THEORY AND TECHNOLOGY OF PARTICLE ACCELERATION

THE C-80 CYCLOTRON SYSTEM. CURRENT STATUS

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The C-80 cyclotron system is intended to produce proton beams with an energy ranging from 40 up to 80 MeV and current up to 200 μA. The beams with the aforementioned parameters will be used for commercial production of a wide assortment of isotopes for medicine including radiation generators. In addition, creation of a special beamline to form homogeneous proton beams of ultra-low intensity ($10^7…10^9$) will allow the proton therapy of eye diseases and superficial oncological diseases as well as tests of radioelectronic components for radiation resistance to be performed. The equipment of the cyclotron and the first section of the beam transport system has been manufactured, tested at test facilities in the Efremov Institute, installed in the PNPI and made ready for acceptance tests.

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Over a number of years, works on designing a cyclotron for the acceleration of H^- ions up to 80 MeV were carried out in the PNPI and Efremov Institute [1 - 4]. Within the frames of a medical program of the NRC "Kurchatov Institute" a decision was made to use this cyclotron as a basis for commercial production of radioisotopes to produce promising radiopharmaceuticals and their generators [5 - 7]. In addition, creation of a special beamline to form homogeneous proton beams of ultra-low intensity ($10^7…10^9$) is planned, which will allow the proton therapy of eye diseases and superficial oncological diseases to be performed as well as tests of radioelectronic components for radiation resistance. Design parameters of the cyclotron are given in Table.

MAJOR UNIT OF THE CYCLOTRON

The major unit of the cyclotron, the electromagnet, has been designed using the magnet of the synchrocyclotron functioning in the PNPI. The magnet was manufactured and assembled in the experimental hall of the synchrocyclotron. On the one hand, this decision allowed the expenditures to be reduced, and on the other hand it limited the choice of design solutions. So, engineering and design solutions adopted in this project mostly depend on these circumstances, in particular:

• overall dimensions of the vacuum chamber and partly the number and layout of hookup elements are specified;

• parameters of the electromagnet power supplies are specified;

• overall dimensions of the resonance system are practically specified;

• the system of external injection of H^--ions is located directly under the electromagnet in the basement;

• beams of accelerated protons are extracted through an output window by stripping on carbon foils of the stripping device equipped with a mechanism to adjust radial and angular position of the foil;

• the range of energy variation of protons extracted from the cyclotron is limited with mutual location of the stripping device and resonance system.

Characteristics of the C-80 cyclotron

Systems/Parameters	Characteristics
Accelerated particles	H^-
Extracted particles	H^+
Beam energy, variable, MeV	40…80
Beam current, μA	200
Electromagnet:	
- type	E-shaped
- pole diameter, cm	2050
- mass, t	245
Resonance system:	
- operating frequency, MHz	41.2
- dee number	2
- RF voltage amplitude, kV	60
RF-generator power, kW	80
Ion source	external
Operating mode	continuous/pulse
Total power consumption, no more, kW:	
- with the beam on	500
- in the stand-by mode	200

A new system for lifting the upper part of the magnet has been designed and manufactured. It consists of 4 pairs of ball bearings and screws equipped with servomechanisms and position sensors. Photo of the electromagnet with the lifting system and vacuum chamber is shown in Fig. 1.

Based on the preliminary magnetic measurements of the magnetic field topology carried out by specialists of PNPI, new magnet sectors (Fig. 2), shims and metal plates have been designed and manufactured.

Fig. 1. The electromagnet with the lifting system of the magnet upper part and vacuum chamber

The vacuum chamber is made of stainless steel. Two openings are made along the central axis of the vacuum chamber. The lower opening is intended to input the beam from the external injection system, and the upper opening serves to house the inflector power leads. The vacuum chamber sidewall is made with branch pipes to house tanks of the resonance system and to extract beams of protons as well as to install two cryopumps, probes and the stripping device.

Fig. 2. Pole piece with sectors

RESONANCE SYSTEM

The resonance accelerating system (Fig. 3) is located completely inside the vacuum chamber. The system consists of two symmetrical quarter-wave resonators.

