NOVEL COMPACT CYCLOTRONS FOR PRODUCTION OF RADIONUCLEDS

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Abstract

The production of radionuclides for medicine is an important field of application of modern cyclotrons for average energies accelerating light particles (protons and deuterons).

A series of compact cyclotrons, such as the CC-12, the CC-18/9 and the MCC-30/15 intended for the production of photon and positron emitters for SPECT and PET diagnostic centers has been designed and manufactured at the D.V. Efremov Scientific Research Institute of Electrophysical Apparatus. The cyclotrons ensure the acceleration of negative hydrogen and deuterium ions up to the following energies: the CC-12 – up to 12 MeV (hydrogen ions); the CC-18/9 – up to 18 MeV (hydrogen ions) and up to 9 MeV (deuterium ions); the MCC-30/15 – variable energy: 18-30 MeV (hydrogen ions) and 9-15 MeV (deuterium ions). An external injection system is used in these cyclotrons; the beams of accelerated protons and deuterons are extracted by ion stripping on carbon foils.

The main advantage of the aforementioned cyclotrons is an easy access to the devices located inside vacuum chambers by moving apart a part of the magnet to a distance of up to 800 mm along the guides (the median plane of the cyclotron is located vertically).

Successful putting into operation of two CC-18/9 cyclotrons, one in Turky, Finland (2005) and the other in St.Petersburg (2006) allows us to realize a serial production of these accelerators intended for use at PET centers

The parameters and characteristics of the main units of the aforementioned accelerators are given.

Medical radiology plays a very important role for the modern health care service. The most promising trends of radiology are diagnostics of a wide spectrum of diseases and treatment of malignant tumours, which are based on the use of artificial radionuclides.

The radionuclides for medicine can be divided into 3 groups: ultra short-lived, short lived and long-lived radionuclides.

Ultra short-lived radionuclides are used to produce radiopharmaceuticals necessary for positron-emission tomography (PET). Most widely used are isotopes of carbon (C-11), nitrogen (N-13), oxygen (O-15) and fluorine (F-18).

The PET-diagnostics makes possible both statical and dynamical examination of patients and in this case a patient is exposed to a lower dose than under X-ray irradiation. However, a short time of a radionuclide‘s life (a half-life is from 2 minutes up to 2 hours) requires that special PET-centers to be created and equipped with the following equipment: a cyclotron to produce beams of accelerated protons or deuterons, targets for production and preparation of radionuclides, a radio-chemical laboratory for synthesis of radiopharmaceuticals, one or several scanners for patients’ examination.

To produce positron emitters, we usually use cyclotrons with a proton energy of 10-18 MeV and a deuteron energy of up to 9 MeV and the beam current on targets no more than 100 μA.

The single-photon diagnostics is now in most use owing to its relative cheapness. To produce the radiopharmaceuticals used in the single-photon diagnostics, short-lived radionuclides are used such as Rb-81, I-123, In-111, Tl-201, Ga-67, Y-87 and others with a half-life from 4.7 hours up to 78 hours. With such life times, production of radiopharmaceuticals and diagnostics carried out using these radiopharmaceuticals can be separated, that is transportation of radiopharmaceuticals in the limits of a region is possible.

An increase in the maximum proton energy up to 30 MeV and in the maximum deuteron energy up to 15 MeV with energy regulated from the 0.6 level up to a maximum value will extends significantly the capabilities of the accelerator. First, the assortment and the yield of single-photon short-lived radionuclides are increased. Second, some long-lived radionuclides (Na-22, Co-57, Cd-109, Ce-139) are produced and investigations can be carried out with the aim of production of new radiopharmaceuticals, which will allow the field of radionuclide diagnostics’ application to be expanded. Third, isotopes to be used in the radiotherapy of malignant tumours are produced. In addition, when equipped with a special target, a cyclotron can be used for neutron therapy of oncological patients.

A series of modern compact cyclotrons intended for production of radionuclides for medicine has been designed and manufactured at the D.V. Efremov Institute (NIIEFA). The main technical characteristics of the aforementioned machines are given in Table 1.

Table 1: Cyclotron technical characteristics

Techical characteristics of cyclotrons	**CC-12**	**CC-18/9**	**MCC-30/15**
Ions accelerated	H^-	H^-/D^-	H^-/D^-
Ions extracted	H^+	H^+/D^+	H^+/D^+
Energy, MeV	12	18/9	18…30 / 9…15
Current, μA	50	100/50	100/50
Power consumed in the operating mode, kW	40	70	120
Magnet mass, t	10	20	41
RF oscillation frequency, MHz	76.4	38.2	40.68
Output power of the RF power supply system, kW	15	20	25

The CC-12 cyclotron is intended exclusively for production of ultra short-lived radionuclides directly in a PET-center. The machine is equipped with two ports to extract accelerated beams. By now, practically all equipment of the cyclotron prototype has been manufactured, and works on testing its units and systems are underway.

