THE CC1-3 CYCLOTRON SYSTEM

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Abstract

A CC1-3 cyclotron system has been designed to be installed in the Vinca Institute of Nuclear Sciences, Belgrade, Serbia. This system will be operated in the laboratory of nuclear-physical methods of the elemental analysis. The system includes a compact cyclotron and a system for beam shaping with specified energy characteristics. The cyclotron ensures the acceleration of negative hydrogen ions up to energy in the range from 1 to 3 MeV and a beam of protons is extracted by stripping on a thin carbon foil. The beam-shaping system ensures the beam of protons with a spectrum width not more than 0.1%. The main unit of the beam-shaping system is a magnetic analyzer with a bending angle of 270º. To date, the equipment of the cyclotron system has been manufactured and tests have been carried out on test facilities in the D.V. Efremov Institute. Installation will be performed in 2012.

The CC1-3 cyclotron system has been designed at the D.V. Efremov Scientific Research Institute of Electrophysical Apparatus (NIIEFA), St. Petersburg with an active participation of specialists from the Vinca Institute of Nuclear Sciences, Belgrade, Serbia. The system will ensure effective technological facilities necessary to carry out analytical research in the Vinca Institute, in particular RBS, PES, NRA и PIXE spectroscopies. Strict requirements are imposed for parameters of accelerated proton beams: the energy range should be from 1 to 3 MeV, spectrum width no more than 0.1%, accuracy of energy setting not worse than 1 keV and current ranging from 10 to 100 nA.

To attain the aforementioned parameters, we have chosen the version of the system consisting of a compact cyclotron with a beam-forming system (Fig. 1) and systems of power supply, automatic control, vacuum pumping and water cooling.

The compact cyclotron is intended to accelerate negative hydrogen ions. An extraction by stripping on a thin carbon foil allows a proton beam with a final energy up to 1-3 MeV to be delivered. The current of the extracted beam of protons is 20 μA. The cyclotron comprises the following units and elements: an electromagnet with a vacuum chamber, resonance system, probes and stripping device, external injection system and high-frequency generator.

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The beam-forming system is designed to ensure beam parameters, which are not typical for cyclotrons. The beam-forming system includes a matching magnet and switching magnets, doublet of quadrupole lenses, correcting electromagnets and magnetic analyzer.

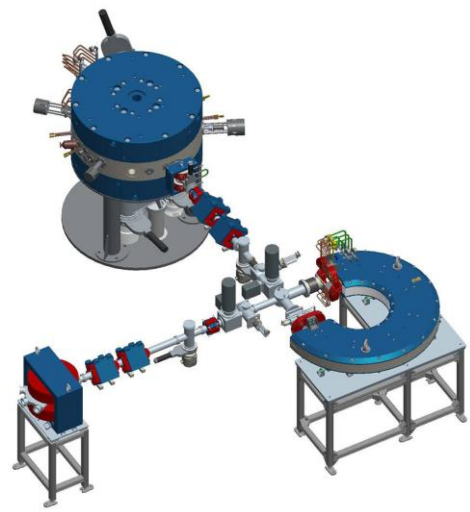

Figure 1: The compact cyclotron CC1-3 with a beam-forming system.

The major part of the cyclotron is a four-sector shielding-type electromagnet (Fig. 2). The electromagnet is 1400 mm in dia, pole diameter is 600 mm and average induction is 0.98 T. Gap hills/values are 50/100 mm. The maximum acceleration radius for the 3 MeV energy is 250 mm. The power consumption of the magnet is 5.2 kW; its mass is 6.5 tons. The upper beam of the magnet can be moved upward up to 500 mm.

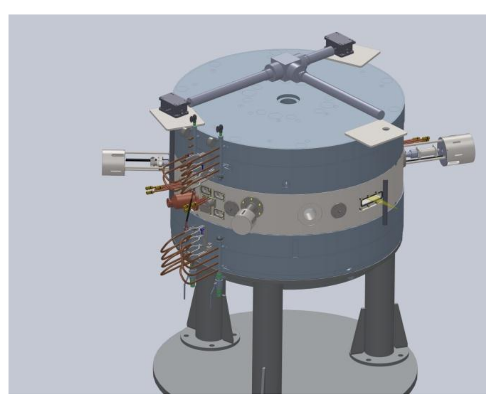

Figure 2: The magnet of the cyclotron.

ISBN 978-3-95450-125-0

The vacuum chamber of the cyclotron (Fig. 3) consists of a casing and two covers. The casing is a hollow thick-walled cylinder of carbon steel, which simultaneously is a part of the iron core. Pole pieces of the magnet with welded rings of stainless steel are the covers of the chamber. Such a structural concept provides necessary mechanical strength of the chamber and also forms a type of a volume to improve pumping of the vacuum chamber. A cryogenic pump, vacuum chamber of the matching magnet, RF power in-feeding device, AFT trimmer, stripping device and probes are fastened to flanges of the vacuum chamber casing.

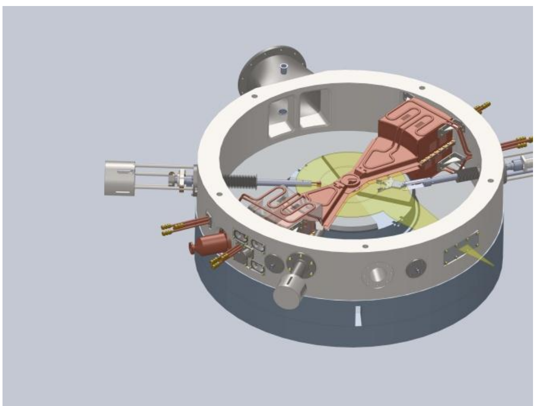

Figure 3: The vacuum chamber with resonance accelerating system, stripping device and probes.