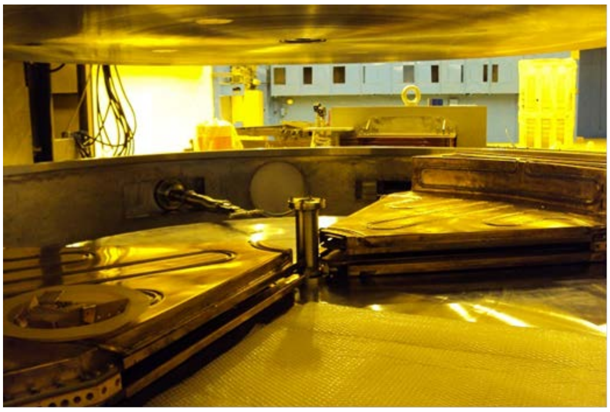

Fig. 3. The resonance system located in the vacuum chamber of the electromagnet

The system is equipped with a capacitor for frequency tuning, an AFT trimmer and RF-probe as well as aligning devices and coiled pipes for cooling heat-loaded units. The operating frequency of the accelerating system RF oscillations is 41.2 MHz. The range for the frequency tuning with the AFT trimmer is 220 kHz. The active loss power is about 29 kW in each resonator at an RF-voltage amplitude of 60 kV.

The cyclotron is equipped with two standard and three diagnostic probes and a stripping device. The standard probes are intended to measure the beam current at normal cyclotron operation. Diagnostic probes are used to measure the beam current at commissioning works and should be replaced for standard probes and the stripping device when running the cyclotron.

All the probes are equipped with:

- a remote drive for radial travel of probes with an accuracy of 0.5 mm;
- removal of the beam power of 200…400 W (the duty cycle is 40…20);
- the probes have similar connection dimensions and are equipped with similar electrical and water connectors, which provides their interchangeability.

The range of diagnostic probes' radial travel is from the minimum position allowed by the design to the maximum acceleration radius.

The range of radial travel for standard probes depends on the minimum and maximum energies of the extracted ion beam (40 and 80 MeV).

The stripping device is equipped with a mechanism to adjust radial and angular position of the carbon foil to provide a required range of final ion energies. The head of the stripping device is made as a "three-fingered fan", onto which three thin carbon foils are fixed. Remote rotation of the head is provided, which allows any of these 3 foils to be placed under the beam.

RF POWER SUPPLY SYSTEM

The RF power supply system consists of a stabilization and control module (designed in NIIEFA) and an RF-power amplifier (the «Coaxial Power System» firm, Great Britain).

The stabilization and control module of the RF-power supply system is intended for:

- generation of the main frequency of 41.2 MHz;
- manipulation of the acceleration voltage and its synchronization with the operation of the rest systems of the cyclotron;
- measuring and stabilization of the dee acceleration voltage amplitude;
- tuning and stabilization of the resonance system natural frequency;
- automatic tuning of the resonance system frequency to the supply voltage frequency.

The RF-power amplifier shall ensure an output power of 80 kW at a frequency of 41.2 MHz. The amplifier with power supply units is located in two cabinets (Fig. 4) installed in the experimental hall basement. The RF-power is transmitted to the resonance system via a flexible coaxial feeder.

Fig. 4. The RF-power amplifier

POWER SUPPLY SYSTEM

The power supply system of the cyclotron (Fig. 5) serves to generate and distribute electric power to the following main equipment of the cyclotron system:

- External injection system;
- Main electromagnet;
- System for the beam extraction and transport;
- RF power supply system;
- Vacuum system of the cyclotron;
- Water cooling system;
- Automatic control system.

Fig. 5. Power supply system for magnets and lenses

Electric power to the external injection system is supplied from power supplies of the Lambda and Spellman firms placed inside two cabinets. The power supply system produced by the Bruker firm, France serves to power the main electromagnet, magnets and lenses of the 1st section of the beam transport system.

EXTERNAL INJECTION SYSTEM

The external injection system serves for generation, shaping and transport of the H^- ion beam from an external source into the cyclotron through an axial opening made in the pole. The system is located under the electromagnet.

The system has been designed taking into account an experience gained in creation of similar systems for modern cyclotrons designed and manufactured in Efremov Institute, namely CC – 18/9 and MCC – 30/15. The system consists of: a plasma ion source with electrostatic optics, beamline with two focusing lenses and two correcting electromagnets, inflector, which is necessary to bend the beam from the axial transport channel to the median plane of the cyclotron and diagnostics, which allow the beam characteristics to be measured. Fig. 6 shows the external injection system; Fig. 7 gives the beam trace on quartz glass (a measuring device is mounted instead of the inflector).

