THEORY AND TECHNOLOGY OF PARTICLE ACCELERATION

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MULTIFUNCTIONAL ACCELERATION COMPLEX OF NSC KIPT – MAIN CHARACTERISTICS

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The results of the development of the multifunctional accelerator complex of the NSC KIPT are considered. The magneto-optical structure of the recirculator, which is the basis of the complex, is presented, which ensures the production of an electron beam with a maximum energy of about 600 MeV when the beam passes through the superconducting accelerating structure three times. Variants of obtaining beams of electrons, gamma quanta, positrons and neutrons for performing fundamental and applied research in the field of nuclear physics and energy, solid-state physics, and nuclear medicine are presented.

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INTRODUCTION

The rapid development of accelerator technologies in the middle of the twentieth century led to the creation of a large number of accelerators, which became the basis for conducting fundamental and then applied nuclear physics research in the world. Powerful sources of electrons, positrons, photons and neutrons were built and are being developed on the basis of accelerators, with the help of which research is carried out, important for nuclear power engineering, nuclear medicine, solid-state physics, plasma physics and many other branches of science and technology. Until 1993, the Kharkiv Institute of Physics and Technology had a number of unique accelerators: the largest linear accelerators in Europe LU-2000 and LU-300, the N-100 accumulator and a number of accelerators for lower energy [1-3]. The institute has formed a large team of highly qualified specialists in nuclear physics and accelerator physics.

The LU-2000 and LU-300 accelerators were developed and manufactured in the late 50s of the previous century and launched in the early 60s. Already in the 80s, it became clear that the beam parameters of these accelerators did not meet the needs of nuclear physics experiments, and modernization was proposed by developing the PSR-2000 beam expander and a synchrotron radiation source with an energy of 3 GeV [3]. The project was developed, work began on the manufacture of the main equipment samples, but, due to the collapse of the USSR, funding for the project was terminated.

After 1993, the production of klystrons for our accelerators was liquidated in Russia and large accelerators were stopped. Experimental work, which is the basis of nuclear physics research, practically ceased, scientific workers were forced to transfer their research to other facilities outside Ukraine or to retrain. The lack of "live" work primarily led to the outflow of young specialists from this field of scientific activity in Ukraine and the aging of personnel.

The project of the basic accelerator facility of the NSC KPTI for nuclear physics and high-energy physics based on the SALO recirculator project [4], which was based on world achievements in the development of accelerator technologies based on superconducting accelerating structures, was not implemented due to the lack of a source of funding.

Currently, only four electron accelerators are operating in Ukraine: the technological accelerator LU10 at an energy of 10 MeV, the accelerator LU30 at an energy of 30 MeV, the accelerator LU40 at the NSC KIPT, whose operation was restored after the damage caused by the war, and the microtron M30 at an energy of 25 MeV at the Institute of Electronic Physics in Uzhgorod. These accelerators were created more than 60 years ago and have long since ceased to meet the requirements of modern nuclear physics research.

The lack of accelerators and nuclear physics facilities built on the basis of the latest technologies has led to a catastrophic decline in the training of specialists in the field of nuclear physics research, which is extremely necessary for maintaining the nuclear energy industry of Ukraine [5]. This also excludes the access of Ukrainian scientists to the creation of modern accelerators for the needs of science and nuclear technologies both in the country and in the world. In this regard, the National Research Center of the KIPT proposed the creation of a new project for a multifunctional accelerator complex [6-8]. The purpose of the development and construction of this complex is to create a material and technical base for the revival of nuclear physics research and the basis for training specialists in this field in Ukraine. The design of the facility is based on world achievements in the development of accelerator technologies based on superconducting accelerating structures. The main element of the complex is an electron beam recirculator with an energy of about 600 MeV.

1. RECIRCULATOR

The general view of the recirculator is presented in Fig. 1. The magneto-optical structure of the recirculator and its main characteristics are described in detail in [9]. A beam with an energy of 29 MeV can be injected into the accelerating structure of the recirculator (Fig. 2). It consists of the energy of the injector, which in the high-charge mode can accelerate the beam to 4 MeV [10], and the energy gain to 25 MeV due to the superconducting accelerating module [11], which is used in the injector complex.

