KIPT, report N.10 from October, 20-th, 2005.

Per 2006 project development was spent in accordance with two themes of the State program fundamental and applied researches on 2004-2010, and also STSU project P233. Within the framework of plans the basic attention has been given to those three problems. The new variant of recirculator magnetooptical structure and systems of injection of a beam [4] has been offered. Draft designs of all recirculator magnetic devices and the draft design of magnetic system as a whole are developed. Opportunities of use recirculator as the subcritical assembly driver [5, 6, 7] are in detail viewed.

Dovbnya Anatolij, Guk Ivan, Kononenko Stanislav, Tarasenko Oleksandr, M. van der Wiel, J.I.M. Botman, M.I. Bratchenko, V.V. Gann, S.V. Dyuldya, Peev Fedor, Perezhogin Sergiy, Hodak Igor, Mytsykov Andriy, Kovalyov Georgiy, Sherbinin Volodymyr, Alexenko Olga, Skirda Vasil have made the basic contribution to the solution of these problems.

Main results of works have been reported at IV conference on a high-energy physics, a nuclear physics and accelerators, on February, 27-th on March, 3-rd, 2006, Kharkov, NSC KIPT; International conference Actual problems of the nuclear physics and atomic power engineering (NPAE-Kyiv2006), on May, 29-th on June, 03-rd 2006, Kiev, Ukraine; European Particle Accelerator Conference, EPAC06, Edinburgh, Scotland, 26-30 June 2006; XX All-Russia conference on charged particle accelerators, RUPAC-2006, on September, 10-14-th, 2006, Novosibirsk, Russia.

The employees from IHENP and Institute of Theoretical Physics, affiliated with NSC-KFTI, have developed a program of basic research in nuclear physics on the facility to be constructed [11] in 2006.

2. ISOCHRONOUS MAGNETO-OPTICAL STRUCTURE OF RECIRCULATOR SALO

With the purpose to minimize the energy spread of accelerated beam and taking into account the improved value of accelerating structure length, which outcome the length of straight sections has increased up to 25 m, the magneto-optical structure (MOS) of SALO recirculator [1] was modified. The minimization of the beam energy spread has been reached by isochronicity of all sections of the beam line, since injection beam line and including two sites of beam recirculation.

For realization such structure it was necessary to refuse from uniform distribution of dipole magnets along the sections of the beam rotation on angle 180^o. Besides, the straight section opposite accelerating one was made "lenses-free", that allows to make independent focusing of both sites of recirculation.

[*]Corresponding author E-mail address: guk@kipt.kharkov.ua

On Fig.1 the general view of reciculator SALO MOS new version together with injection beam lines is shown.

For injection the magnet b7, included in three magnets bypass (b5, b6, b7), is used. Such a system allows to produce injection of $9.5\,MeV$ beam, bypassing magnet B10 of arc which designed for a field $\sim$ 1.2 T and has the leakage fields intensive enough. Besides, such injection system allows to regulate smoothly the accelerated beam energy.

