PHYSICAL START-UP OF THE C-80 ISOCHRONOUS CYCLOTRON

Yu.N. Gavrish, A.V. Galchuck, S.V. Grigorenko, A.N. Kuzhlev, V.G. Mudrolyubov,
JSC "NIIEFA", St. Petersburg, Russia
D.A. Amerkanov, S.A. Artamonov, E.M. Ivanov, G.F. Riabov, V.I. Yurchenko
PNPI, Gatchina, Leningrad region, Russia

Abstract

Works on the installation of a cyclotron system for the acceleration of H$^-$ ions at energies ranging from 40 up to 80 MeV have been completed in the B.P. Konstantinov Petersburg Nuclear Physics Institute (PNPI), the National Research Centre "Kurchatov Institute". The cyclotron is intended for production of a wide assortment of radioisotopes including radiation generators (Sr-Rb, Ge-Ga) for medicine, proton therapy of ophthalmic diseases, tests of radioelectronic components for radiation resistance and studies in the field of nuclear physics and radiation material science.

In June, 2016 physical start-up of the cyclotron was realized in the pulsed mode. To date, the beam of ~38 µA was obtained at the inner probe of the cyclotron, the extracted beam at the first diagnostic device was ~28 µA. The beam transport to the final diagnostic device of the beamline (~35 m long) practically without losses was demonstrated. In the near future we plan to obtain the design intensity of 100 µA.

PURPOSE AND MAIN CHARACTERISTICS

The C-80 cyclotron system developed by specialists of PNPI and the D.V. Efremov Institute is intended for production of proton beams with energies ranging from 40 up to 80 MeV and current of up to 100 µA. The beams with such parameters will be used to finalize the development of the technology for production of a wide assortment of radioisotopes for medicine including radiation generators and for commercial production of these radioisotopes [1-3]. In the nearest future the following works are planned:

- Creation of a special line to form homogeneous proton beams of ultra-low intensity (10^7-10^9) for proton therapy of ophthalmic diseases.
- Creation of a test facility to carry out studies on the radiation resistance of radioelectronic equipment using intensive beams of protons and neutrons.

The cyclotron system equipment with the transport system of an accelerated proton beam to remote target stations is mounted in the experimental hall of building 2 and in its basement. The equipment of the cyclotron and that of the first section of the beam transport system is located on the first floor (see Fig. 1), the external injection system, the RF generator and the system for the beam transport to three targets are mounted in the basement. The main characteristics of the cyclotron are given in Table1.

The major unit of the cyclotron, an electromagnet, was designed using a model of the magnet of the synchrocyclotron operating in PNPI and further updated. Such a decision limited significantly the choice of engineering solutions when designing the cyclotron. In the process of commissioning works some structural deficiencies made at the design and manufacturing stages were detected and eliminated.

Figure 1: The C-80 cyclotron system.

Table 1: The main Characteristics of the Cyclotron

System, parameter	Characteristic, value
Type of accelerated particles	H$^-$
Type of extracted particles	H$^+$
Beam energy, variable, MeV	40-80
Beam current, µA.	100

TESTS AND RESALTS

In the process of preliminary tests of the cyclotron, appreciable losses of the beam intensity in the cyclotron central region were found out. Measurements of current performed with a three-electrode probe inside the cyclotron chamber demonstrated a noticeable beam shift relative to the median plane (see Fig. 2).

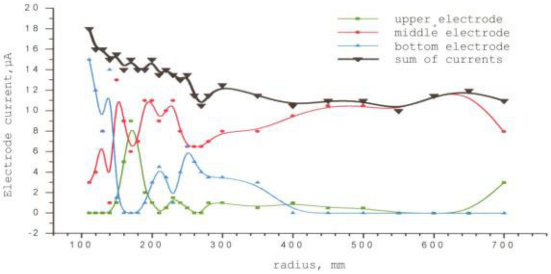

Figure 2: Results of current and beam position measurements in the process of acceleration.