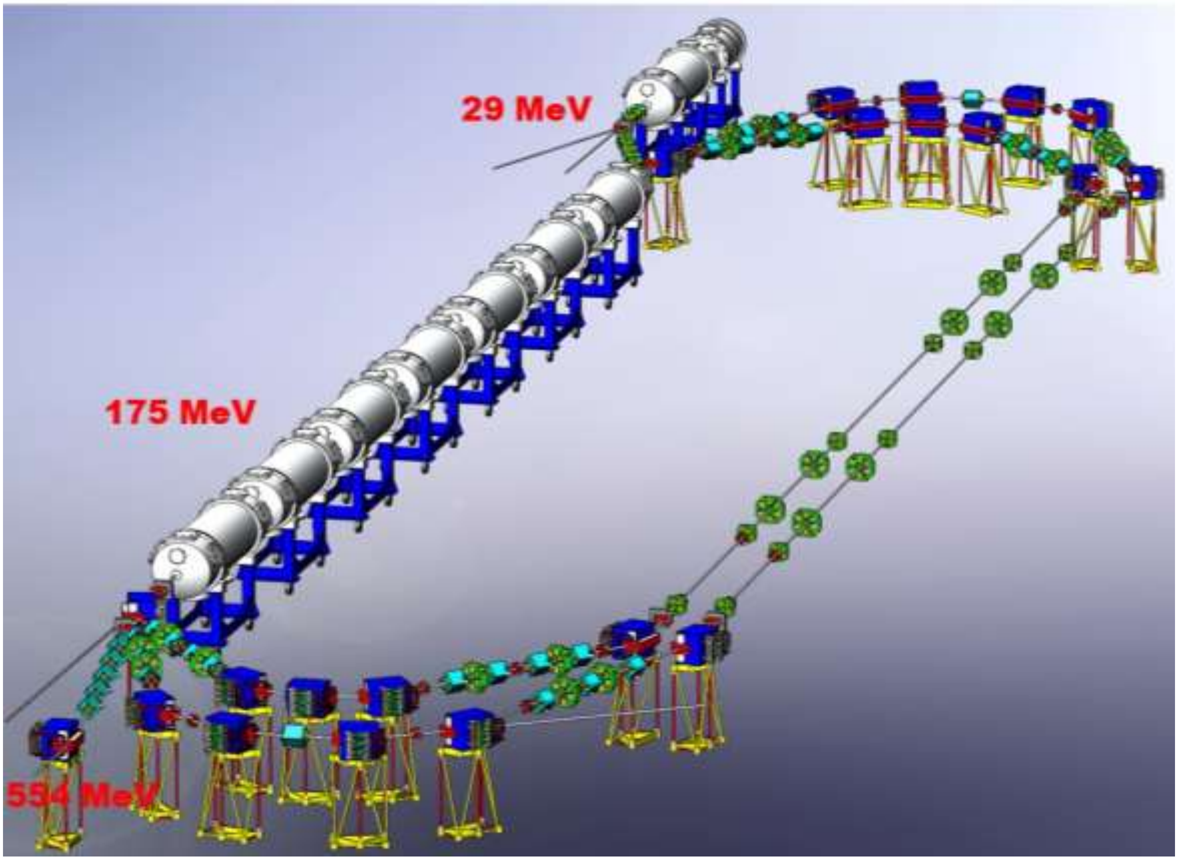

Fig. 1. General view of the magneto-optical structure of the recirculator

Further, the beam in seven accelerator modules will be able to gain energy of 175 MeV. To further increase the energy, two magnetic rings are used, with the help of which the beam passes through the accelerator two more times. The maximum electron energy can be increased to 554 MeV.

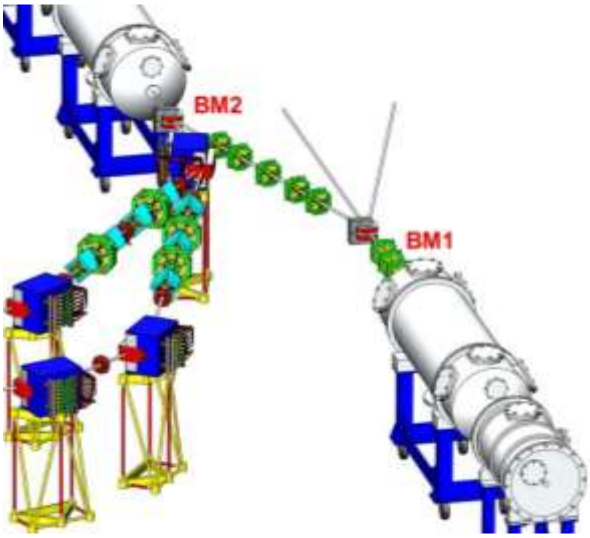

Fig. 2. Injection of electrons into the accelerator

The amplitude and dispersion functions of the recirculator rings are shown in Figs. 3 and 4 [10].