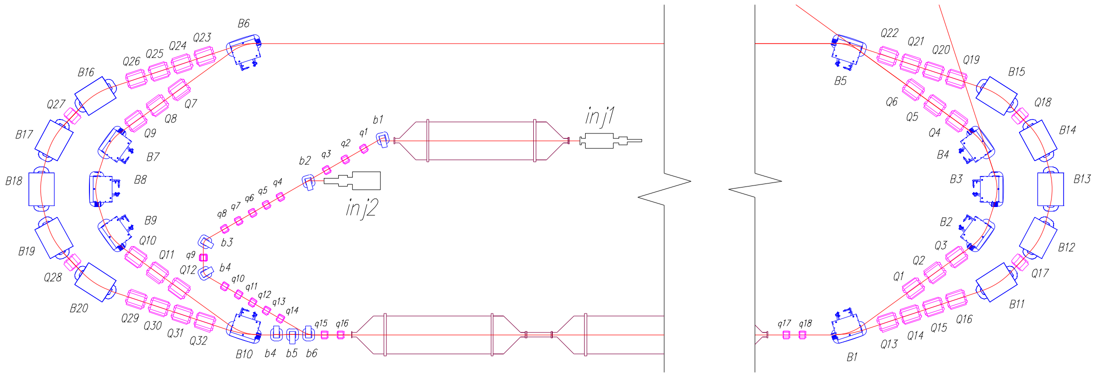

Fig.1. *Recirculator lay-out*

With use of TRANSPORT code at initial energy spread in beam 0.1% and a longitudinal size $0.082\,cm$ the energy spread for a beam with energy 249.5, 489.5 and $729.5\,MeV$ has been calculated. The values of relative energy spread are accordingly $6.5 \cdot 10^{-5}$, $3 \cdot 10^{-5}$, $2 \cdot 10^{-5}$ for each energy. The maximum values of enveloping are $\sigma_x \approx 0.3\,cm$, $\sigma_y \approx 0.65\,cm$. The general view of installation which will be disposed in a hall of targets, is presented on Fig.2.

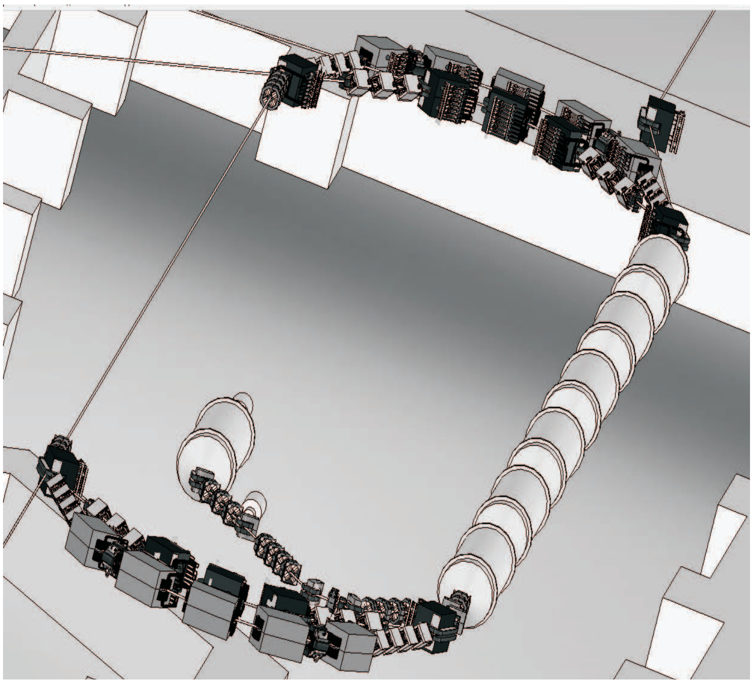

Fig.2. *The general view of facility*

As accelerating structure we choose the module for two superconducting sections TESLA which is made by corporation ACCEL Instruments GmbH (Germany) [8]. It is supposed to use six modules which will be disposed in recirculator rectilinear gap.

As prototype injector of the polarized electrons we select an injector developed for SEBAF accelerator [3]. As energy of electrons in it does not exceed $100\,KeV$, for accelerating electrons up to $9.5\,MeV$ it is supposed to use one more module. It will be situated after the electron-emitting source.

For operations with unpolarized beams it is supposed to use the high-frequency gun developed at centre ELBE (Germany). The gun allows to gain a electron beams with energy up to $9.5\,MeV$ with current up to $1\,mA$ [3]. This gun can be manufactured by corporation ACCEL Instruments GmbH (Germany).

Now leading firms of Europe, USA and Japan make enough great many RF power sourses which can operate at frequency $1300\,MHz$. These devices can be bought for use in facility.

3. DRAFT DESIGN OF RECIRCULATOR SALO MAGNETIC SYSTEM

Within the framework of the Agreement, 2003 saw delivery from Eindhoven University to NSC-KFTI of ten dipole and thirty two quadrupole magnets taken down from the EUTERPE storage ring [3]. By development of the preliminary design of recirculator magnetic system these magnets were used for making the first ring of recirculation. The general view of these magnets is presented on Fig.3 and Fig 4.

