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ФИЗИКА И ТЕХНИКА УСКОРИТЕЛЕЙ

POSITRON EMISSION ISOTOPE PRODUCTION CYCLOTRON AT DLNP JINR (STATUS REPORT)

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A C10 cyclotron for radioisotope production is under construction at DLNP JINR. It is a compact isochronous cyclotron for H^- ions acceleration to the energy of about 10 MeV. Magnetic system, vacuum chamber and accelerating system are under fabrication now. Results of the calculation and forming of the cyclotron magnetic field and study of the beam dynamics from an ion source to an extraction system in calculated magnetic field are presented.

В Лаборатории ядерных проблем им. В. П. Джелепова Объединенного института ядерных исследований создается циклотрон Ц-10 для производства позитрон-эмиссионных изотопов. Ускоритель представляет собой компактный изохронный циклотрон для ускорения H^--ионов до энергии ~ 10 МэВ. Магнитная, ускоряющая системы и вакуумная камера в настоящее время находятся в производстве. Представлены результаты расчета магнитного поля циклотрона и характеристики динамики движения и вывода пучка в полученном магнитном поле.

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INTRODUCTION

C10 cyclotron is under construction at DLNP JINR on a basis of Ш-shape magnet. The main parameters of this machine are presented in the Table together with the characteristics of the other cyclotrons in the same energy range.

The C10 cyclotron based on a compact magnet with increased power consumption provides enough large energy of the accelerated protons to produce the positron emission isotopes.

MAGNETIC SYSTEM

The magnetic system of C10 cyclotron consists of Ш-shape magnet with a diameter of poles 640 mm, gap between poles is (130 ± 0.03) mm. The main coils are located on the poles of the magnet and consist of five two-layer pancakes, with 10 turns in each layer. The conductor is a copper wire of a rectangular 8.5×8.5 mm cross section with 5 mm

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The basic parameters of C10 cyclotron and some similar accelerators

Parameter	C10-L IBA, Belgium	RDS111 CTI, USA	C10 JINR, Russia	CC18/9 Efremov SRIEPA, Russia
Energy H^- (D^-), MeV	11	11	10	12–18 (6–9)
Current of H^- (D^-) beam, μA	70	100	60	100 (50)
Numbers of sectors	4	4	4	4
Form of sectors	Straight	Straight	Extending	Straight
Average field, kG	13	11.7	14.45	12.5
Field in hill/valley, kG	19/4	19/4	21/9	19/7
Gap in hill/valley, mm	30/800	15/400	20/70	27/118
Diameter of pole, mm	760	900	640	1150
Span of sector, °	54	56	30–42	46.3
Coil current, A·turns	112 000	51 000	60 000	
Power consumption, kW	17	22	24	7
Weight of a magnet, t	12	10	6	20
Frequencies HF H^- (D^-), MHz	42	72	44.36	38.2
Number of dees	2	4	2	2
Harmonic of acceleration	2	4	2	2(4)
Dee voltage, kV	32	30	50	35
Angular width of dee, °	30	30	30	30
RF power, kW	10	10	12	25

hole for cooling water. The isolation is made from fiber glass fabric and epoxy resin. All ferromagnetic elements of the magnet are made of steel ST-10. The general view of the cyclotron is shown in Fig. 1.

In the gap of the magnet the vacuum chamber is restricted from top and bottom by the steel pole disks of 30 mm thick and 320 mm radius. The rings from non-magnetic material are welded to these disks, which together with the vertical cylinder made from stainless steel form a vacuum volume. In the vacuum chamber in the gap of a magnet (h_m = 70 mm) there are four pairs of sector shims with thickness of 25 mm. The sectors begin from radius of 31.5 mm and have azimuth extension 30° in the central area and up to 42° at final radius. They are used to form growing isochronous magnetic field. A gap in the hill is 20 mm. Dependence of the calculated average magnetic field via radius is presented in Fig. 2.

For realization of the assembly and arrangement works a top of the magnet together with the coil and top-cover of the chamber can be lifted. To achieve a high accuracy of the magnet gap and parallelism of the poles, all details connected in horizontal plane of the magnet are groaned.