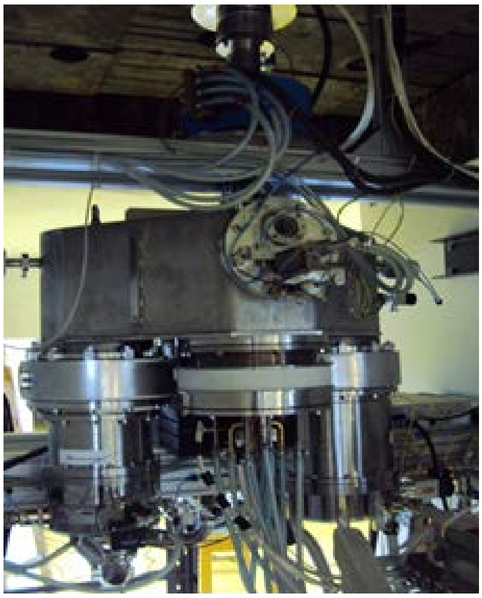

Fig. 6. The external injection system mounted on the cyclotron

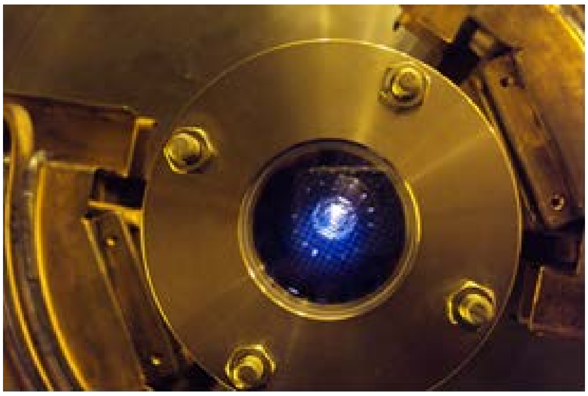

Fig. 7. Beam trace on quartz glass

To produce high vacuum in the cyclotron chamber, two Velco 322 cryopumps of the HSR firm, Liechtenstein, are used. Turbomolecular pumps (Edwards, Great Britain) are used in the external injection and beam transport systems.

The water cooling system is intended to remove the heat, totally of about 500 kW, from the heat-loaded components and units of the cyclotron and stabilize the heat carrier temperature at the input to these components accurate within 1…2°C. A double-circuit cooling system is used.

The heat carrier (distilled water) circulates in the inner circuit and cools heat-loaded components of the cyclotron; the coolant (process water) is used in the outer circuit. The heat removed by the heat carrier from heat-loaded components is transferred to the coolant in a plate-type heat-exchanger.

To extract the heat released in the process of the cyclotron operation into the atmosphere, the outer circuit of the water cooling system is connected to the circulating water cooling system of the building. At the atmospheric air temperature of 25ºC, the heat is removed through a water-water chiller.

The heat carrier is supplied to heat-loaded elements of the cyclotron through water distribution boards.

AUTOMATIC CONTROL SYSTEM

A distributed automatic control system is used. It consists of Mitsubishi and Fastwel IO controllers and computers, each being responsible for the control of one or several sub-systems of the cyclotron. The main unit of the control system is an industrial (host) computer, which inquires slave controllers and transmits the information acquired to computers of the operator's workstation; receives commands from the operator's workstation and performs their arbitration and distribution. Data exchange is realized via network interfaces of three types: the Ethernet, an upper level network, the ProfiBus DP and RS-485, low-level networks. The Ethernet networks the host Mitsubishi controller, host computer, computers of the operator's workstation, computer of the beam current measuring system and an industrial computer, which controls the RF system. The ProfiBus DP links the host controller, controllers of devices of the cyclotron and beam-forming system, vacuum system, power switchboard, power supply cabinets of the external injection system, water cooling system as well as control units of the power supply system for magnets and lenses.

The RS-485 networks the host computer, vacuum measuring units and controllers of turbomolecular pumps as well as the computer of the beam current measuring system and drivers of step motors of the devices for measuring the beam current density. In addition, the RS-485 links the controller of the cyclotron and beam-forming system devices with drivers of the step motors of probes and stripping device.

BEAM TRANSPORT SYSTEM

The beam transport system of the C-80 is intended for transport of the extracted proton beam to interaction chambers, the magnetic separator, units for radioisotopes' production and research of radiation resistance of radioelectronic components, etc. To date, the equipment for the 1st section of the system (Fig. 8) has been designed and manufactured, namely, the matching magnet, correcting electromagnet, quadrupole lens doublet and diagnostics comprising the Faraday cup and beam profile monitor.