When chose a construction of a dipole magnet of the second recirculator ring and other magnetic devices three-dimensional model of a field was used. The construction of a magnet with closed magnetic circuit core, shown on Fig.5, allows to gain more compact device, than we use c-magnet. A field distribution in a magnet and geometrical sizes of a magnet are presented on Fig.6. Powerful quadrupole with a gradient of $26\,T/m$ for the second ring is presented on Fig.7.

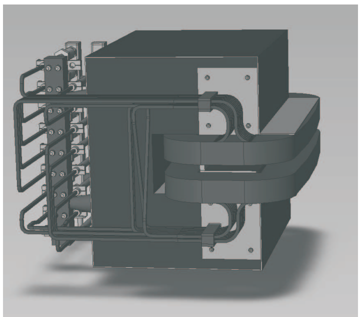

Fig.3. *EUTERPE dipole magnet*

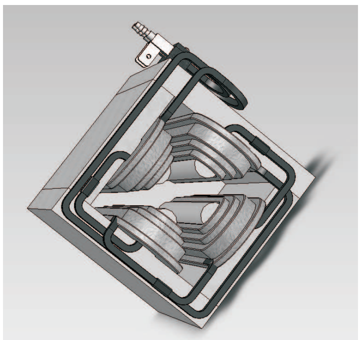

Fig.4. *EUTERPE quadrupole magnet*

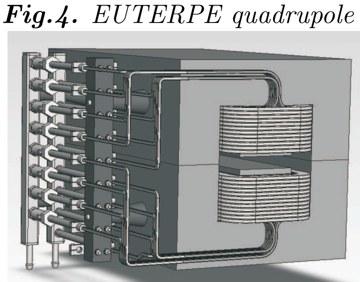

Fig.5. *Dipole magnet*

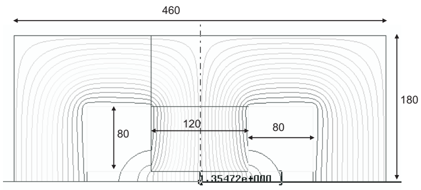

Fig.6. *Field distribution in magnet*

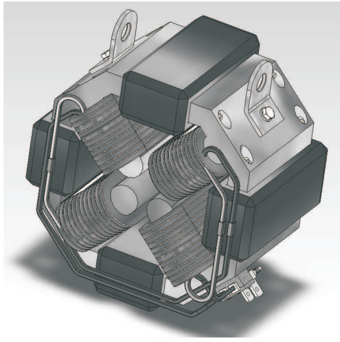

Fig.7. *Powerful quadrupole*

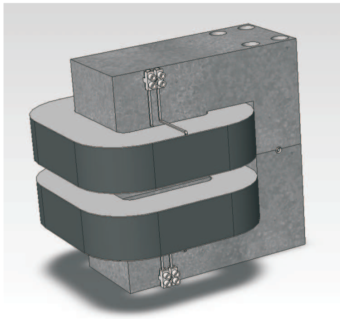

Fig.8. *Injection dipole magnet*

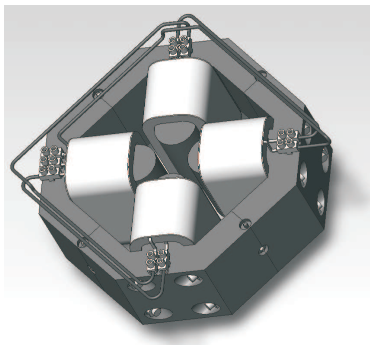

Fig.9. *Injection quadrupole magnet*

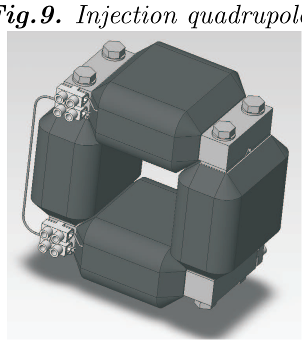

Fig.10. *Corrector magnet*

Seven dipole magnets (see Fig.8) and 13 quadrupoles (see Fig.9) are used in a section of beam injection. A quantity of these quadrupoles can be used in channels of an extraction of particles on a target.

