NEW COMPACT CYCLOTRON CC-18/9 DESIGNED AND MANUFACTURED IN NIIEFA

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Abstract

In the paper is presented a brief description of a cyclotron providing the acceleration of negative hydrogen and deuterium ions to energies of 18 and 9 MeV respectively. The cyclotron is intended to produce short-lived and ultra short-lived radio isotopes. The beam is extracted by charge-exchange of ions by stripping foils. The specific feature of the machine is location of the resonance system inside the vacuum chamber of a shielding-type magnet as well as the vertical position of the median plate of the magnet. The cyclotron has a beamline to transport the beam to remote targets. Two such machines have been manufactured and put into operation: one cyclotron is operated in the PET center of Turku, Finland and the other is functioning in the medical center in Pesochnaya in St.Petersburg, Russia.

Nowadays cyclotrons are mainly applied to produce radionuclides for medicine. A compact cyclotron CC-18/9 has been designed in the D.V. Efremov Institute to produce both short-lived radio-isotopes (Ga-67, Rb-81 and In-111, I-123) and ultra short-lived radio-isotopes (C-11, N-13, O-15 and F-18). The machine ensures the acceleration of negative hydrogen and deuterium ions up to 18 and 9 MeV and extraction of accelerated beams of protons and deuterons practically without losses by using carbon foils (strippers).

The major parameters of the accelerator are given in Table 1.

The general view of the cyclotron is given on photo 1.

A shielding-type magnet with the vertical position of the median plane and four-sector elements forming the isochronous field were used in the cyclotron. The gaps in the "hill" and "valley" were 27 and 118 mm respectively. Movable shims were installed in special recesses made inside hills to correct the "shape" of the field and to ensure the isochronous field when changing the type of ions accelerated. The vacuum chamber of the machine consists of a casing and two covers. The casing of the chamber is a hollow thick-wall cylinder made of carbon steel; it is simultaneously a part of the iron core. The pole shoes of the magnet with the stainless steel flanges welded to them serve as the covers for the vacuum chamber, which ensures the necessary mechanical strength of the vacuum chamber and forms a certain collector to facilitate its pumping [1]. To have easy access to the in-chamber components, an electromechanically operated device with a reducer is provided for to move away the moving part of the magnet along its guides to a distance of 800 mm.

Table 1: Major parameters

System, parameter	Characteristics, value
1. Type of accelerated particles	H^-, D^-
2. Type of extracted particles	H^+, D^+
3. Particle energy, fixed, MeV	18/9 resp.
4. Extracted beam current, μA	100/50 resp.
5. Magnet:	shielding-type
- iron core diameter, см	200
- pole diameter, cm	115
- mass, t	20
- average field at the final radius,	1.253
T	7
- supply power, kW	
6. Resonance system:	38.2
- operating frequency, MHz	2
- dee number	35
- RF-voltage amplitude, kV	
7. External injection system:	multi-pole
- source type	18.4/9.2
- ion energy, H^-/D^-, keV	1/0.5
- beam current, mA	60
8. Total power consumed, kW	
9. Cooling water (distilled) flow	5.5
rate, m^3/hour	

Figure 1: The CC-18/9 cyclotron with the external injection system.

Photo 2 shows the magnet with its parts moved apart. One can see the open vacuum chamber with the resonance system. In the left part of the photo one can see the beam transport system.

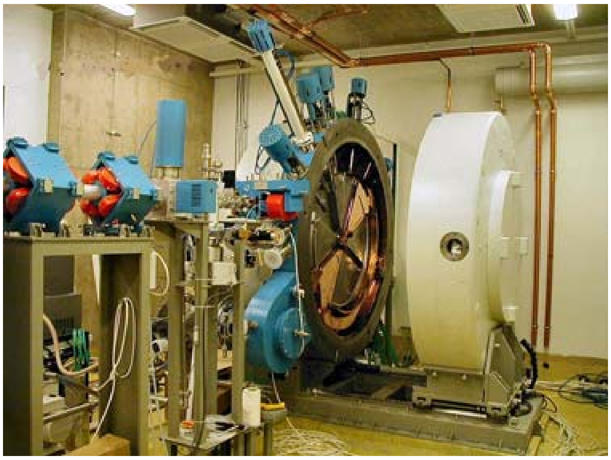

Figure 2: The CC-18/9 cyclotron with the open vacuum chamber.

The resonance system is a distributed resonator, the central conductor of which consists of two dees and two stems, which are mirror symmetrical and have a common part near to the shorting flange; the dees located in the vicinity of the magnet are halvanically coupled with a crossbar [2]. The resonator is located completely inside the vacuum chamber and fixed to the side surface of its body. It is equipped with a capacitor intended for frequency tuning, an AFT trimmer and a double-electrode RF-probe. The power of ohmic RF loss is less than 12 kW.

