

# THE CC1-3 CYCLOTRON SYSTEM FOR NON-DESTRUCTIVE NUCLEAR-PHYSICAL METHODS OF THE ELEMENT ANALYSIS

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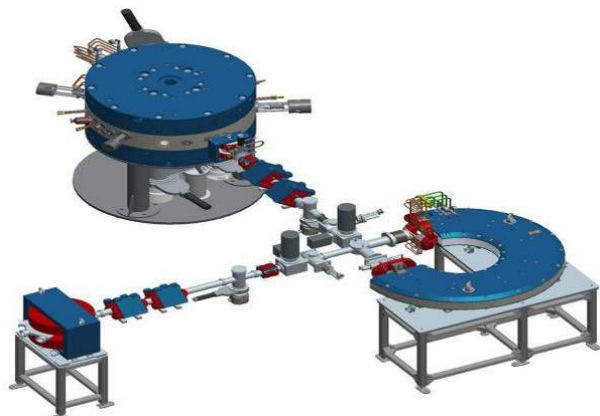
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The CC1-3 cyclotron system is intended to be installed in the laboratory of nuclear-physical methods of the element analysis of the Vinca Institute of Nuclear Sciences, Belgrade, Serbia. The cyclotron system ensures production of a beam of protons with energy in the range from 1 to 3 MeV with a spectrum width not more than 0.1%. The equipment of the cyclotron system has been manufactured and tested on test facilities in the D.V. Efremov Institute.

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The CC1-3 cyclotron system has been designed at the D.V. Efremov Scientific Research Institute of Electrophysical Apparatus (NIIEFA), St.-Petersburg. The system will ensure effective technological facilities necessary to carry out analytical research in the Vinca Institute, Belgrade, Serbia in particular RBS, PES, NRA и PIXE spectroscopies. Strict requirements are imposed by the End User 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.



*Fig. 1. The CC1-3 cyclotron with a beam-forming system*

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 variable in the range of 1...3 MeV to be delivered. The current of the extracted beam of protons is 20  $\mu$ A. 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.

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.



*Fig. 2. The magnet of the CC1-3 cyclotron*

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. 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.

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 (see Fig. 3). 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 connect-

ing 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<sup>th</sup> harmonic of the revolution frequency for hydrogen ions. The power of active losses in each resonator is 1.6 kW at an RF voltage amplitude of 20 kV.



*Fig. 3. The resonance system of the CCI-3 cyclotron*

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 –  $1 \cdot 10^{-7}$ , phase stability –  $\pm 0.5^\circ$ , 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.

In the process of designing we considered three versions of generation of a negative ion beam: 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 (Fig. 4).



*Fig. 4. The external injection system*

It 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 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  $0.3 \pi \text{ mm-mrad}$ .

The cyclotron is equipped with two probes designed for removal of the maximum beam power of 60 W. The probes have similar connection dimensions and are equipped with similar electrical and water connectors. A remote drive ensures radial travel of the probes from the minimum allowed position of  $\sim 100 \text{ mm}$  to the position when the probes are outside the acceleration area. The stripping device is also 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  $0.2 \mu\text{m}$  thickness with a glue substrate. We were not sure if this foil would suit us as 1 MeV ions lose  $\sim 15 \text{ keV}$  when passing through the foil. In this connection, pilot samples of this foil were manufactured and successfully tested on the operating cyclotron CC-18/9 with anion energy of 1...2 MeV. Simultaneously, a technique for fabrication of foils with a smaller thickness (not more than  $1 \mu\text{m}$ ) has been developed and tried out, which will allow energy losses to be reduced and reliability of the stripping device to be increased.

The beam-forming system is designed to satisfy requirements for the beam energy spectrum, which are not typical for cyclotrons. The beam-forming system includes a matching magnet, a switching magnet, a doublet of quadrupole lens, correcting magnets and an analyzing magnet (Fig. 5).



*Fig. 5. The beam-forming system*

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  $0^\circ$  or  $\pm 15^\circ$ . To measure parameters of the beam 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 major part of the beam-forming system is an analyzer, which consists of an analyzing magnet and collimators installed at the inlet and outlet of the analyzing magnet vacuum chamber. The analyzing magnet (Fig. 6)

ensures a bending angle of  $270^\circ$  with a bending radius of 600 mm. To expand the potentialities of the beam-forming system, three fixed dimensions of the input and output collimator slits of 0.5, 1 and 2 mm are provided. The design energy resolution behind the output slit is not worse than 0.05%.

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 power switchboard distributes electric power to primary consumers, and protects cable lines from long-term overloads and cable faults.



Fig. 6. The analyzing 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, the 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 valves, 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.

By the present moment, the equipment has been designed, manufactured, tested at test-facilities of the D.V. Efremov Institute and made ready for delivery to the Vinca Institute of Nuclear Science.

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### ЦИКЛОТРОННЫЙ КОМПЛЕКС СС1-3 ДЛЯ НЕРАЗРУШАЮЩИХ ЯДЕРНО-ФИЗИЧЕСКИХ МЕТОДОВ ЭЛЕМЕНТНОГО АНАЛИЗА

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Циклотронный комплекс СС1-3 предназначен для оснащения лаборатории ядерно-физических методов элементного анализа Института ядерных наук Винча, Белград, Сербия. Циклотронный комплекс обеспечивает получение пучка протонов с энергией в диапазоне от 1 до 3 МэВ при ширине спектра не более 0,1%. Оборудование циклотронного комплекса изготовлено и испытано на стендах НИИЭФА им. Д.В. Ефремова.

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