For change of beam position correctors (Fig.10) will be used, allowing to change a path of a beam in vertical and horizontal planes.

4. USE RECIRCULATOR AS A DRIVER OF SUBCRITICAL ASSEMBLY

Module which we choose allows to receive a gain of energy 20 MeV for a current 1 mA [3]. In the linear accelerator of an accelerating complex SALO it will be used such six modules. Thus, the maximal beam energy on an output of the accelerator will be close to 130 MeV. This operating mode will be used for a variant of use accelerator as the driver for subcritical assembly [3, 5, 6, 7]. In this operating mode the high-frequency injector, injection beam formation system, accelerating system and system electrons formation in the transportation channel which includes magnetic system of the first arch will be used.

On Fig.2 elements of magnetic system of a complex which allow realizing this mode are presented. The beam output can be carried out in three directions. On the end of transportation channels the system of dipoles and quadrupoles settles down, allowing to receive a beam of the necessary sizes on targets surface [4].

Apparently from Fig.1,2 channels beam transportation on subcritical assembly are possible. They can be realized at turning on of first three, four or all dipole magnets of an arch. As these channels, except for length, have no key differences, it is enough to observe transportation of electrons one of them (see Fig. 11 and 12). Two quadrupole triplets (N1Q1 - N1Q6) provide transportation of a beam from magnet B3 up to magnet BV1 on distance of $\sim 58\,m$ with following parameters: maximum horizontal size 1.7 cm, maximum vertical size 0.25 cm In Fig.11 are shown vertical and horizontal beam envelope curve on a section of transportation. Two 45° magnets BV1, BV2 (see a Fig.12) turn a beam on 90° in a vertical plane. Beam cross-section on an entry in the first rotary magnet minimally and close to round. It provides the small vertical aperture of rotary magnets. Then electron beam power $\sim 130\,kw$ it is necessary to lead on target had apart of 1.9 m from edge of magnet BV2 (the distance is determined by sizes of volume in which it is supposed to place subcritical assembly). Beam size on a target should be such to not allow excessive heating of a target and simultaneously to minimize beam losses on vacuum channel walls. At target diameter of 6 cm beam diameter on it should be $\sim 5\,cm$. In this case beam losses on walls of vacuum chamber will not exceed 1%.

Calculations have shown, that in case of providing the necessary beam sizes on the target with the help only of triplets N1Q1-N1Q6 the beam size in magnet BV1 equals $\sim 4\,cm$ and this demands the vertical aperture of magnets not less than 5 cm. The use in BV-magnets the edge focusing allows to reduce the vertical aperture, however in this case the opportunity of beam size adjustment on the target will be lost. It is more expedient to adjust the beam sizes on the target with the help of lenses N1Q7 and N1Q8, which are located between magnets BV1 and BV2. In this case the space behind magnet BV2 is not achromatic. When $\triangle E/E \cong 10^{-4}$, like it takes place in our case, the energy spread contribution to the beam sizes on the target does not exceed $\sim 1\,mm$. On Fig.12 the beam envelope for the beam-line from the lens N1Q4 up to neutron producing target is shown. The given curves and appropriate to them magneto-optical structure are typical for all presumable beam lines.