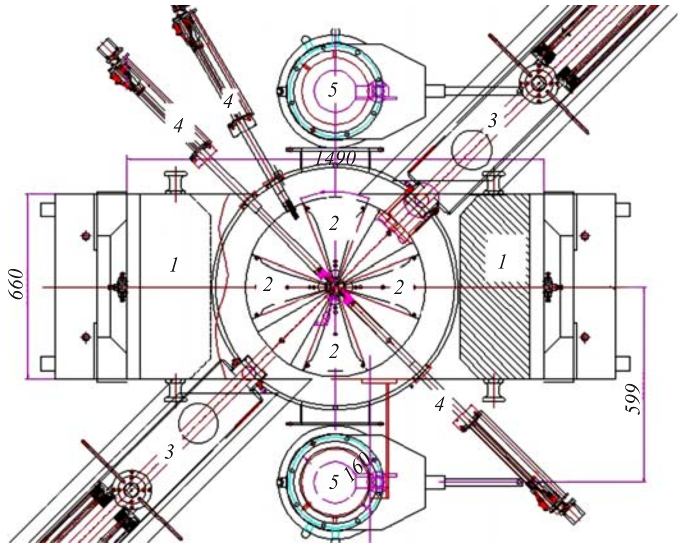

Fig. 1. Plane view of the cyclotron: *1* — yoke; *2* — sectors; *3* — resonators with dees; *4* — probes; *5* — high vacuum pump

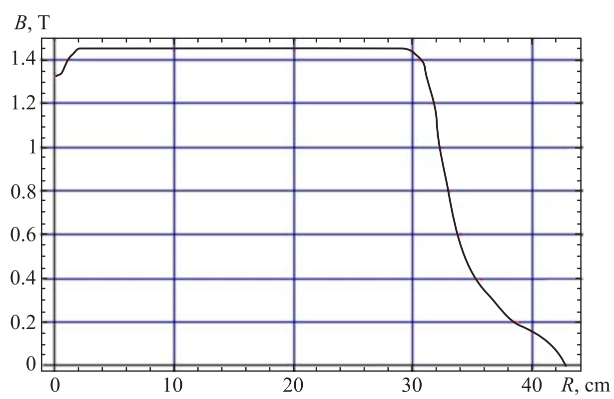

Fig. 2. Calculated average magnetic field of the cyclotron

A simulation of the magnetic system was carried out by 3-dimentional code. The results of the beam dynamics in the calculated magnetic field are presented below.

ACCELERATING SYSTEM

The accelerating system is located in two opposite valleys of the magnet and occupies $45°$ in azimuth and 70 mm in height. The dees are placed on the rods mounted to the end of a resonant line, where the electrical contacts for adjustment of own frequency of the line are located. The dees have azimuth extension $30°$. The second harmonic of acceleration was chosen due to angular span of the dees and 40 MHz RF-frequency generator. The arrangement of accelerating system is also shown in Fig. 1. The distribution of an accelerating voltage along radius in an accelerating range was calculated by 3-dimensional code and composes ~ 50 kV.

CYCLOTRON CENTRAL REGION

The central region of cyclotron and two first turns of a beam acceleration are shown in Fig. 6. The ion source is located so as the centre of its hole is on 21 mm radius. The central steel plug is used for providing the required magnetic field without the first harmonic.

BEAM DYNAMYCS

Magnetic Field Map Analysis. Closed orbit analysis [1] was used to define the focusing properties of the magnetic system. Frequencies of free betatron oscillations are shown in Fig. 3. There is focusing in both vertical and radial directions in the magnetic field map used.