The resonance accelerating system is located completely inside the vacuum chamber volume and is fixed to a side surface of the vacuum chamber casing. The system consists of two mirror-symmetrical quarter-wave resonators. An inner conductor of each resonator consists of a dee and a stem. The dees in the vicinity of the magnet axis are galvanically coupled. An outer conductor of the system is claddings of the magnet and vacuum chamber valleys as well as plates connecting the upper and lower claddings of chamber. The side surfaces of the valley claddings follow the shape of the side surfaces of the magnet sectors and serve as dummy dees. The system is equipped with an inductive RF power in-feeding device, AFT trimmer and RF-probe. Stems, dees and claddings are cooled with water. The central part of the dees is made removable and it is cooled by thermal contact with the dees. The operating frequency of the resonance system is 59.7 MHz and it corresponds to the 4^{th} harmonic of the revolution frequency for hydrogen ions. The design power of active losses in each resonator is 1.6 kW at an RF voltage amplitude of 25 kV.

The high-frequency generator consists of a control and stabilization module and RF-power amplifier. The main parameters of the high-frequency generator are as follows: operating frequency – 59.7 MHz, frequency stability – 1.10^{-7}, phase stability – ±0.5°, output power – 5 kW and accelerating voltage amplitude stability – 10^{-3}. Generator triode 3CW5000A7 is used in the power amplifier. The RF power is transmitted to the resonance system through a flexible coaxial feeder.

Three versions of a negative ion beam generation are considered in the technical project: radial or axial inner sources and an external injection system. Stringent requirements are imposed on the energy spectrum of the accelerated ion beam and current stability, therefore the last version of the aforementioned has been chosen. The external injection system is located under the electromagnet. The system consists of a source of negative ions with an ion-optical system for the beam additional acceleration and focusing, differential pumping chamber, two electrostatic lenses, spiral inflector and an ancillary equipment. The ion beam current at the injector output is 0.5 mA, ion energy is 11.5 keV, calculated normalized emittance is not more than 0.3 π mm·mrad.

The cyclotron is equipped with two probes designed for removal of the maximum beam power of 60 W. The probes have similar connection dimensions, electrical and water connectors. A remote drive ensures radial travel of the probes from the minimum allowed position of ~ 100 mm to the position when the probes are outside the acceleration area. The stripping device is equipped with a drive, which allows one of three charge-exchange foils to be quickly installed to the working position and also the foil radius and angle of location to be varied. The charge-exchange foil is a carbon film of 0.2 µm thickness with a glue substrate. We were not sure if this foil would suit us as 1 MeV ions lose ~15 keV when passing through the foil. In this connection, pilot samples of this foil were manufactured and tested on the operating cyclotron CC-18/9 with an ion energy of 1-2 MeV. Simultaneously, a technique for fabrication of foils with a smaller thickness has been developed and tried out, which will allow energy losses to be reduced and reliability of the stripping device to be increased.

The major part of the beam-forming system is an analyzer, which consists of an analyzing magnet (Fig. 4) and two collimators installed at the inlet and outlet of the analyzing magnet vacuum chamber. The analyzing magnet ensures a bending angle of 270° with a bending radius of 600 mm. To expand the potentialities of the beam-forming system, three fixed dimensions of the input and output slits of 0.5, 1 and 2 mm are provided. The design energy resolution behind the output slit is not worse than 0.05%.

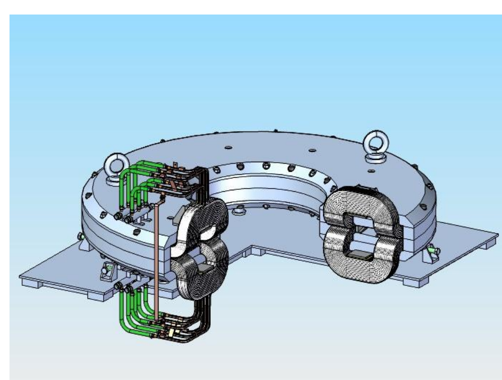

Figure 4: The analyzing magnet.

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The matching magnet is intended to make coincident the axis of the extracted beam with the ion guide axis. A doublet of quadrupole lenses focuses the beam to the input slit of the analyzer. The switching magnet specifies the beam bending angle for its further transport, either 0° or ±15°. To measure the beam parameters when it is transported to targets, the beam transport system contains the following diagnostic means: beam profile monitors (scanners), which are used to measure the beam profile in horizontal and vertical planes, and Faraday cups to measure the beam current.

The power supply system is intended to supply electric power to the cyclotron equipment. The maximum installed power of the equipment is 40 kW. The system consists of a power switchboard, two power supply racks for magnets and lenses and two power supply racks for the external injection system as well as power supply units for step motors and the mechanism moving upward the upper beam of the magnet.

The automatic control system is of distributed architecture. 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, which is responsible for the control, interlock and signaling sub-system, 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 racks of the external injection system, water cooling system as well as control units of the power supply system of 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 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 step motors of probes and the stripping device.

The vacuum system contains a cryogenic pump used in the vacuum chamber of the cyclotron, four turbomolecular pumps for the external injection system and beam-forming system, mechanical dry pumps, gate valve, valves, leak valves and pressure gages to measure low and high vacuum.

The equipment of the cyclotron will be cooled with distilled water circulating in the water-cooling loop of the cyclotron building. Four water distribution boards are used to distribute cooling water to remove the heat released by the heat-loaded components and units of the cyclotron, to control pressure and stabilize water flow rates.

At present, the equipment has been designed, manufactured and tested at test-facilities of the D.V. Efremov Institute. Installation of the system is planned to have been finished by the end of 2012.

ISBN 978-3-95450-125-0