Deuteron cyclotron complex as meson and neutron generator.

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Abstract

The characteristics of the cyclotron complex for acceleration of deuterons up to the energy of 800 MeV/nucl with beam intensity in the mA range are considered. The complex consists of a RFQ-linac and two superconducting sector cyclotrons. The results choosing parameters and constructing full-scale prototypes of some systems are given.

1 INTRODUCTION

The problem of acceleration of high-intensity particle beams at medium energy in cyclotrons,which are more compact and efficient accelerators in comparison with linear machines, has been studied at the laboratory of Nuclear Problems of JINR for many years. On the basis of this research a proposal to construct a high current cyclotron for acceleration of protons up to the energy of 800 MeV has been presented [1]. Progress in studying $dt\mu^-$ catalysis reactions [2] has opened up new opportunities for practical use of high current beams. That is why we have chosen deuterons to be accelerated in the cyclotron complex. The final purpose of the project is to build a Deuteron Cyclotron Complex (DCC) of energy 800 MeV/nucl with average beam intensity in the milliampere range and as large in size as modern cyclic meson factories. The complex consists of a linear RFQ accelerator-injector and two superconducting sector cyclotrons DC-1 and DC-2 of energy 100 MeV and 1600 MeV respectively. The facility could be used for solving a wide variety of scientific and applied problems such as neutrino physics,generation of intense neutron beams for scientific and power production purposes, creation of high μ^- meson fluxes for using muon catalyzed dt fusion in electronuclear processes [3], high quantity isotope production.

2 CHOICE OF PARAMETERS

The main idea underlying the choice of the DCC parameters was to minimize the dimensions and common power consumptions at the fixed maximal energy per nucleon. Development of superconducting magnets with a high magnetic field [4], progress in decreasing beam losses at acceleration [5] and in designing highly efficient beam extraction systems [6] permits both the maximal energy and the maximal intensity of the cyclotrons to be increased. Magnets with the field strength at the level of 10 T have opened up the opportunity to design a DCC of energy up to 1 GeV /nucl with working radii below 3–4 m.

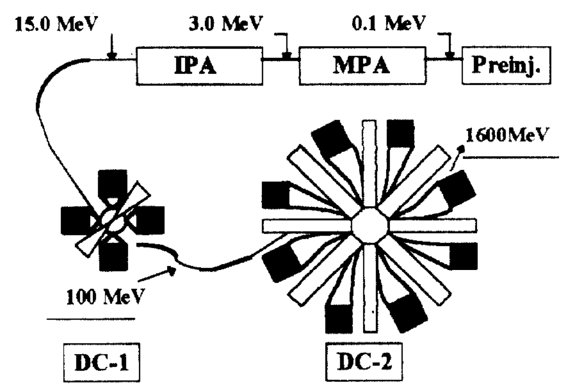

Figure 1: Accelerator layout

Strong focusing has permitted as to consider the accelerated beams with very high space charge [7]. A general view of the DCC is shown schematically in Fig 1 . The main parameters are presented in table 1. The strength of focusing in every element permits acceleration of beams with intensity in the range of 10-th mA. We plan to use the orbit expansion effect in order to increase the turn separation on the radii of injection and extraction. In this case, if beam emittances for two neighbouring turns are completely separated, the extraction efficiency will reach 100%. The experimental studies of the possibilities of the strong focusing and effective orbit separation, which were carried out with the electron model of the relativistic isochronous cyclotron [8] have confirmed the reliability of the theoretical calculations [9,10].

