APPLIED CYCLOTRONS DEVELOPED AND CONSTRUCTED IN NIIEFA

V.A.Glukhikh, Yu.P.Vakhrushin, M.F.Vorogushin

D.V.Efremov Scientific Research Institute of Electrophysical Apparatus, USSR, Leningrad

ABSTRACT

Brief description and the main parameters of four types of applied cyclotrons, developed in NIIEFA, are given. Possible fields of their application, manufacturing and delivery are considered. The advantages of the complex on the base of the cyclotrons unified technological series are shown.

Applied cyclotrons are being developed and constructed in D.V.Efremov Institute in accordance with the technological series /I/ composed basing on the analysis of the most important fields of their application and taking into account physical processes occuring at the accelerated ions-target material interaction. Defining the parameters of the particular cyclotron type, comprising the abovesaid technological series, not only the beam energy and intensity required in order that the nuclear reaction proceed with the necessary cross-section, but also the target specific features, cost of the accelerator main equipment and the building itself were taken into account. The development of the accelerators technological series was aimed at the cyclotrons equipment unification, use of the advantages given by the present-day module principle of the electrophysical apparatus designing, compactness, high efficiency, safe and reliable operation and the machine control simplicity requirements.

The main parameters of isochronous cyclotrons of the technological series designed in NIIEFA are given in the Table.

Cyclotron DC - is a compact cyclotron for acceleration of deuterons up to 3 MeV fixed energy at outer beam intensity 100mkA and also the doubly-charged helium and molecular hydrogen ions up to 1.5 MeV/nucleon energy. The cyclotron was put into operation in 1987 and is used for activation analysis of low concentration light elements (boron, carbon, nitrogen, etc) in heavy materials matrices.

The cyclotron is compact due to shielding-type electromagnet, simultaneously intended for shaping the vacuum chamber volume. The cyclotron overall dimensions permit its installation in 4x5 m^2 shielded room and the electric power supply and control system in 12 m^2 room.

Cyclotron MGC - small-size cyclotron for the hydrogen ions, deutrons, helium-3 and helium-4 acceleration in the energy range from 5 to 20 Z^2/A MeV with the intensity of the beam on the inner target up to 300mkA and on the outer - 100mkA. This cyclotron is used in the experimental investigations on nuclear physics, study of the structural materials radiation strength and the machine details wearing processes and also for the production of short-lived isotopes for medical purposes and beam therapy /2/.

These accelerators are in a great demand due to the appropriate choice of parameters, their compactness and efficiency. Nowadays 7 cyclotron prototypes have been manufactured and delivered to the scientific centres in the USSR and abroad. The contracts for delivery of some more cyclotrons are being negotiated.

To locate MGC-cyclotron with its power supply and control systems, 80 m^2 - area is necessary. The beam distributed transport ports are complemented with the NIIEFA -developed unified quadrupole lenses, 45° - bending magnets, 115° - analyzing magnets with 0.1% energy resolution and, if

necessary, special scattering chamber for investigations in the nuclear physics field.

Cyclotron RIC is aimed at protons acceleration up to 30 MeV at the beam intensity on the inner target 1500mkA and up to 200mkA on the outer one.

The cyclotron comprises "shielding" type electromagnet which reduces the residual radiation background in the shielded room, improves the vacuum chamber construction and the accelerator general layout. For more convenient maintenance and repair the upper grider can be lifted hydraulically.

The ion source with the "hot" cathode is axially introduced into the chamber, the separate locking of the filament and the source in the process of maintenance is provided. Rf-system comprises quarter-wavelength resonance line and the amplifier, the final stage of which is attached directly to the resonator, being its loop. The extraction system involves the electrostatic deflector with 40° angle and radially focusing magnet channel. Three probes are provided which are used to define the amplitude of the beam radial and vertical oscillations and also the orbits are centered in the process of acceleration.

