THE CC1-3 CYCLOTRON SYSTEM. INSTALLATION AND TEST RESULTS

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Abstract

Works on the installation and adjustment of a unique CC1-3 cyclotron system in the Vinca Institute of Nuclear Sciences, Belgrade, Serbia have been finished. The cyclotron system will be used in the laboratory of nuclear-physical methods of the elemental analysis. A compact cyclotron and a beam-forming system produce an accelerated proton beam in a wide range of energies from 1 to 3 MeV with a spectrum width not more than 0.1%. Tests of the cyclotron system have been carried out at proton energies of 1.0, 1.7 and 3 MeV with the beam transport to the final diagnostic device.

PURPOSE

The CC1-3 cyclotron system has been developed and manufactured in the D.V. Efremov Scientific Research Institute of Electrophysical Apparatus. Unique parameters of accelerated proton beams (energy ranging from 1 up to 3 MeV, energy spectrum width of not more than 0.1 %) allow the use of this system as an effective technological equipment for analytical studies on the basis of nuclear-physical methods [1]. A distinctive feature of these express methods is a high sensitivity and comprehensive analysis (detection of small concentrations up to 10^{-5}–10^{-7} g/g). Possibility for non-contactnon-destructive analysis of substances or objects is of special interest.

The following fields were defined as the main applications of this system:

- X-ray method for the elemental analysis with a possible extraction of the proton beam into the atmosphere to irradiate samples for a detailed study of their surface layer.
- The method of analysis based on the Rutherford backscattering (RBS) to study both the elemental composition and the concentration profile of elements implanted into a sample.
- Spectral (Y–ray) analysis, the method based on recording of γ–radiation produced by nuclear reactions (P, X, γ).
- In future, potentialities of the system can be extended by developing a new equipment, which will make possible the realization of the method for the target potential modulation to study the concentration profile of implanted elements by recording the secondary Y-radiation produced by nuclear reactions under irradiation with an accelerated proton beam.

BRIEF DESCRIPTION

The cyclotron system consists of a compact cyclotron and a system for the beam forming and transport to remote analytical chambers including the beam extraction into the atmosphere as well as systems for power supply, automated control, vacuum pumping and water cooling [2].

The compact cyclotron provides acceleration of negative hydrogen ions to the final energy in the range of 1-3 MeV and extraction of a proton beam to the beam transport system by stripping of two electrons on a thin carbon foil. The cyclotron comprises an electromagnet with a vacuum chamber, resonance system, diagnostic devices (probes) and stripping device, external injection system and RF generator.

The major part of the cyclotron is a four-sector shielding-type electromagnet 1400 mm in diameter with a horizontally located median plane (see Fig. 1). The pole diameter is 600 mm; the average induction of 0.98 T was chosen to provide an optimal separation of orbits to minimize the energy spread. To make easy maintenance/repair of the equipment located inside the vacuum chamber, the upper beam of the magnet can be moved upward up to 500 mm.

Figure 1: Electromagnet of the CC1-3 cyclotron.

The resonance accelerating system is located completely inside the vacuum chamber of the electromagnet (see Fig. 2) and is equipped with an inductive RF power in-feeding device, AFT trimmer and RF-probe. The operating frequency is 59.7 MHz and it corresponds to the 4th harmonic of the hydrogen ions revolution frequency.

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

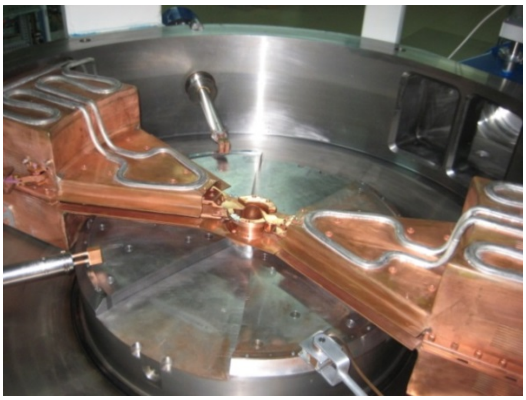

Figure 2: Resonance system.

The external injection system is located under the electromagnet (see Fig. 3). 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.

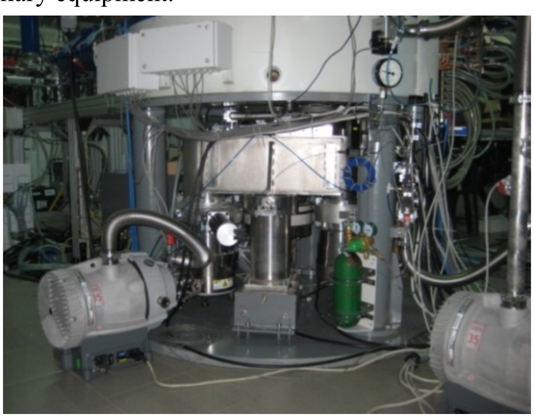

Figure 3: External injection system.

