THE KIEV 240-CM ISOCHRONOUS CYCLOTRON

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A B S T R A C T

In Nuclear Research Institute of Ukrainian Academy of Sciences in Kiev the construction of 240-cm isochronous cyclotron is being accomplished. The accelerator design is developed by D.V.Efremov Scientific Research Institute of Electrophysical Apparatus in Leningrad. The cyclotron is being in the state of assembly and adjustment. The cyclotron provides for variable-energy protons up to 80 MeV of high beam quality as well as neutron pulses with duration less than two nanosec at pulse rate from 1 kHz to 100 kHz. At joint operation with the designed tandem generator xenon ions can be accelerated up to the energy being higher the Coulomb barrier. In the present paper main data concerning the cyclotron and its main mode operation are described.

INTRODUCTION

The design of 240-cm isochronous cyclotron was developed by D.V.Efremov Scientific Research Institute of Electrophysical Apparatus (Leningrad) in 1966 to order of Nuclear Research Institute of Ukrainian Academy of Science (Kiev). The characteristics of cyclotron design were published in[1÷3]. In 1969-1971 in order to widen the accelerator possibilities its initial design was considerably changed. Magnetic structure of the cyclotron was changed. The ion source, inserted in the accelerating chamber in median plane was replaced by an axial one. For neutron spectrometry a number of new units is designed (pulse deflectors with power supply systems, neutron target and some other), earlier developed designs of central optics of cyclotron and dee were also changed. These and other changes should essentially change the range of nuclear - physical experiments, carried out at 240-cm cyclotron. The accelerator will operate in three relatively independent modes: the mode of constant orbit geometry, neutron pulse source mode and heavy ion acceleration mode. The first mode has high-quality beam (energy resolution is better than 3.10^{-3}, radial emittance, $\pi XX'$, is about 20 mm mrad, longitudinal bunch length is controlled from several degrees to 30÷40°) at the possibility of smooth variation of final energy.

The decreasing of energy spread from 3.10^{-3} up to 2.10^{-4} is possible at using 270° analysing magnet or designed system of active external beam monochromatization (at 50% intensity loss). Induction at beam extraction radius is controlled within 5000-13000 Gs, which corresponds to the energy from ~12 to 80 MeV for the protons. At cyclotron operation in neutron pulsed source mode protons are accelerated to the maximum energy of 100 MeV (with switched valley coil) and deuterons up to 65÷70 MeV (without valley coil). Time duration of ion bunches is less than 1 nsec. In heavy ion acceleration mode induction at external radius can be increased to 17000 Gs which corresponds to maximum ion energy of 140 Z^2/A MeV.

At present accelerator building construction is being ended, assembly and adjustment works of engineering systems are being continued.

1. MAIN CYCLOTRON PARAMETERS

Below a brief description of only essentially changed units of the cyclotron is presented. The beam transport system was described earlier in detail in the paper[2].

a. Magnet. Modelling results

The main criteria of parameters choice of new magnetic structure at its modelling was weak dependence of field map on the level of excitation magnet. To this effect the gap between sectors in the "hill" was left 232 cm and air gap in the valley was decreased from 960 to 532 mm.

To decrease iron saturation effect the sector edges were rounded. Fig.1 shows sector forms and arrangement of valley and harmonic coils.

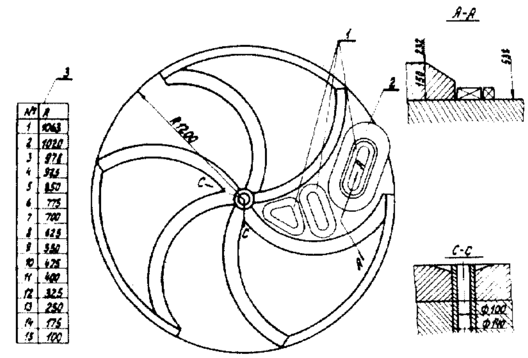

Fig.1
Magnetic structure of the cyclotron:
1 - harmonic coils;
2 - valley coil;
3 - average radii of concentric coils

Fig.2 shows the dependence of the focusing function value F_z near extraction radius on the magnetic field. It is seen, that up to 12000 Gs focusing properties of magnetic structure change little.

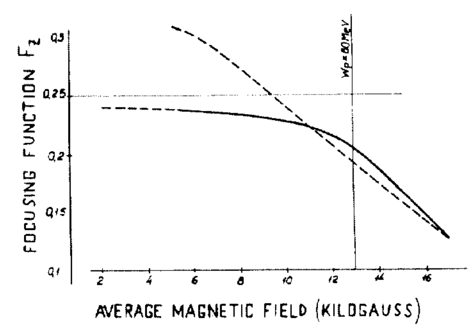

Fig.2. The dependence of focusing function on induction at maximum radius

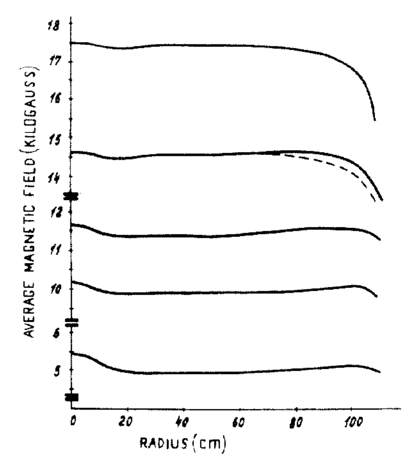

Fig.3 shows the radial dependence of the average magnetic field for several excitation levels. Dotted line shows the average field view at switching valley coil in proton acceleration mode up to 100 MeV.

