

THE C-80 CYCLOTRON SYSTEM. TECHNICAL CHARACTERISTICS, CURRENT STATUS, PROGRESS AND PROSPECTS.

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Abstract

A 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 μ A.

Over a number of years, works on the designing a cyclotron for the acceleration of H^- ions up to 80 MeV were carried out in the PNPI in cooperation with NIIIEFA specialists [1-4]. Since September 2010, NIIIEFA and PNPI have been carrying out works on building the C-80 cyclotron system intended for production of isotopes, proton therapy of eye diseases and superficial oncologic diseases as well as for fundamental and applied research. In addition, the cyclotron is supposed to be used as an injector of the C-230 synchrotron to ensure an additional acceleration of the extracted proton beam up to approximately 230 MeV. This will allow the Bragg's peak-based procedures to be applied in the proton therapy of oncologic patients.

Rapid advancement of modern methods of the nuclear medicine resulted in higher demand for the radioisotopic products used both in diagnostics and therapy. A rapid upgrowth of the PET diagnostics is observed, which uses radiopharmaceuticals based on radioisotopes with a half-life from several seconds up to several minutes. It is clearly enough that PET diagnostics can be done only in the direct vicinity of functioning cyclotron systems, that is, in large regional centers. The situation can be changed by using Sr-Rb generators, which can be produced on 70-90 MeV cyclotrons under irradiation of a Rb-85 target with protons. The parent isotope, Sr-82 with a half-life of 25.3 days decays and produces a daughter positron emitter Rb-82 used in the production of radiopharmaceuticals for PET. Thus, if Sr-82 is available, a PET center can function in hospitals located sufficiently far from the cyclotron system.

In view of the above, the most evident and cost-effective is the use of the C-80 cyclotron for commercial production of Sr-82. At the 200 μ A design current of the extracted proton beam, 40-50 mCi of Sr-82 will be produced for one hour; the price of 1 mCi is not less than 250\$. However, this fact does not exclude the possibility to produce commercially the whole assortment of isotopes for medicine as well.

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Parameters of the C-80 cyclotron (Table 1) make possible the realization of the proton radiation therapy of eye diseases and superficial oncologic diseases as well as the implementation of a research program aimed at the development of innovative methods of the proton therapy and promising radionuclides for diagnostics and therapy. Long-term fruitful cooperation of specialists from the PNPI and medical specialists from the Research center for Radiology and Surgical Technology, St.Petersburg in the treatment of patients using the TS-1000 accelerator is of great importance in this matter.

Table 1: Major characteristics of the C-80 cyclotron

Systems/Parameters	Characteristics
Accelerated particles	H^-
Extracted particles	H^+
Beam energy, variable, MeV	40...80
Beam current, μ A	2000
Electromagnet	
- type	E-shaped
- pole diameter, cm	2050
- mass, t	245
Resonance system	
- operating frequency, MHz	41.2
- 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

The major unit of the cyclotron, the electromagnet, has been designed using the magnet of the synchrocyclotron functioning in the PNPI. The main electromagnet has a traditional design with an E-shaped magnet yoke. The system to move upward the magnet upper part (the half-yoke) is worn-out and outdated. It was decided to replace it for 4 pairs of ball bearings and screws equipped with servomechanisms and position sensors. The height of the half-yoke lifting is not less than 600 mm, the setting accuracy is not worse than 50 μ m. Figure 1 shows the

magnet with the half-yoke lifting system. Based on the magnetic measurements, new magnet sectors have been designed and manufactured. To form a magnetic field, 17 packs of metal plates have been assembled on each sector.



Figure 1: Electromagnet.

The resonance accelerating system (Fig. 2) is located completely inside the vacuum chamber. The system consists of two symmetrical quarter-wave resonators. An inner conductor of each resonator consists of a 60° dee and a stem. The dees in the vicinity of the magnet center are galvanically coupled. The accelerating system is equipped with two capacitors for frequency tuning, an AFT trimmer and RF-probe. 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.



Figure 2: Resonance 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; measuring and stabilization of the dee acceleration voltage amplitude; manipulation of the acceleration voltage and its synchronization with the operation of the rest systems of the cyclotron; tuning and

stabilization of the resonance system natural frequency; automatic tuning of the resonance system frequency to the supply voltage frequency.

Structurally the module consists of mother and daughter cards built into an industrial computer housed in the RF-power amplifier cabinet.

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 a cabinet installed in the experimental hall basement. The RF-power is transmitted to the resonance system via a flexible coaxial feeder.

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 in the pole. The system is located under the magnet. It consists of: a plasma ion source with electrostatic optics, beamline with two focusing lenses and two correcting electromagnets, inflector and diagnostics.

The cyclotron is equipped with a stripping device, 2 standard and 3 diagnostic probes.

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

The power supply system of the cyclotron includes the main switchboard and systems for consumers’ secondary power supply.