The cyclotron is equipped with remotely-operated probes, which ensures radial travel of the probes to control the beam in the acceleration area. The stripping device defining the energy of the extracted proton beam is also equipped with a drive. This allows quick installation of one of three charge-exchange foils to the working position and, in addition, variation of the foil radius and angle of location. Thickness of the charge-exchange foil should be optimized to minimize energy losses of hydrogen ions and to provide a sufficient mechanical strength. On the basis of experimental studies performed by us, thickness of a carbon film was chosen to be 0.15 mg/cm^2. Film samples were tested on an operating cyclotron at energies ranging from 1-3 MeV.

The beam-forming system is designed to meet the requirements for the proton beam energy spectrum, which are not typical for cyclotrons. The major part of the system is an analyzer, which consists of an analyzing magnet (see Fig. 4) with a bending angle of 270° and a bending radius of 600 mm and two collimators installed at the inlet and outlet of the analyzing magnet vacuum chamber.

Figure 4: Analyzing magnet.

A possibility to choose one of three fixed dimensions of collimator slits (without vacuum deterioration) is provided (0.5, 1 and 2 mm).The energy resolution behind the output slit is shown in Table 1.

Table 1: Energy Resolution of Magnetic Analyzer

Input slit total width, mm	**Energy spread, ΔE/E, %**	
	Design field index n=0.8317	**Measured field index n=0.8324**
2.0	0.0561	0.05587
1.0	0.02805	0.02793
0.5	0.014025	0.01397

The beam-transport system includes matching, switching and correcting magnets, a doublet of quadupole lenses and diagnostics, in particular, the Faraday cup and beam profile monitors.

The power supply system consists of a power switchboard, power supply racks for the external injection system, electromagnets and lenses as well as power supply units for step motors and a mechanism moving upward the upper beam of the main 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 major unit of the control system is an industrial (host) computer, which inquires slave controllers and transmits the information acquired to personnel computers of the operator's workstation; receives commands from the operator's workstation and performs their arbitration and

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distribution. Fig. 5 shows as an example the status of the vacuum system units displayed on the operator's monitor.

The vacuum system contains a cryopump, four turbomolecular pumps, mechanical dry pumps, gate valves, valves, leak valves and pressure gages to measure low and high vacuum.

The equipment of the cyclotron is 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.

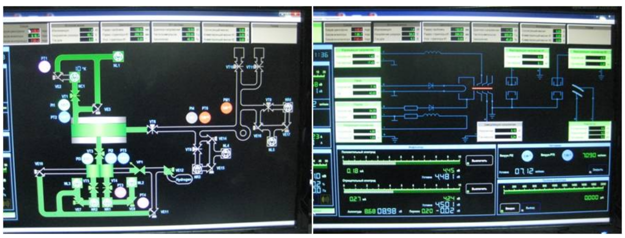

Figure 5: Status of the vacuum system and external injection system units displayed on the operator' s monitor.

In 2015 the cyclotron system was delivered to the Vinca Institute of Nuclear Sciences, Belgrade, Serbia. Installation of the equipment and separate tests of all systems have been carried out. General view of the system is given in Fig. 6.

TEST RESULTS

Tests of the whole system with the beam on were carried out for boundary values of the design range of proton energies (1 and 3 MeV) and an intermediate value of 1.7 MeV. Acceleration of negative hydrogen ions, proton beams extraction from the cyclotron and their transport through the beam-forming line, including the analyzer, up to the Faraday cup located behind the switching magnet have been implemented. The beam current of 104 nA was obtained at a maximum proton energy and collimator slits widths of 2 mm; current of 60 nA was fixed at minimum and intermediate energies, which correspond to the design value (10-100 nA). At present, the cyclotron system is ready for operation.

Figure 6: The CC1-3 cyclotron with the beam-forming line.

REFERENCES

[1] V.G. Mudrolyubov et al., "The CC1-3 Cyclotron System", RuPAC2012, St. Petersburg, September 2012, FRACH03, pp.191-193; http://www.JACoW.org

[2] O.L. Veresov et al., "The CC1-3 Cyclotron System for Non-Destruction Nuclear-Physical Methods of the Element Analysis", Problems of Atomic Science and Technology, Series "Nuclear Physics Investigation" (61), V. 6(88), Kharkov, 2013, pp. 13-15.

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