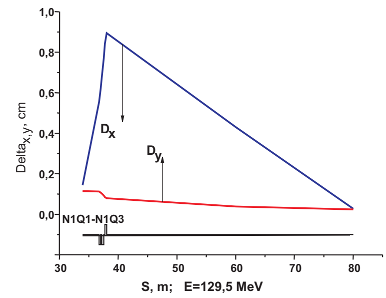

Fig.11. *The transverse sizes of beam on a section of transportation from recirculator exit up to an entry in triplet N1Q4-6*

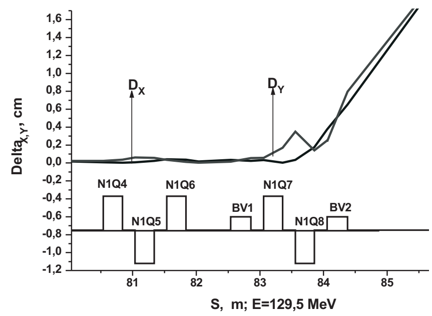

Fig.12. *Beam sizes on last section transportation channel on a target*

A little bit simplified model of one of the typical embodiments of assembly on the basis of the modified fuel elements of VVER-1000 reactor type [9, 12] (see Fig.13) has been observed. The assembly consists of 42 cylindrical fuel cells ($\emptyset 0.772 \times 45\,cm$) in Cr shells thickness of 0.74 mm, density 6.506 g/cm^3 and temperature 400 K. Fuel cells contain UO_2 (10.96 g/cm^3, 600 K) with enrichment of 19.8% on uranium-235. They are disposed in the hexagonal pattern with a step of 2.8 cm and surrounded by moderating material (^1H_2O 0.9982 g/cm^3, 320 K).

Graphitic (^6C, 2.3 g/cm^3, 300 K) cylindrical reflector of the assembly ($\emptyset 100 \times 110\,cm$) contains coaxial ($\emptyset 6 \times 33\,cm$) vacuum channel on which end it is had irradiated target in length of 5 cm, consisting of seven hexahedrons densely packed with a step 2.8 cm from the poor uranium (^{238}U, 19.1 g/cm^3, 400 K).

For calculation system subcritical coefficient and spatial distributions of neutrons density in the assembly have been applied Monte-Carlo methods modelling of radiation transport in three-dimensional geometries. It was used developed in NSC KIPT functional analog of package MCNPX - program RaT [13] grounded on freely passed round object-oriented libraries Geant4 Toolkit [10].

By means of program RaT 3.0 three-dimensional spatial distributions of density of neutrons in continius conditions of subcritical assembly operation (see Fig.13,14) are counted.

One electron generates in such target 0.0608 neutrons at energy $100\,MeV$. Full neutrons stream are equal $\leq 3,8\Delta 10^{14}\,n/s$ at beam power of $100\,kw$.

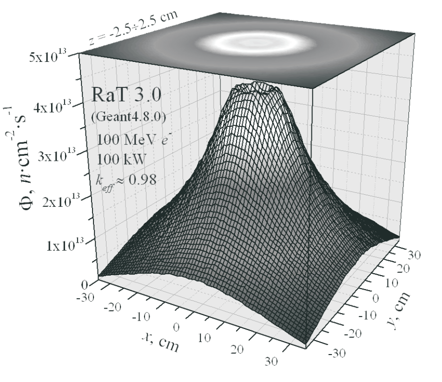

Fig.13. *Allocations of density of neutrons in a cross-section subcritical assembly at a level of the target*

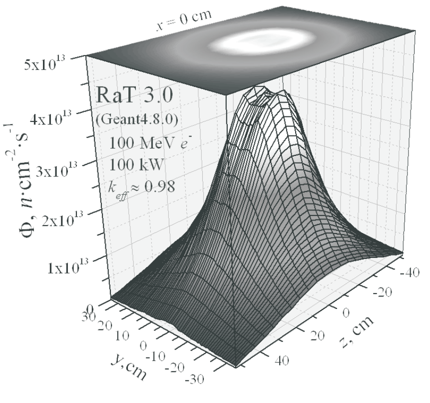

Fig.14. *Allocations of density of neutrons in a cross-section subcritical assembly in a plane containing an axis of the assembly*

Calculations show, that for a typical assembly construction such parameters of the driver provide the characteristic densities of neutron streams $4 \cdot 10^{13}\,n/(s \cdot cm^2)$ in a reacting region and $1 \cdot 10^{13}\,n/(s \cdot cm^2)$ in the graphitic reflector of assembly at coefficient of amplification of power nearby 3.3.