In case of the maximum power beam on the inner target (30-35 KW) the mode of "non-centered" orbits acceleration is introduced, what means resonance excitation of the radial coherent oscillations in the centre of the machine using the harmonic coils. Simultaneously with the increased (up to 4 cm) beam vertical dimension on the target and inclination of the irradiated surface to the axial trajectory the abovesaid mode permits to obtain the beam cross-section on the target up to 40-50 cm^2 what improves the machine heat regime.

Nowadays, the physical start-up of the cyclotron mainly aimed at commercial production of the broad set of radionuclides (cobalt-57, gallium-67, cadmium-109, thallium-201 and so on) has been realized.

Cyclotron U-250 is meant for ions acceleration in A/Z range from 3 to 12 with the maximum energy 200 Z^2/A^2 MeV and intensity of the order of 10^{13} - 10^{14} particles/s /3/. It will make possible the experimental investigations in the field of the nuclei interaction and fission, radiation material study and also to solve the problem on obtaining the microporous nuclear filters, realization of the deep layer-by-layer implantation of ions into the different substances including the monocrystals.

This cyclotron is designed on the base of H-shaped electromagnet, whose poles are the tapered cones with 270 cm diameter in the place of their attachment to the grider. The magnet comprises 4 pairs of the sectors with 45° angles. The required radial profile of the magnetic field is formed due to the sectors thickness radial change. The air gap in the hill varies from 4.6 cm in the centre to 2.6 cm at the pole edge. Regulations of the field isochronous dependencies is performed by 10 pairs of the concentric coils, located on the positioning coils under the sections. Two groups of the harmonic coils located in the valleys are intended for correction of the lower harmonics of the magnetic field azimuthal nonuniformity.

The head of an axial ion source is 6 cm shifted relatively the pole center and is introduced into the accelerator zone through the hole in the ferromagnetic "plug". The head position is remotely regulated in the limits ± 1.5 cm for the beam centering in case of the ion type change.

The accelerating system with the panel resonators is used in the cyclotron. Two dees with 42° angles are located in the opposite valleys. Rf-power is fed by conductive coupling from the rf-amplifier final stage, located directly near the resonator tank.

For beam extraction the electrostatic deflector and magnetic channel are provided alongside with the stripping foil. The pumps total production capacity is 12000 l/s to obtain the necessary vacuum 10^{-6} mm of Hg.

At present the cyclotron prototype equipment is being manufactured in NIIEFA. The authors hope that it will be widely used both in our country and abroad.

In conclusion we should say that construction of the cyclotron-based accelerating complexes permits broad unification of the units and systems, promotes shorter time for the accelerator manufacturing and putting into operation and also reduces their investment and operating cost.

Cyclotron main parameters

Cyclotron type Parameter	DC	MGC
Energy, MeV	$6\frac{Z^2}{A}$	$(5\text{-}20)\frac{Z^2}{A}$
Particles type	protons deuterons	protons deuterons Helium-3
Outer beam intensity,mkA	100	50-1500
Electromagnet	shielding-type	H-shaped
Pole diameter,m	60	103
Field strength, T	1.4	0.7-1.45
Dee angle,degrees	180	180-140
Aperture, cm	2.9	1.9
Voltage, kV	25	30
Frequencies range, MHz	10.7	8.5-26
Rf-power, kW	6	50
Cyclotron weight, t	7	27
Electrical power consumption,kVA	50	170

Cyclotron type Parameter	RIC	U-250
Energy, MeV	30	$200\frac{Z^2}{A}$
Particles type	protons	heavy ions
Outer beam intensity,mkA	1500	$10^{13} - 10^{14}$
Electromagnet	shielding-type	H-shaped
Pole diameter,m	150	250
Field strength,T	1.15	1.9
Dee angle degrees	180	42
Aperture, cm	5.0	3.0
Voltage, kV	50	100
Frequencies range, MHz	17.3	8-19
Rf-power, kW	100	200
Cyclotron weight,t	90	450
Electrical power consumption, kVA	380	800

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