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To identify the reasons for such a behavior of he beam, additional magnetic measurements were carried out, which showed that the actual field in the central region exceeded significantly the calculated value and the field formed prior the vacuum chamber assembly. The main reason of such a difference is magnetic properties of non-stainless steel, which was used as a material for the vacuum chamber. Fig. 3a shows the isochronous magnetic field formed prior the vacuum chamber assembly, and Fig. 3b demonstrates the difference between the actual magnetic field and the isochronous magnetic field formed after the assembly.

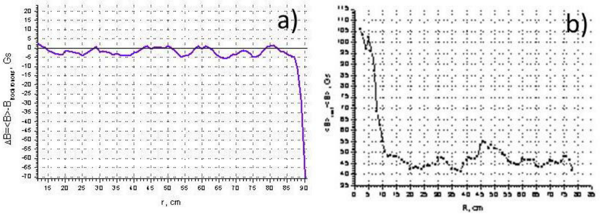

Figure 3: Difference between the actual magnetic field and calculated isochronous magnetic field: a) prior the vacuum chamber assembly; b) after the vacuum chamber assembly.

In addition, the analysis of the results obtained allowed us to suppose that large intensity losses result from the magnetic field radial component occurrence in the median plane [4]; unfortunately, there are no means to measure it correctly with account for the actual geometry of the cyclotron central region.

The use of additional valley coils did not made the situation better because of their remote location from the central axis of the electromagnet. To place the coils closer to the axis is impossible as the central region is limited in space, and sizes of the channel to input the beam from the external injection system should be kept unchanged. Therefore, the only method to reduce the intensity losses of the accelerated beam is an experimental choice of the position, size and shape of additional magnetic elements (plugs, additional rings, etc.) located in the cyclotron central region.

The resonance acceleration system consists of two symmetrical quarter-wave resonators and is placed completely inside the vacuum chamber. The system is equipped with a capacitor for frequency tuning, AFT trimmer and RF probe. The operating frequency of RF oscillations is 41.2 MHz, which corresponds to the 2nd harmonic of the ion revolution frequency. The normal value of the RF voltage amplitude is 60 kV. When manufacturing the vacuum chamber, a required rigidity of covers was not provided, and this resulted in smaller gap between them and deformation of resonator claddings in the process of pumping-down**.** This made necessary changing of vertical sizes of dee stems and resonator tanks with a subsequent radiotechnical tuning of the system. Under tests of the RF-system at a high power level, an appreciable heating of a ceramic unit of the trimmer stem took place and its illumination and subsequent destruction was observed, which resulted from a poor choice of the trimmer position in the tank of one of resonators. A new unit was designed, manufactured and installed, which allowed the trimmer location outside the resonator volume and thus its heating was excluded.

The RF power supply system consists of a stabilization and control module and RF-power amplifier. The stabilization and control module designed in the Efremov Institute provided reliable operation in the process of generating 41.2 MHz operating frequency, tuning and stabilization of the natural frequency of the resonance system and accelerating voltage amplitude.

The RF power amplifier designed and delivered by the «Coaxial Power Systems», Great Britain should provide an output power of 80 kW at a frequency of 41.2 MHz. From the results of initial tests of this equipment in operating modes, a pressing need for fundamental updating was identified. Six additional fans, each 0.25 kW, and additional partitions were installed; perforations were made in available partitions, which provided an optimal distribution of air flowsand requiredthermal mode. The insulators used by the CPS firm in the final stage were completely replaced because of their systematic breakdowns. We detected and eliminated the whole series of errors in circuitry which did not allow a necessary stability of the output signal to be obtained and prevented normal operation of the RF system:

- The high-voltage input of the final stage was re-designed, re-manufacturedand newly installed; the leading-in power cable was replaced for a shorter one.
- The circuit of transistor amplifiers' power supply was modified and one of power supply units was replaced for a more powerful.
- Voltage filters of the final stage anode were replaced.
- The fans' power supply circuit providing an effective cooling of heated electronic components after amplifier's turn-off was modified.
- The switch-on time of the power supply system of tube filaments was changed to improve their operation stability.
- The circuit-breaker for mains' power input was replaced.
- Inspection of cable inter-connections in the amplifier was conducted with subsequent replacement where necessary, etc.