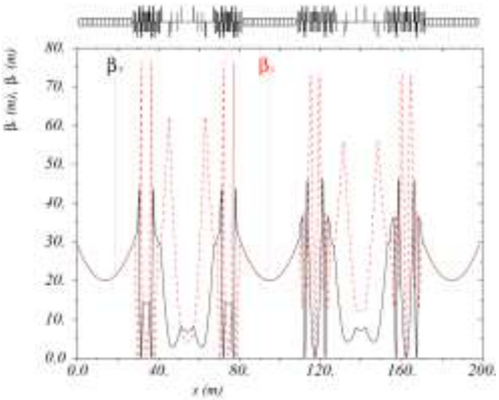

Fig. 3. Amplitude functions of two recirculator rings

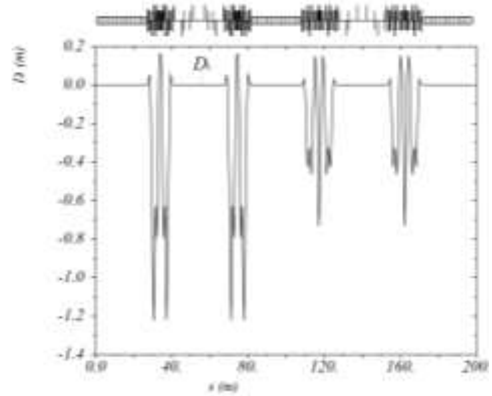

Fig. 4. Dispersion function of the recirculator

The cross-section of the beam at the output of the second magnet of the output channel (beam energy E = 554 MeV) is presented in Fig. 5 [10].

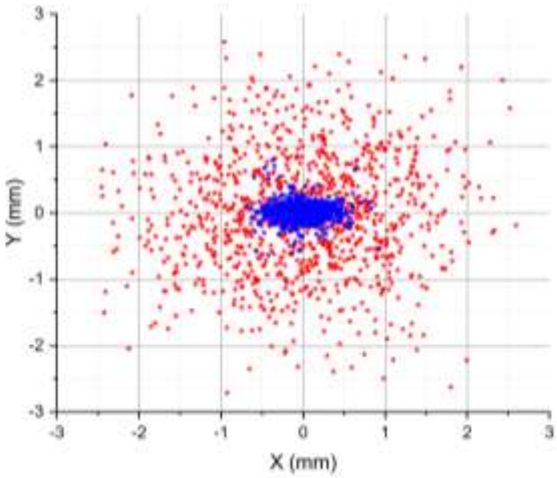

Fig. 5. The beam with the highest energy at the output of the output channel

The energy spectrum of the beam with maximum energy is presented in Fig. 6.

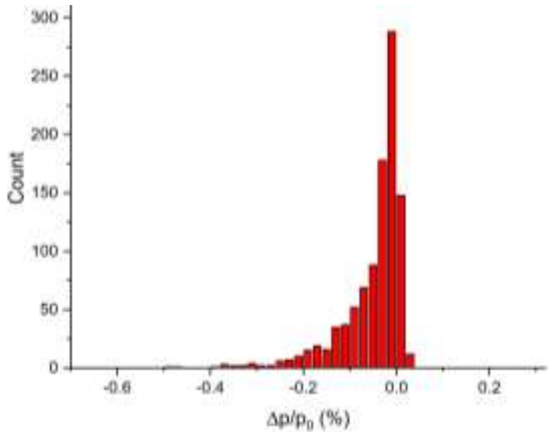

Fig. 6. Spectrum of the beam with the highest energy

2. WHAT BEAMS CAN BE OBTAINED FOR PHYSICAL EXAMINATIONS?

ELECTRONS

The electron output channels can produce beams in a wide range of energies.

As can be seen from Fig. 2, the beam injection into the recirculator occurs using magnets BM1 and BM2. If these magnets are switched off, it is possible to use quasi-continuous beams with an energy of 29 MeV and a current of about 1 mA for radiation treatment of materials and production of medical isotopes.

When using magnet BM1, another channel with such energy will allow creating a source of positrons for Positron Annihilation Spectroscopy, which allows studying the smallest atomic defects in crystals, metals, semiconductors and polymers, such as voids in the nanometer range, as well as chemical structures in liquids and biological systems [12].

On the basis of the channel with the maximum electron energy (Fig. 7), a complex of magnetic spectrometers for nuclear physics research, as well as a free-electron laser, can be placed.