The RF power supply system consists of a control and stabilization block and an RF power amplifier. The control and stabilization block is intended to generate a sinusoidal signal with an operating frequency, to implement the operating mode (either continuous or pulse mode with a preset duty cycle), to control, measure and stabilize the amplitude of accelerating voltage, to tune and automatically stabilize the frequency of the resonance system.

The 25A38CP RF power amplifier (produced by PLC RIMR, the “TIRA” corporation) is located in the common rack with an individual power supply system. A coaxial feeder is used to transfer the power from the amplifier to the resonance system.

The external injection system consists of a source of negative ions, a vacuum chamber, two correcting magnets, a solenoid, a buncher with an RF power supply block, an electrostatic lens and a helical inflector as well as blocks of power and gas supply [3].

Beams of protons and deuterons are extracted through three windows made in the vacuum chamber**.** Two of these windows serve to install targets directly onto the magnet, and through the third window the beams are transported to remote targets.

A cryogenic and three turbo-molecular pumps are used for high-vacuum pumping.

The power supply system is based on standard blocks produced by the Bruker, Glassman и Xantrex firms.

The automated control system of distributed type is made on the basis of the programmable logic controller PLC (Mitsubishi); the PROFIBUS and ETHERNET interfaces are used to transfer data. The interactive menu of the PC Pentium-4 computer allows all the systems of the cyclotrons to be automatically controlled and necessary information to be displayed either automatically or by an operator choice. The chosen configuration ensures the real-time operation of the control system, allows fast data exchange between components of the system and displaying necessary information on the monitor. The interlock system is an integral part of the automated control system; it uses the same PLC and so no additional equipment is needed.

By now, two CC-18/9 cyclotrons have been delivered to customers and put into operation: one machine is now operated in the PET center of Turku, Finland and the other is functioning in the medical center in Pesochnaya, St.Petersburg, Russia.

The cyclotrons differ in the beam transport systems, namely: the first machine uses four remote targets and the second machine employs three remote targets.

Below are presented the results obtained when putting the cyclotron into operation in the PET centre in Turku, Finland. Preliminary tests were carried out in the pulse mode with DC = 0.1. The results are given below in table 2.

Table 2: The results of CC-18/9 cyclotron preliminary tests, PET centre in Turku

Operating mode	**Discharge current, A**	**Extraction potential, kV**	**Injector current, mA**	**Average current on internal target, μA**	**Efficiency of particles' capture in the acceleration mode, %**
Hydrogen, buncher is off	15	1.4	1.0	7.8	7.8
Hydrogen, buncher is on	15	1.4	1.0	15.6	15.6
Deuterium, buncher is off	14	1.26	0.5	4.25	8.5
Deuterium, buncher is on	14	1.26	0.5	6.44	12.9

Under tests, the beams of protons and deuterons were transported to each of four remote targets (approximately 6 m) in the continuous mode with the buncher on. The current of the beam of protons having passed a collimator of diameter 10 mm was 118 μA; corresponding current of the deuteron beam was 51 μA.

Simultaneous irradiation of two targets, if necessary, has been demonstrated. The proton beam currents were 2.78 μA (close target) and 3.15 μA 9 (remote target) at DC = 0.05.

It should be noted that the relationship of currents on targets can be varied over a wide range by moving the stripper (carbon foil) the first on the path of the beam.

Successful putting into operation of two practically identical cyclotrons CC-18/9 allows the small-scale production of specialized cyclotrons for PET centers to be realized.

REFERENCES

[1] P.V. Bogdanov, A.A. Budtov, V.G. Mudrolubov, A.V. Popov, Yu.I. Stogov, “The MGC-30 multipurpose compact cyclotron”, Proceedings of the XVIIth International Conference “Charged Particle Accelerators”, Protvino, October 2000.

[2] M.F. Vorogushin, P.V. Bogdanov, V.G. Mudrolubov, Yu.V. Smirnov, “Compact Accelerating System for Cyclotrons”, Proceedings of the XVth International Conference “Charged Particle Accelerators”, Protvino, 1996.

[3] O.L. Veresov, S.V. Grigorenko, A.V. Sidorov, A.P. Strokach, S.Yu. Udovichenko, M.S. Fomin, S.S. Tsygankov, “External Injection System for Negative H^-/D^- ions on the CC-18/9 cyclotron”, Proceedings of the XIth International Conference ICAA’05, St.Petersburg, October 2005