



THE DUBNA 4-METER ISOCHRONOUS HEAVY ION CYCLOTRON

G. Flerov

► To cite this version:

G. Flerov. THE DUBNA 4-METER ISOCHRONOUS HEAVY ION CYCLOTRON. Journal de Physique Colloques, 1976, 37 (C5), pp.C5-233-C5-235. 10.1051/jphyscol:1976516 . jpa-00216596

HAL Id: jpa-00216596

<https://hal.science/jpa-00216596>

Submitted on 4 Feb 2008

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

THE DUBNA 4-METER ISOCHRONOUS HEAVY ION CYCLOTRON

G.N. Flerov

Joint Institute for Nuclear Research, Dubna, USSR

The U-400 Heavy Ion Cyclotron currently under construction at the JINR Laboratory of Nuclear Reactions is a development of the technique of acceleration of multiply-charged ions used in this Laboratory. The principal Laboratory accelerator (the U-300) is a classical cyclotron with a pole diameter of 310 cm, which is used to carry out numerous experiments in different fields of nuclear physics. This cyclotron provides acceleration of $^{11}\text{B}^{2+}$, $^{12}\text{C}^{2+}$, $^{14}\text{N}^{2+}$, $^{15}\text{N}^{3+}$, $^{16,18}\text{O}^{3+}$, $^{20,22}\text{Ne}^{4+}$, $^{28}\text{Si}^{5+}$, $^{31}\text{P}^{5+}$ and $^{40}\text{Ar}^{6,7,8+}$ ions with the A/q parameter of 5 to 7, where A is the mass number and q is the charge of the ion accelerated. The energy of the accelerated ions is equal to $E = 250 q^2/A$ MeV. An improvement made to the available multiply-charged ion source has furnished acceleration of $^{48}\text{Ca}^{7+}$, $^{48,50}\text{Ti}^{7,8+}$, $^{51}\text{V}^{8+}$, $^{54}\text{Cr}^{8+}$, $^{56,58}\text{Fe}^{9+}$ and $^{64,66,68}\text{Zn}^{10+}$ ions with intensities of 10^{12} to 10^{10} particles/sec to an energy above the Coulomb barrier.

Since 1968 the U-200 Isochronous Heavy Ion Cyclotron with a pole diameter of 200 cm has been in operation. The ion energy at this cyclotron is defined by the formula $E = 156 q^2/A$ MeV.

By using the tandem system of the U-300 and the U-200 Cyclotrons we succeeded in producing germanium, krypton and xenon beams with an energy of 7.5 MeV/nucleon and an intensity of about 5×10^{10} part/sec.

During the recent years the Laboratory of Nuclear Reactions Cyclotrons have been operated under limiting conditions and could not provide a higher intensity or the possibility of accelerating the heavier ions. Therefore it has been decided to make a 4-meter cyclotron similar to the 2-meter isochronous cyclotron. Primarily it was intended to construct a cyclotron with a pole diameter of 400 cm by modifying the existing U-300 Cyclotron. In particular, it was supposed to increase the pole diameter, to introduce the azimuthal variation of the magnetic field and to increase its induction to 2 T. However, the large experimental programme on the synthesis

and investigation of new elements in the Laboratory has not allowed to shut down the U-300 Cyclotron for reconstruction. It has been decided to create the U-400 Cyclotron by making use of the main assemblies already manufactured for the U-300, such as the electromagnet pole tips, the vacuum chamber, sectors, r.f. resonators, etc. Other units including the electromagnet had to be manufactured anew.

The 1770 ton electromagnet yoke of the proposed cyclotron is being assembled from separate steel sheets directly in the cyclotron hall. The diameters of the electromagnet pole and the pole tips serving as the top and bottom walls of the vacuum chamber are equal to 400 cm. The gap between the pole tips is 30 cm. The full radius of acceleration is 180 cm. The main recoil of the electromagnet contains twice 224 windings of aluminium conductor with a $53 \times 53 \text{ mm}^2$ cross section and an internal channel 34 mm in diameter for water cooling. With an excitation current of 2200–2500 A in the coil the magnetic field in the centre is equal to 2.15 T. The stability of the current in the main coils is 5×10^{-5} .

The magnetic field azimuthal variation is furnished by four pairs of spiral sectors with a sector angle of 45° . The spiral maximum angle is equal to 30° . The sectors have a variable height from 9.5 cm in the centre to 11 cm on the periphery and are mounted on the pole tips on gaskets with a 1.8 cm gap. Thus the hill and valley gaps are equal to 4.4–7.4 cm and 30 cm, respectively.

Isochronous magnetic field is provided by a variable height of the sectors and by ten pairs of circular trimming coils placed in the gap between the sectors and the pole tips. Each coil has three turns of water-cooled copper conductor. The insulation of the windings is furnished by glass fibre filled with epoxy compound.

The azimuthal harmonics of the magnetic field are adjusted by coils mounted in two valleys.