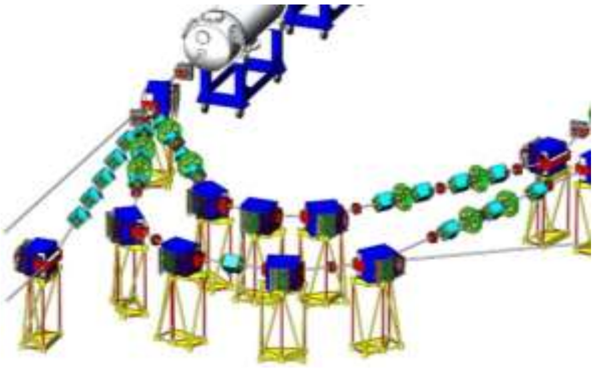

Fig. 7. Possible electron extraction channels for nuclear physics research

By switching off the fourth magnet of the second recirculation ring (see Fig. 7), an additional channel can be organized for studies with energies up to 380 MeV. All electron extraction channels are shown in Fig. 8. Switching off the third magnet of the first ring allows injecting a beam with an energy of 200 MeV into the synchrotron radiation source – an electron ring with an energy of 1.2 GeV [16].

NEUTRONS

As can be seen from Figs. 7 and 8, a direct beam with an energy of about 200 MeV can be used in a pulsed neutron source [13].

The superconducting injector of the complex in the high-charge mode will accelerate electron bunches with a charge of 1 nc, a length of 15 ps with a frequency of about 500 kHr. The average current at the injector output in this mode will not exceed 0.5 mA. After acceleration in a linear accelerator, the electron energy will reach 200 MeV.

One electron with an energy of 200 MeV in a uranium target generates ~0.14 neutrons. The total average neutron flux at the output of the neutron channel will be $4.4 \cdot 10^{14}$ s^{-1}. The pulsed flux will reach $6 \cdot 10^{19}$ n/s. Such beam parameters, as demonstrated in works [14, 15], allow, due to the short electron pulse and small target size, to obtain neutron fluxes on short flight bases that are not inferior to installations with proton accelerators.

POSITRON

In recent years, the number of positron spectrometers in various scientific centers has increased dramatically. This is due to the fact that positron annihilation provides information about the structure of matter that is unavailable for study by other experimental methods.

In [12], the creation of a positron source for annihilation spectroscopy is considered in detail. In the proposed structure of injection into the recycler [9], a beam with an energy of 29 MeV can be used for this, which interacts with a tantalum target. Due to the time structure of the electron beam, it is possible to obtain pulsed positron beams with a bunch length of about 5 ps.

To obtain positrons with high energy, a converter is used, located in front of the dipole magnet VM1 (see Fig. 2). The positron beam, which is captured by the magnetic system of the injection channel, which consists of dipoles VM1, VM2 and five quadrupoles, is accelerated to an energy of 181 MeV. This beam can be output to an experimental setup located on the direct channel. The use of the magnetic system of the first recirculation ring will allow increasing the positron energy to 356 MeV and outputting the beam through a special channel to the experimental setup.

More detailed parameters of the positron beam are given in [12].