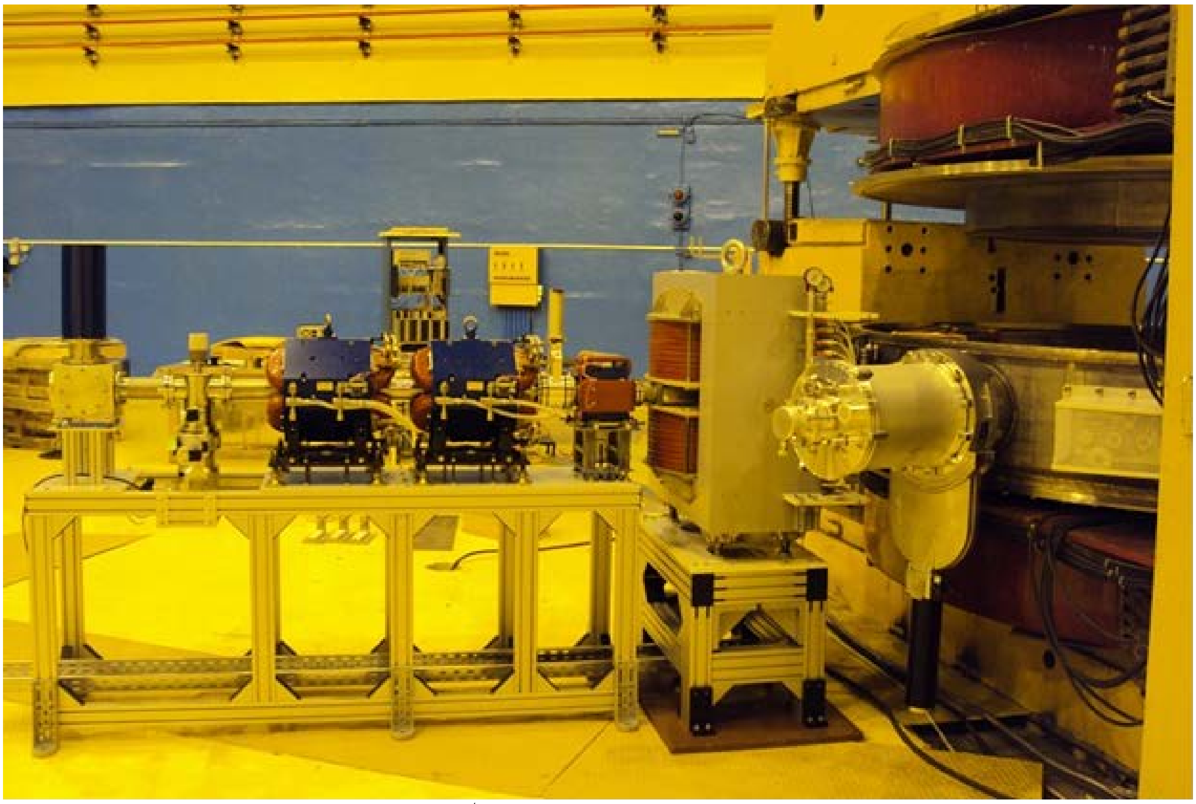

Fig. 8. The 1st section of the beam transport system

The equipment for the 2nd section of the system, which serves to transport the proton beam to target devices for production of radionuclides, has been designed and manufactured (Fig. 9). In this section, a switching magnet is installed, which directs the beam to several beamlines.

The first beamline will be equipped with an innovation target system cooperatively designed by specialists of Efremov Institute and PNPI for production of promising radioisotopes for medicine and industry. The second beamline will be equipped with standard equipment for production of Sr-Rb generators. In the third beamline will be installed the magnetic separator also cooperatively designed by specialists of Efremov Institute and PNPI for production of radioisotopes of high purity.

CONCLUSIONS

To date, installation of the equipment of the main cyclotron systems and the first section of the beam transport system has been finished. Commissioning works are underway. Physical start-up of the cyclotron and obtaining a proton beam on the diagnostics of the first section of the beam transport system are planned to have been realized by the end of 2013.