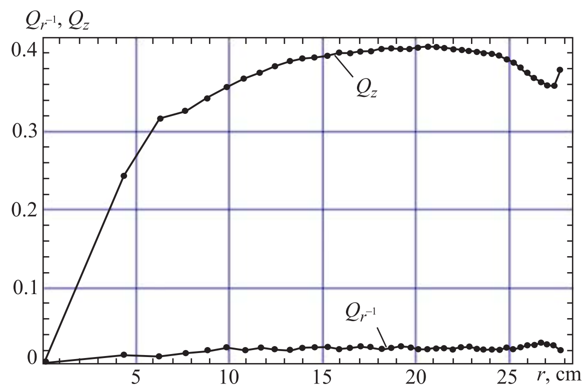

Fig. 3. Frequencies of betatron oscillations

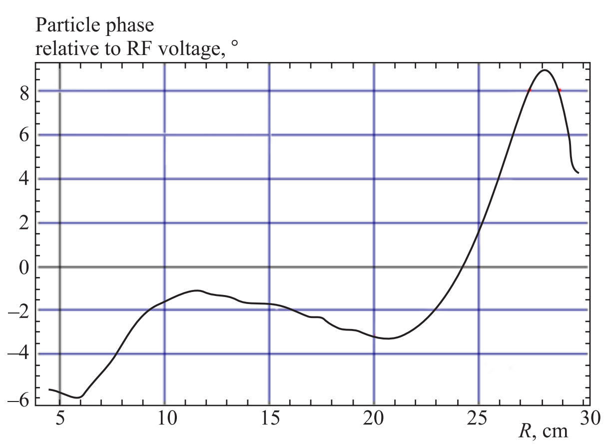

Fig. 4. Phase motion of the equilibrium particle

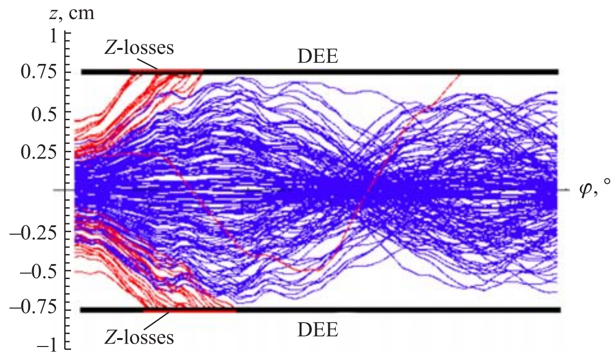

Fig. 5. Axial motion of 200 particles during the first 3 turns

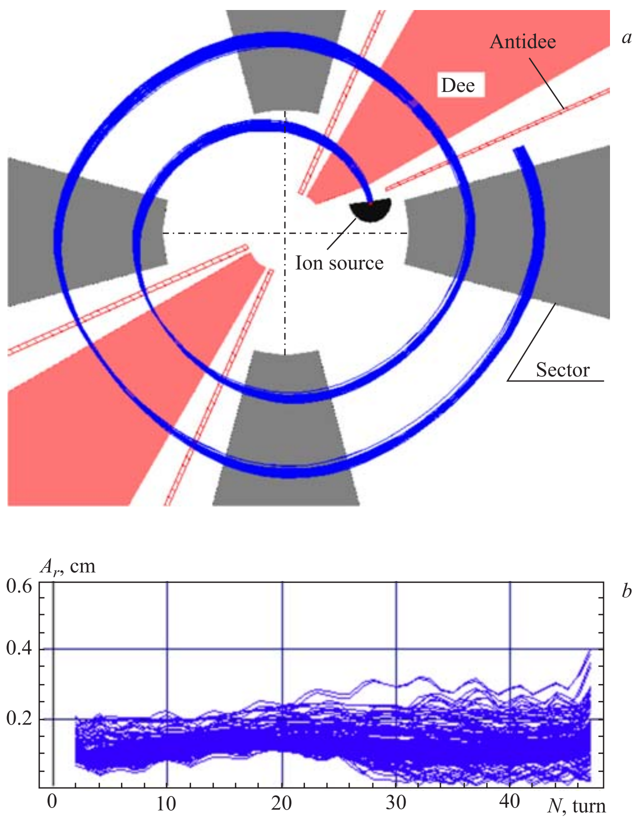

Fig. 6. *a*) Plane view of the cyclotron centre — motion of particles during the first 2 turns. *b*) Radial amplitudes of 200 particles

Acceleration in the Main Region. An «equilibrium-accelerated» particle (which has the amplitude of free radial oscillations 1 mm or less) was found by selection of the optimal starting position in the $(r,\ p_r)$ phase plane, initial phase relative to RF voltage, value of the gap between the ion source and the puller, and the angle between the ion source and the axis of symmetry of the cyclotron. Phase motion of this particle is presented in Fig. 4.

Fig. 7. View of magnetic system for this moment

One can see from Fig. 4 that the phase of particle lies in $\pm 10^\circ$ interval relatively to RF voltage, which means good agreement between the magnetic field used and the isochronous one.

Then, a bunch of 1000 particles normally distributed in the (r, p_r) and (z, p_z) phase plane and uniformly distributed in the (w, RF-phase) plane was generated around the equilibrium particle and accelerated up to the final radii. The vertical and radial size of the bunch and starting angles of particles are specified by the geometry of the ion source hole (supposed to be 1×10 mm), the RF-phase of the bunch equals 20° RF. The results of this simulation are presented in Figs. 5 and 6 (200 particles were taken for more suitable presentation).

There are considerable axial losses during the first turn (24% of particles) which are caused by bad vertical focusing in the central region (the aperture of the dees equals 15 mm in these calculations).

EXTRACTION SYSTEM

An extraction of the beam is made by charge exchange on a carbon foil, which settles down on one of three probes (see Fig. 1). A target for the medical isotopes production is located on a branch pipe of the pump.

CONCLUSIONS

Now the manufacturing of magnetic system is finished. In some months the magnetic field measurements will be executed. In Fig. 7 the magnetic system is seen under construction for this moment, the high frequency generator device is visible on the background view.

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