5. STAGES OF FACILITY START

During design there is apparent an expediency of facility start in two stages. The first stage guesses maximum use of existing equipment for realization of double pass of beam through accelerating structure with an extraction of particles in an existing hall of spectrometers. Dipole both quadrupole magnets and the modernized machine assemblies for their feed will be used. It is necessary to get six accelerating modules and a source of nonpolarized electrons, and also a liquefier for maintenance of accelerating structures operation. Also it is necessary to buy seven complete sets RF of radiants a fuel system for them. It is necessary to makeproduce for system of injection of 6 dipole and 12 quadrupole magnets; vacuum tube devices and pump-down systems. Start of this part equipment will allow to begin physical experiments with electron beams with energy up to $490\,MeV$.

The second stage guesses manufacturing source of the polarized electrons, accelerating module and RF source for it. It is necessary to produce ten dipole and four quadrupole magnets for the second ring of recirculation and necessary vacuum devices for this ring. For the complete maintenance facility with fluid helium it is necessary to get additional liquefier.

With producers estimations of manufacturing cost and purchases of inventory have been lead. An expense for the first stage will make 9,5 million euro, and for second-3 million.

Per 2007 the basic force will be guided on detailed development extraction particle channels on the physical installations stipulated by the program of experiments [11].

REFERENCES

1. I.S. Guk, A.N. Dovbnya, S.G. Kononenko, A.S. Tarasenko. *The choice of a variant of the base accelerating facility NSC KIPT on nuclear physics and high-energy physics*: Preprint. KIPT, 2003-3, Kharkov: NSC KIPT, 2003. p.72 (in Russian).

2. Yu.M. Arkatov, A.V. Glamazdin, I.S. Guk, A.N. Dovbnya, S.G. Kononenko, M. van der Wiel, J.I.M.Botman, F.A. Peev, A.S. Tarasenko. *BASELINE ACCELERATOR FACILITY AT NSC-KIPT FOR NUCLEAR AND HIGH-ENERGY PHYSICS RESEARCH, "SALO" PROJECT*. Kharkiv, National Science Center-Kharkiv Institute of Physics and Technology, 2004, 94p. (in Russian).

3. Yu.M. Arkatov, A.N. Dovbnya, A.V. Glamazdin, I.S. Guk, S.G. Kononenko, M. van der Weil, J.I.M. Botman, F.A. Peev, A.S. Tarasenko *"SALO" project.* Kharkiv: National Science Center Kharkov Institute of Physics, Technology. 2005, 104p.

4. A.N. Dovbnya, I.S. Guk, S.G. Kononenko, F.A. Peev, A.S. Tarasenko, M. van der Weil, J.I.M. Botman, "Isochronous magneto-optical structure of recirculator SALO" // *Proceedings of EPAC 2006*, Edinburgh, Scotland, 2006, p.2035-2037.

5. M.I. Bratchenko, V.V. Gann, I.S. Guk, A.N. Dovbnya, S.V. Dyuldya, S.G. Kononenko, F.A. Peev, A.S. Tarasenko, M. van der Wiel, J.I.M. Botman, SUPERCONDUCTING DRIVER FOR SUB-CRITICAL ASSEMBLY // *International Conference Current Problems in Nuclear Physics and Atomic Energy (NPAE-Kyiv2006) May 29-June 03, 2006* Kyiv, Ukraine, 2006,book of abstracts, p.135.

6. I.S. Guk, A.N. Dovbnya, S.G. Kononenko, F.A. Peev, A.S. Tarasenko, M. van der Wiel, J.I.M. Botman. Recirculator "SALO" project-facility for fundamental and applied research in nuclear physics and atomic energy // *International Conference Current Problems in Nuclear Physics and Atomic Energy (NPAE-Kyiv2006) May 29-June 03, 2006* Kyiv, Ukraine, 2006,book of abstracts, p.170.