Works on updating the RF power amplifier slowed down considerably the completion of commissioning works and demonstrated a pressing need for using our own efforts to design proper amplifiers for our cyclotrons.

The cyclotron is equipped with remotely-operated diagnostic probes intended to measure the beam current. In the process of commissioning works a high level of the RF noise was observed, which made difficult correct displaying of the beam current on the central monitor of the operator workstation. We managed to eliminate the observed noise by placing additional protection screens on probe electrodes.

A distributed automatic control system (ACS) 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. To ensure normal operation of the automated control system, there must be a reliable special grounding to provide electromagnetic compatibility of the cyclotron equipment. At the initial stage of works, this grounding did not meet the requirements, which resulted in failures of several controllers and made us to prolong the time for carrying out commissioning works.

The beam transport system of the C-80 cyclotron is intended to transport the extracted proton beam to final devices. Fig. 4 shows the schematic of the beam transport system layout and photos of its equipment.

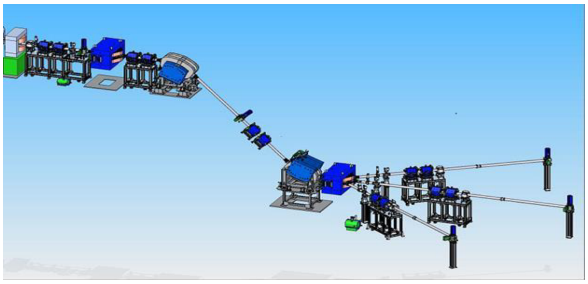

Figure 4: Layout of the beam transport system.

The first section of the beam transport system consisting of matching, correcting, switching and bending magnets, doublet of quadrupole lenses and beam diagnostics is located in the experimental hall. The second section of the beam transport system comprising bending, switching and correcting magnets, quadrupole lenses doublets and beam diagnostics is housed in the basement of the experimental hall. Because of large length of an inclined part between bending magnets in the experimental hall and in its basement, the quadrupole lenses doublet and diagnostic device are placed here.

In June, 2016 physical start-up of the C-80 cyclotron system was realized. Works were carried out in the pulse mode at low currents of the accelerated beam to exclude strong activation of the equipment to make possible safe continuation of works in the cyclotron vacuum chamber, with the components of the beam transport system, etc. When choosing the operating modes, available permissions granted by supervising authorities to carry out commissioning works were taken into account. At this stage, a beam of ~38 µA was obtained at the inner probe of the cyclotron; an extracted beam obtained at the first diagnostic device was ~28 µA. The beam transport practically without losses to the final diagnostic device of the beam transport system (~35 m) was demonstrated. Physical start-up was realized in the automated control mode under monitoring of all the systems of the cyclotron. Fig. 5 presents information on the status of all the cyclotron systems and their parameters in the process of performed works.

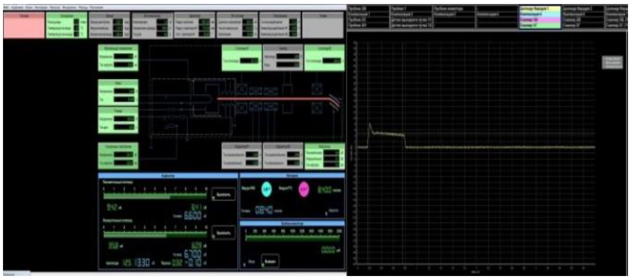

Figure 5: Information on the status of the cyclotron systems.

CONCLUTIONS

Our short-term plans include attaining of the design intensity of 100 µA by using reserves untapped so far:

- Completion of works on optimization of the electromagnetic field in the cyclotron central area.
- Increase of the injection current up to its specified value (from 900 up to 2500 µA).
- Use of the buncher potentialities with the anticipated effect of not less than two times higher current of the extracted beam; in works on the physical start-up, the buncher installed in the external injection system line was not used.

Efforts made towards these lines guarantee the attaining of design parameters of the C-80 cyclotron system and will offer opportunities for further increase of the accelerated proton beam intensity.

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