3 MAGNETS

The magnetic field of the circular cyclotrons can be formed with the help of sector superconducting magnets. The phase and transverse stability of the accelerated beam in DC-1 can be achieved with the help of straight sector magnets with convex windings [11], but in DC-2 it is necessary to use spiral magnets. After the first proposal of DCC in 1981 [12] much work has been done on the magnetic system of DC-1 [13]. For DC-1 magnets we have chosen the scheme with a cold iron pole and a c-shaped iron yoke. The winding consists of 8 modules. Superconducting cable NbTi 2×3.5 mm^2 in size with critical current 2000 A at 5 T in the form of double pancakes (6 pancakes in a section) is wound directly on a sction of the iron pole. The

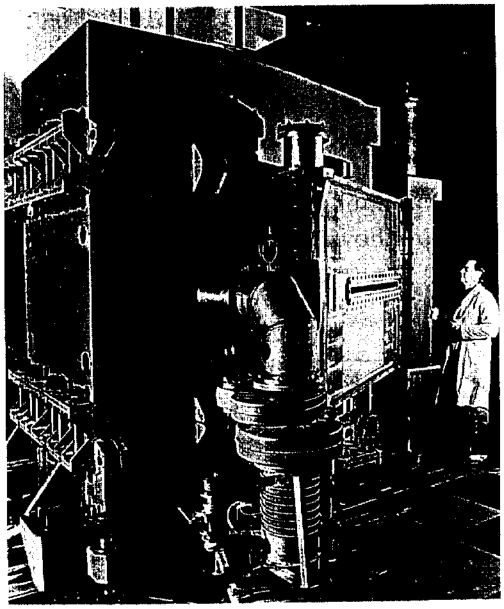

Figure 2: Sector of the DC-1 magnet

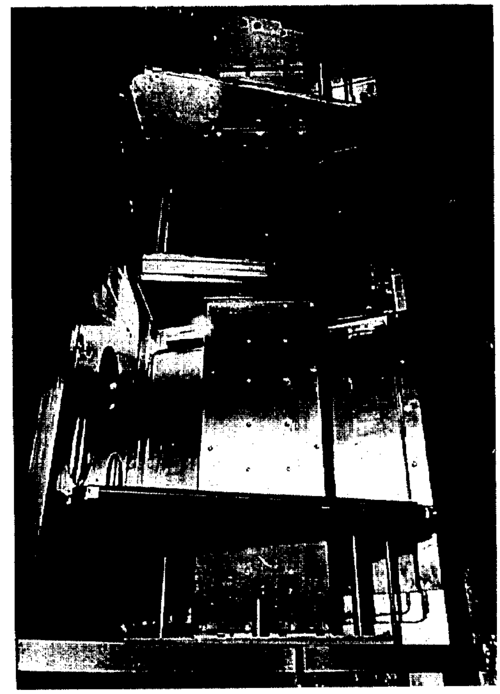

Figure 3: Acceleration resonator of the DC-1 with open side wall

finished sections are put into a double side stainless steel case on both sides and compaunded. The modules are divided into two parts (4 in each) for the upper and lower pole, are installed in the cryostat and cooled down to operating temperature. Two-phase helium circulating in the channels of the case will be used for cooling. For fast heating of the winding after the quench the scheme proposed in [14] will be used. The whole winding will shift to the normal state in t= 0.03 s after switching off the power supply, which ensures uniform heating of the winding up to 80 K. The holes of the special shape in the iron pole will be used for shimming the average magnetic field with a precision $\pm 3 \cdot 10^{-3}$ T. At the present time one of four sector of the DC-1 magnet has been made. It is shown in the photograph of Fig 2. The main parameters of the magnetic systems of the cyclotrons are presented in table 1. Now we continue winding the superconducting coils. Our plan is to start the measurements of the magnetic field at the end of the next year.