7. V.V.Gann, I.S. Guk, A.N. Dovbnya, S.G.Kononenko, A.S. Kostromin, F.A. Peev, I.M. Prochorets, C.A. Soldatov, A.S. Tarasenko M., van der Wiel, J.I.M. Botman. Recirculator "SALO" - a basis for creation of a model of sub-critical reactor controlled by the accelerator // *Journal of Kharkov National University, number721, Physical series "Nuclei, Particles, Fields", issue 1/29/*, 2006, p.19-30 (in Russian).

8. Michael Pekeler, Hanspeter Vogel, Peter vom Stein, Industrial production of superconducting 1.3 GHz accelerator modules and components for FEL application // *Proceedings of the 2004 FEL Conference.* 2004, p.379-380.

9. V.V. Gann, A.N. Dovbnya. Computer Modeling of Design for Neutron Source Subcritical Assembly // *Proc. of Ukraine-USA Meeting "Accelerator Driven Sub-critical Assembly Facility", Kharkiv, Feb. 24-25, 2005*,Kharkiv, Ukraine, 2005, NSC KIPT, p.33-37.

10. S. Agostinelli, J. Allison, K. Amako, J. Apostolakis, et al. Geant4 - a simulation toolkit // *Nuclear Instruments and Methods in Physics Research. Section A: Accelerators, Spectrometers, Detectors and Associated Equipment.* 2003, v.22, No.3, p.250-303.

11. A.Y. Buki, V.B. Ganenko, A.Yu. Korchin, V.V. Kotljar, N.G. Shevchenko and others. *"FUNDAMENTAL AND APPLIED RESEARCH ON KHARKOV SUPERCONDUCTING ELECTRON ACCELARATOR ON ENERGY UP TO 730 MeV". (PROJECT "SALO")*, part 1, Kharkov, NSC KIPT, 2006, 116 p.(in Russian).

12. V.V Gann, S.V. Dyuldya, M.I. Bratchenko. Modelling of neutron fields in controllabled by accelerator of electrons subcritical assembly // *IV Conference on high energy, nuclear physics and accelerators, Kharkov, Feb.27-Mar.3, 2006*, book of abstracts,Kharkov, NSC KIPT, 2006, p.55.

13. S.V. Dyuldya, M.I. Bratchenko, M.I. Skorobogatov. RaT - the multipurpose program of modelling of the health-monitoring quantities by Monte-Carlo method // *IV Conference on high energy, nuclear physics and accelerators, Kharkov, Feb.27-Mar.3, 2006*, book of abstracts, Kharkov, NSC KIPT, 2006, p.80.

ПРОЕКТ РЕЦИРКУЛЯТОРА SALO – РАБОТЫ, ВЫПОЛНЕННЫЕ В 2006 ГОДУ

И.С.Гук

В 2006 году разработка проекта рециркулятора осуществлялась в рамках трёх программ. С целью уменьшения поперечного эмиттанса пучка и энергетического разброса предложена и оптимизирована новая система инжекции, позволяющая плавно регулировать энергию пучка. Оптимизирована новая изохронная структура магнитооптической системы рециркулятора. Подробно рассмотрены основные аспекты работы рециркулятора в составе драйвера подкритической сборки. Предложены варианты реализации каналов транспортировки пучка на мишень. Разработаны эскизные проекты всех магнитных элементов рециркулятора и эскизный проект магнитной системы в целом.

ПРОЕКТ РЕЦИРКУЛЯТОРА SALO – РОБОТИ, ВИКОНАНІ У 2006 РОЦІ

І.С.Гук

У 2006 році розробка проекту рециркулятора виконувалась в рамках трьох програм. З метою зменшення поперечного эмітансу пучка та енергетичного разкиду запропонована і оптимізована нова система інжекції, яка дозволяє плавно змінювати енергію пучка. Оптимізована нова ізохронна структура магнітооптичної системи рециркулятора. Детально розглянуті основні аспекти роботи рециркулятора в складі драйвера підкритичної збірки. Запропоновані варіанти реалізації каналів транспортування пучка на мішень. Розроблені ескізні проекти всіх магнітних елементів рециркулятора та ескізний проект магнітної системи в цілому.