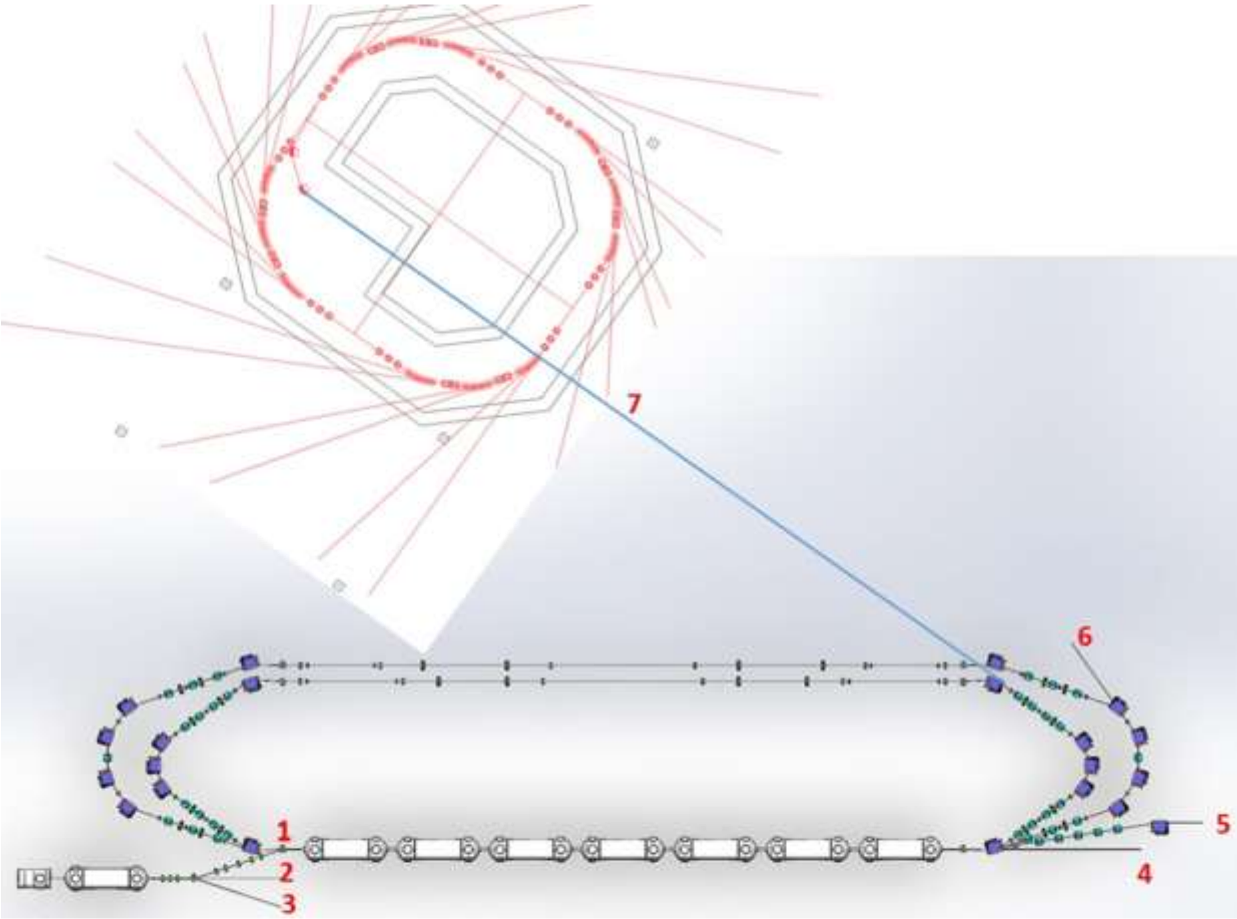

Fig. 8. General view of the electron output channels. 1 – Energy up to 29 MeV, injection of electron and positron beams into the recirculator. 2 – Energy up to 29 MeV, for work with radiation technologies, production of isotopes for medicine, etc. 3 – Energy up to 29 MeV, for creating a positron source for positron annihilation spectroscopy. 4 – Energy up to 200 MeV, for the target of a pulsed neutron source. 5, 6 – Maximum energy 555 and 380 MeV, nuclear physics research, free electron laser. 7 – Energy 200 MeV, injection into the accumulator, synchrotron radiation source with an energy of 1.2 GeV

GAMMA QUANTUM

The most common method of generating such radiation is the process of “brake radiation,” in which a beam of electrons (positrons) is directed into a substance (e.g., a metal target), losing energy during collisions with atoms and releasing this energy in the form of radiation.

The nature of this radiation can be dramatically changed by using a single crystal target. In this case, depending on the target's orientation relative to the electron (positron) beam, polarized quasi-monochromatic coherent radiation and channeled radiation can be produced. For a positron beam, annihilation radiation is additionally produced when it passes through a target. Their different angular dependence was used to distinguish the annihilation radiation from the braking radiation.

Channeling of positrons leads to a significant increase in the contribution of annihilation radiation to the total radiation spectrum of positrons moving along the crystallographic axis of a single crystal [17].

CONCLUSIONS

The calculations of beam parameters of the KIPT multifunctional accelerator complex demonstrated the possibility of conducting a large amount of research in many fields of science using nuclear physics methods.

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БАГАТОФУНКЦІОНАЛЬНИЙ ПРИСКОРЮВАЛЬНИЙ КОМПЛЕКС ННЦ ХФТІ – ОСНОВНІ ХАРАКТЕРИСТИКИ

П.І. Гладких, І.С. Гук, Г.Д. Коваленко

Розглянуто результати розробки багатофункціонального прискорювального комплексу ННЦ ХФТІ. Приведена магнітооптична структура рециркулятора, який є основою комплексу, що забезпечує одержання електронного пучка з максимальною енергією біля 600 МеВ при триразовому проходженні пучка через надпровідну прискорювальну структуру. Представлено варіанти одержання пучків електронів, гамма-квантів, позитронів та нейтронів для виконання фундаментальних та прикладних досліджень у галузі ядерної фізики і енергетики, фізики твердого тіла, ядерної медицини.