4 ACCELERATION SYSTEM

The acceleration system of DC-1 must produce energy gain of 1 MeV/turn for single charged ions. The radius of injection in this high B-field accelerator is quite small and we have chosen a half-wave resonator with a Δ-shaped accelerating electrode as the best system for the maximal energy gain on the internal and external radii of acceleration. The angle of the Δ -electrode (15°) was determined both by the distance between magnets and by the breakdown voltage in the accelerating gap between the radial edges of the Δ -electrode and the protrusions on inner sides of the resonator walls. A prototype of the -resonator has been designed and constructed [15]. Its photograph without a side wall is shown in Fig 3.The resonator is a straight prism with upper and lower base in the form of an isosceles trapezoid. The azimutal size of the resonator is 30°. Movable shorts and a trimmer capacitor (which changes the capasity between the external wall of the Δ - electrode and the resonator) can be used both for tuning and for changing the accelerating voltage distribution. The edges of the electrodes of the acceleration gap have a special shape in order to decrease the electric field strength on the surface [16]. In this case $\frac{E_{max}}{E_0} = 1.135$, where $E_{\max}$ is the maximum field strength on the surface, E_0 is the field in a flat gap. The accelerating voltage distribution has a typical minimum at the radius R=0.6 m. Depending on tuning, $U(R_{\min}) = (0.93 - 0.96) \cdot U(R_{\max})$ and $U_{\min} = (0.82 - 0.86) \cdot U(R_{\max})$ This voltage distribution simplifies beam injection and extraction. The optimal acceleration system for the cyclotron DC-2 is a single gap rectangular resonator with protrusions to form the accelerating field [17]. The experimental data show that protrusions increase the voltage at the beginning of the acceleration gap in comparison with the sinusoidal voltage distribution [18]. This makes it easier to inject particles into the accelerator. The main parameters of the acceleration system are shown in table 1.

5 LINEAR ACCELERATOR-INJECTOR

We have chosen an RFQ linear accelerator as an injector in DC-1. It consists of a 100 keV ion gun , a 3 MeV

Table 1: The main parameters of the Deuteron Cyclotron complex.

Circular cyclotrons	DC-1	DC-2
General characteristics		
Energy of inj./ext., MeV	15/100	100/1600
Radius of inj./ext. R_i/R_e, m	0.47/1.11	1.19/3.21
Number of magnet sectors	4	8
Angle of spirality at R_e,o	0	45
Freq. of radial oscillation	1.22÷1.25	1.11÷2.0
Freq. of axial oscillation	1.13÷1.32	1.39÷1.43
Orbital frequency, MHz	12.375	12.375
Harmonic of acceleration	6	6
Magnets		
Dimensions of sector,m	2×1.2 x 2.8	4×1.4 x 4.8
Weight,tons	30	150
Max./average field at R_e,T	4.26/1.53	8.02/2.95
Supercon./operating temp.K	NbTi/4.2	Nb_3Sn/4.2
Pole gap,cm	14	21.6
Operating current,kA	0.83	5.0
Stored energy,MJ	5	70
Acceleration system		
Number of resonators (gaps per turn)	2/4	8/8
Energy gain per turn,MeV	1	2.4/4.8
Operating frequency,MHz	74.25	74.25
Maximal voltage,kV	300	600
Power loss per resonator,kW	80	200
Linear accelerator-injector	IPA	MPA
Energy of inj./extr.,MeV	0.1/3.0	3.0/15
Maximal beam current,mA	100	100
Normalized emitt.,cm·mrad	$(0.2\div0.4)\pi$	$(0.3\div0.5)\pi$
Operating frequency,MHz	148.5	148.5
Operating voltage,kV	130	290
Power loss,MW	0.48	0.48
Lenght/diameter,m	6/0.6	6/0.5

initial part of the accelerator (IPA) with space-uniform RFQ focusing and the 15 MeV main part of the accelerator (MPA) with space-periodic RFQ-focusing. The operating frequency of the injector is two times larger than in cyclotrons, which leads to decrease in the phase length of the bunches in cyclotrons. The parameters of the accelerator have been chosen on the basis of the experience in design, construction, commissioning and operation of the accelerator-injector for the booster-synchrotron of U- 70 (IHEP, Serpukhov) [19]. A special four chamber resonator [20] will be used as an hf resonant system both in the IPA and MPA. In the IPA acceleration and focusing will be executed in the electromagnetic fielid between the electrodes of the four-wire line. The accelerating component of the electric field will be produced by means of modulation of the distance between single-potential electrodes of the line. In the MPA the quadrupole component of the hf field will be created by means of the protrusions on the edges of the drift tubes. Some characteristics of the accelerator are presented in table 1.

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