The CC-18/9 [1] cyclotron can be used in diagnostic centers in a small region. The machine has three ports to extract accelerated beams, namely: two ports are used to install targets directly on the magnet output pipe and the third port serves to transport the beams to remote targets. Two similar machines have been put into operation in the PET-centers in Turku, Finland and in Pesochnyi, St.Petersburg.

The MCC-30/15 cyclotron is intended for operating in radiological centers in large regions. The machine is equipped with two ports to extract accelerated beams to two beam lines. By now, the design documentation for the cyclotron equipment has been worked out, and the works on manufacturing the magnet, RF system and units of the external injection system have been started.

When designing the cyclotrons, special attention was paid to reduction of the induced activity. First, the main magnet of the shielding type with a limited number of holes in the core was used (the RF systems of all the cyclotrons are completely located in the vacuum cavity of the magnet). Second, negative ions of hydrogen and deuterium were chosen as the particles to be accelerated, and the beams were extracted by stripping on thin carbon foils practically without loss. Third, the cyclotrons are equipped with external injection systems, which reduce significantly the leakage of the working gas from the source to the vacuum chamber, makes more easy the production of high vacuum and, consequently, reduces the ion loss in the process of acceleration because of the charge exchange by the residual gas molecules.

The median plane of the magnets in these cyclotrons is vertically located, which gives an easy access to the in-chamber devices as the movable part of the magnet can be moved apart along the rails. Besides, maintenance of units of the external injection system can be done directly from the floor. In the cyclotrons with horizontal median plane of the magnet the external injection system is located either in a basement or on the upper yoke of the magnet.

BRIEF DESCRIPTION OF THE MAIN SYSTEMS

A shielding type magnet with the vertical median plane and four-sector elements forming the isochronous field are used in the cyclotron. Movable shims are provided to correct the “shape” of the field and to ensure the isochronism when the type of ions accelerated is changed. The magnet is installed on a support, which should be placed on a foundation plate. The magnet consists of two half-yokes with poles, pole tips and a coil; the median part of the magnet is made of carbon steel as a thick-wall ring and serves as an iron core ring, which is fixed to the stationary half-yoke. If needed, a movable half-yoke can be moved apart to a distance of up to 800 mm along the rails. For this purpose an electromechanically operated device with a reducer is provided; fixing pins ensure the positioning precision not worse than 0.025 mm when connecting the parts of the magnet.

The vacuum chamber of the cyclotron consists of a casing and two covers. The casing of the chamber is a hollow cylinder made of carbon steel and simultaneously it serves as the magnet core. The pole tips of the magnet with stainless steel flanges welded to them serve as the covers of the vacuum chamber. Through holes are made in the chamber for vacuum pumping, extraction of accelerated beams and to insert stripping foils, probes and so on into the vacuum volume. Cryogenic pumps, matching magnets of the beam transport system, stripping devices and probes are attached to the flanges of the casing.

The double-dee accelerating system is located completely inside the vacuum chamber and fixed at the lateral surface of the chamber casing. The dees located in the vicinity of the magnet are galvanically coupled with a crossbar. The system is equipped with an RF power input, a capacitor for frequency tuning, an AFT trimmer and a double-electrode RF probe.

The RF power supply system consists of a control and stabilization module and an RF power amplifier. The RF power is transmitted to the accelerating system via a flexible coaxial feeder.

The external injection system is intended to generate and transport beams of negative ions to the cyclotron through an axial hole made in the pole. The system comprises: a multi-cusp ion source with an ion-optical system for the beam additional acceleration and focusing, a solenoid lens, correcting magnets, an electrostatic lens, an RF buncher (in the CC-18/9 and MCC-30/15 cyclotrons), a helical inflector and an inflector current input as well as power supply and control units and vacuum equipment.

Cryogenic pumps are used to produce high vacuum in the chamber of the cyclotron, and turbomolecular pumps serve to produce high vacuum in the external injection channel and beam lines.

The power supply system is based mainly on standard equipment produced by the Bruker and Glassman firms.

All the systems of the cyclotrons are controlled automatically by an operator. The system of automated control consists of an operator's workstation and a control rack.

REFERENCES

[1] P.V. Bogdanov, I.N. Vasilchenko, O.L. Veresov et al., "New compact cyclotron CC-18/9 designed and manufactured in NIIEFA", RuPAC-2006, Novosibirsk, September 2006; http://www.JACoW.org.