The measurements of the magnetic field of the future U-400 accelerator have been carried out on a model half of its natural size. The radial distribution of the magnetic field, whose magnitude in the centre is 2.15 T, and which is formed only by the sectors, differs from the field required for the isochronous acceleration of ions to an energy of 10 MeV/nucleon by not more than 0.005 T. The flutter of the magnetic field determined as

$$|\langle B^2 \rangle - \langle B \rangle^2| / \langle B \rangle^2$$

is 0.055 in this case. With a magnetic field of 1.8 T isochronism is provided for the ion acceleration to an energy of 50-60 MeV/nucleon. In this case the magnetic field flutter is equal to 0.10.

To accelerate particles at the U-400 Cyclotron, two dees are used with a dee angle of 45° , which are placed in the opposite valleys where azimuthal trimming coils are absent.

The range of the r.f. system is 6 to 12 MHz, which provides the possibility of accelerating ions from A/q of 3 to 12 on the first-fifth harmonics of the accelerating voltage. The coarse adjustment of the high frequency of the accelerating voltage is provided by moving the shorting plane of the resonance system.

The U-400 Cyclotron will use the same type of ion source as that employed successfully at the available Laboratory cyclotrons. This ion source is an arc one with radial ion extraction. It is inserted through the upper vertical channel 20 cm in diameter made in the magnet yoke and the pole tip. The ion source can be replaced through the vacuum lock without destroying the vacuum. In the future it is intended to substitute the internal ion source by an external one.

To decrease ion losses during acceleration due to the stripping of the atoms of the residual gas, high vacuum is required. Estimates indicate that for a 30% decrease the gas pressure in the chamber should be 1×10^{-4} Pa. It is supposed that such vacuum may be produced by seven diffusion oil pumps of the BA-8-7 type, connected in series with booster pumps of the BH-3 type, with a total pumping speed of 28000 liters per second. The results of testing the chamber and the r.f. resonators of the cyclotron have confirmed the possibility of obtaining a pressure of below 1×10^{-4} Pa in the U-400 cyclotron. In the future it is supposed to combine the cryo-

genic and diffusion pumping of the accelerator chamber to obtain a pressure of 3×10^{-5} Pa of the residual gas. To improve the vacuum in the central part of the accelerator chamber an additional pumping of the working gas through the bottom vertical channel in the electromagnet yoke is possible.

To extract the ion beam from the cyclotron chamber, a method of ion beam extraction by stripping, developed and used at the U-200 cyclotron will be employed. The main idea of this method is that after passing through a thin stripper placed on the boundary between the valley and the hill, the ions increase their charge and this leads to a change in the ion trajectory and to their release from the cyclotron chamber. The peculiar feature of the method is that after passing through the stripper the ions have a spectrum of charges, e.g. during the acceleration of $^{40}\text{Ar}^{5+}$ ions one will be able to extract three separate argon beams with charges of 16+ (15%), 17+ (46%) and 18+ (37%) and use them simultaneously in different experiments. The total intensity of all the three beams extracted will amount to approximately 100% of the internal beam intensity. An automatic replacement of the carbon foil stripper $40\text{-}60 \mu\text{g}/\text{cm}^2$ thick will be provided. The horizontal and vertical emittances of external beams will be 40 and 20 mm mrad, respectively.

A total of 6 ion beams will be extracted from the U-400 cyclotron chamber in two opposite directions. The beams extracted will be divided in the horizontal plane by septum magnets.

The median plane of the U-400 cyclotron magnet is 4 meters above the floor. At this level it is intended to carry out work with relatively light experimental devices. Beam transport to a level of 1.3 m above the floor is also foreseen to work with heavy and bulky experimental apparatus. The beam lowering will be achieved by electromagnets with $BR = 1.2 \text{ T}\cdot\text{m}$ and a deflection angle of 90° . The total number of channels is 12.

At the U-400 heavy ion cyclotron a great variety of ions with the A/q values indicated above will be accelerated. The main range of the mass numbers of the accelerated ions is $20 \leq A \leq 140$. In addition, in some experiments there will be a possibility of accelerating ions of adjacent mass numbers, e.g. $12 \leq A \leq 20$ and $140 \leq A \leq 240$. The ions of the main range are supposed to be accelerated to an energy of about 10 MeV/nucleon. The ion energy is determined by the

relation $E=725 q^2/A$ MeV. Relatively light ions such as carbon to neon can be accelerated to an energy of 50-60 MeV/nucleon.

The beam intensity at an ion energy of 10 MeV/

nucleon will amount to about 10^{14} part/sec at $20 \leq A \leq 80$ and to $10^{11}-10^{12}$ part/sec at $80 \leq A \leq 140$. Some of the ions to be accelerated at the U-400 cyclotron are listed:

Ion	$^{20}\text{Ne}^{2+}$	$^{40}\text{Ar}^{4+}$	$^{48}\text{Ti}^{5+}$	$^{51}\text{V}^{6+}$	$^{58}\text{Fe}^{6+}$	$^{84}\text{Kr}^{9+}$	$^{136}\text{Xe}^{13+}$
E/A	7.2	7.2	7.9	10.0	7.8	8.3	6.6 MeV/nucleon.