The electric power to the external injection system is supplied from power supplies produced by the Lambda and Spellman firms. The power supplies are housed in 2 cabinets. The power supply system of the BRUKER firm serves to power the main electromagnet and magnets and lenses of the 1st section of the beam transport system.

To produce high vacuum in the cyclotron chamber, two Velco 322 cryopumps of the HSR firm, Liechtenstein, are used. Turbo-molecular 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 working coolant temperature at the input to these components accurate within 1-2°. A double-circuit system is used. Distilled water (the heat carrier) circulates in the inner circuit, and process water (the coolant) 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 is connected to the circulating water cooling system of the building. At the atmospheric air temperature of 25° C, the heat is removed through a water-water chiller.

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.

The experimental system of the cyclotron consists of a system for production of radioactive isotopes located in the basement, unit for the radiation ophthalmology installed in the experimental hall and unit for the radiation tests of electronic components and devices. Figure 3 shows the layout of the cyclotron and experimental system in the experimental hall.

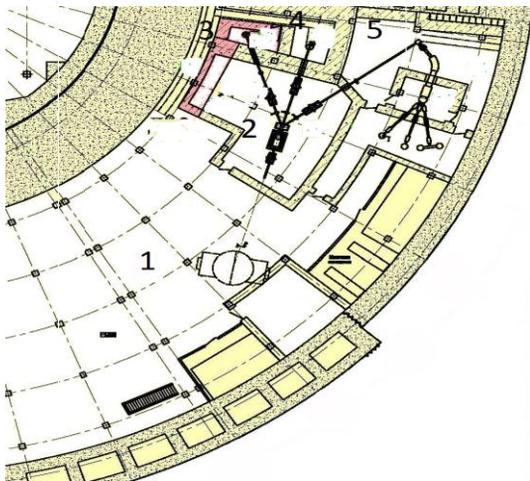


Figure 3: Cyclotron layout: 1-cyclotron; 2-switching magnet; 3, 4 – targets for production of isotopes; 5- target for electromagnetic separation of isotopes.

The beam transport system of the C-80 is intended for transport of the extracted proton beam to interaction chambers and radio-therapeutic units for proton therapy. To date, the equipment for the 1st section of the system (Fig. 4) has been designed and manufactured: matching magnet, correcting electromagnet, quadrupole lens

doublet and diagnostics comprising Faraday cup and beam profile monitors. 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 is under manufacturing. In this section, a switching magnet is installed, which directs the beam to several beamlines. When the switching magnet power is off, the beam is directed to a system of two bending magnets, which transport the beam to the second switching magnet installed in the basement (Fig. 3, № 2) and further to one of three target devices (Fig. 3, № 3, 4 and 5). For the beam focusing and control of its parameters, 5 quadrupole lens doublets, 4 correcting magnets and 2 diagnostic devices are installed in the 2nd section of the beam transport system.

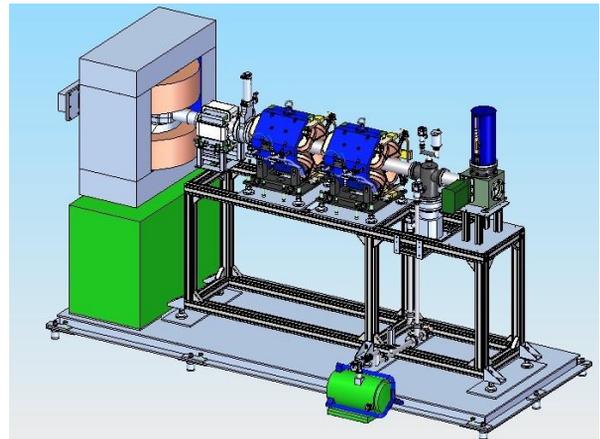


Figure 4: First section of the beam transport system.

If power is on, the magnet will direct the proton beam of ultra-low intensity and high stability to the beamlines for the proton therapy of eye diseases and superficial oncologic diseases. When the polarity of the magnet is changed, the beam is directed to the beamline intended for studying the radiation resistance of radioelectronic devices. These beamlines will be designed in 2013.

To date, reconstruction of the hall and rooms housing the cyclotron equipment has been finished. New sectors, shims and sector metal plates have been manufactured, and the magnetic field has been formed. The equipment of the cyclotron and the 1st section of the beam transport system has been manufactured and installed in the experimental hall, basement and corresponding rooms. In compliance with schedule, physical start-up is planned for the end of 2012.

REFERENCES

- [1] N.K. Abrosimov, S.A. Artamonov, P.V. Bogdanov et al., Proc. of XIII Intern. Cyclotron conference, Vancouver, Canada, July 1992, p. 58.
- [2] N.K. Abrosimov et al. Proc. of XIII Conference on Accelerators, Dubna, 1993, V. 2, p. 205.
- [3] N.K. Abrosimov et al., Proc. of XIV Conference on Accelerators, Protvino, 1994, V. 4, p. 5.
- [4] N.K. Abrosimov et al. Proc. of V Intern. Cyclotron conference, Caen, France, June 1998, p. 58.