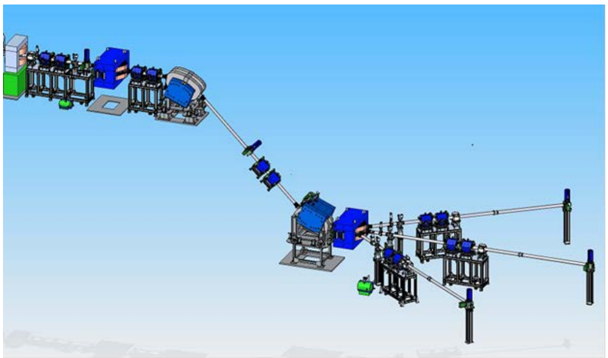

Fig. 9. The 2nd section of the system for the proton beam transport to remote targets for radionuclides' production

REFERENCES

1. N.K. Abrosimov, S.A. Artamonov, P.V. Bogdanov, et al. // *Proc. of XIII Intern. Cyclotron Conf.*, Vancouver, Canada, July 1992, p. 58-62.
2. N.K. Abrosimov et al. // *Proc. of XIII Conf. on Accelerators*, Dubna. 1993, v. 2, p. 205.
3. N.K. Abrosimov et al. // *Proc. of XIV Conf. on Accelerators*, Protvino. 1994, v. 4, p. 5.
4. N.K. Abrosimov et al. // *Proc. of V Intern. Cyclotron Conf.*, Caen, France, June 1998, p. 58.
5. P.V. Bogdanov, Yu.N. Gavrish, E.M. Ivanov, et al. Major Technical Characteristics of the C-80 Cyckotron System // *Problems of Atomic Science and Technology. Series «Nuclear-Physical Research» (58).* 2012, № 3(79), p. 10-14.
6. A.A. Vorobiev, E.M. Ivanov, A.G Krivshich, et al. Center of proton Therapy of the B.P. Konstantinov Petersburg Nuclear Physics Institute // *Problems of Atomic Science and Technology. Series «Nuclear-Physical Research» (59).* 2012, №4(80), p. 146-150.
7. P.V. Bogdanov, I.N. Vasilchenko, Yu.N. Gavrish, et al. The C-80 Cyclotron System. Technical Characteristics, Current Status, Progress and Prospects. coatings // *XXIII Russian Particle Accelerator Conf. (RuPAC-2012),* Saint-Petersburg, Russia, 2012, http://accelconf.web.cern.ch/accelconf/, RuPAC-2012, Proc. Volume, p.106-108.

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СТАТУС РАБОТ НА ЦИКЛОТРОННОМ КОМПЛЕКСЕ Ц-80

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Циклотронный комплекс Ц-80 предназначен для получения протонных пучков с энергией 40…80 МэВ и током до 200 мкА. Пучки с такими параметрами будут использоваться для производства широкого спектра изотопов медицинского назначения, в том числе генераторов излучения, в коммерческих масштабах. Кроме того, создание специального тракта формирования гомогенных пучков протонов ультрамалой интенсивности ($10^7…10^9$) позволит осуществлять протонную лучевую терапию глаза и поверхностных форм онкологических заболеваний, а также проводить испытания радиоэлектронных изделий на радиационную стойкость. Оборудование циклотрона и первого участка системы транспортировки изготовлено и испытано на стендах НИИЭФА им. Д.В. Ефремова, смонтировано в ПИЯФ им. Б.П. Константинова и подготовлено для проведения приемосдаточных испытаний.

СТАТУС РОБІТ НА ЦИКЛОТРОННОМУ КОМПЛЕКСІ Ц-80

О.Л. Вересов, Ю.М. Гавриш, А.В. Галчук, С.В. Григоренко, В.І. Григорьєв, Л.Є. Корольов, А.М. Кужлєв, В.Г. Мудролюбов, А.П. Строкач, С.С. Циганков, С.А. Артамонов, Є.М. Іванов, Г.А. Рябов

Циклотронний комплекс Ц-80 призначений для отримання протонних пучків з енергією 40...80 МеВ і струмом до 200 мкА. Пучки з такими параметрами використовуватимуться для виробництва широкого спектра ізотопів медичного призначення, у тому числі генераторів випромінювання, в комерційних масштабах. Крім того, створення спеціального тракту формування гомогенних пучків протонів ультрамалої інтенсивності ($10^7…10^9$) дозволить здійснювати протонну променеву терапію ока і поверхневих форм онкологічних захворювань, а також проводити випробування радіоелектронних виробів на радіаційну стійкість. Устаткування циклотрона і першої ділянки системи транспортування виготовлене та випробуване на стендах НДІЕФА ім. Д.В. Єфремова, змонтовано в ПІЯФ ім. Б.П. Константинова і підготовлено для проведення приймальноздавальних випробувань.