Fig.3. The dependence of the average magnetic field on radius for different excitation levels of the main magnet coils. The dotted line - proton acceleration mode up to 100 MeV (with switched valley coil).

b. Accelerating chamber (beam injection and extraction system)

At acceleration of protons, deuterons, H_{e4}^{2} and H_{3}^{2} ions a new axial ion source will be used with a number of advantages compared with a radial one: convenient arrangement and fine accuracy of setting in the given position (up to 0.2 mm). Phase bunch selection is carried out by two flag collimators installed beyond the dee. The calculation of initial motion showed, that if it is necessary to obtain the bunches with 5° time duration, the amplitude of non-coherent radial oscillations at the start of acceleration will be less than 1 mm. In bunch acceleration mode with time duration up to 30° the amplitude of radial oscillations will not exceed the value 1 mm, if the ion source and the puller are rotated by 15°. Otherwise, the amplitude increases to 3 mm.

At the end of acceleration orbit separation on isochronous radius is just higher than 1 mm. At beam extraction from the dropping field it is possible to increase orbit separation up to the value about 5 mm. After the deflector a compensated current septum-type channel is installed. The channel length is about 640 mm, the aperture for beam passing is 30x32 mm (over copper). The channel provides for induction decreasing by 2200 O_e at supply power up to 80 kw. The value of the radial positive field gradient of the channel is equal to $\sim$150 Gs/cm. The magnetic field pertubations in the beam acceleration region quickly drop as they remove from septum and do not exceed 10 Gs over the first harmonic of the field. After the current channel (in the valley) the iron magnetic shield is installed. At changing the external field between 4000-7500 Gs the shielding coefficient changes from 0.1 go 0.5. The effective positive field gradient up to 350 Gs/cm is created at the expense of the variable vertical aperture of the channel and the side faces By ratio selection between these components one can obtain weak dependence of the focusing shielding gradient on the external field. Magnetic field pertubations, contributed by the field, are compensated by two pairs of the iron plates.

The extracted beam angle of entry into the ion tube is corrected by a special magnet with additional quadrupole coils. The main field strength of the correcting magnet is controlled between-1700--4000 Gs. The quadrupole coils create the gradient 250 Gs/cm.

c. Beam diagnostics system

For the internal beam diagnostics in the accelerator vacuum chamber three probes are installed through 120° for the measurement of frequencies and betatron oscillation amplitudes by the shading method [4]. One probe of them is universal. It can be used as differential for ΔR - diagnostics. To measure large currents the internal probe with rotating head is designed for radiation on the internal beam.

Apart from multi-finger probes and "Faraday cup" -type probes, pendulum-type scanners will be used for beam diagnostics in the layout track. At operator wish the beam scanning can be observed by any of 40 devices, installed in different points of beam layout. Scanning devices, installed after the electromagnetic lenses of the layout track, allow to measure the beam emittance [5].

2. ACTIVE EXTERNAL BEAM MONOCHROMATIZATION SYSTEM

To increase the extracted beam monochromaticity without intensity loss the active monochromatization system is being developed [6] (fig.4). The quadrupole lenses $Q_1 \div Q_5$ and the bending magnet BM_2 compensate the extracted beam dispersion, caused by the fringing field of the cyclotron magnet, and the lenses Q_6 and Q_7 form the required beam geometry at 135° magnet entry M_1. After this magnet dispersed trajectories are oscillated by the lens Q_8. The longitudinal momentum particle separation is achieved in the 270° magnet. The system is symmetrized and achromatized by the lens Q_9 and the magnet M_2. Thus the beam with initial energy spread 4.10^{-3} has 45° phase stretching. The debuncher generator operates on the second harmonic of ion revolution in the cyclotron. 80 MeV protons require maximum debuncher potential equal to 110 kv. Stabilization and control of energy is accomplished by debuncher phase changing through error signals from the electrodes PE after the analyzing magnet AM, controlled by the NMR pickup. After the magnetic analyzer half of the particles have the energy spread up to 2.10^{-4} and 45° phase width, if the initial phase width is 3° and energy spread 4.10^{-3}.

Fig.4 also shows the system beam transport into experimental areas. The secondary particle analysis system includes a precision magnet analyzer and a wide-range spectrograph.

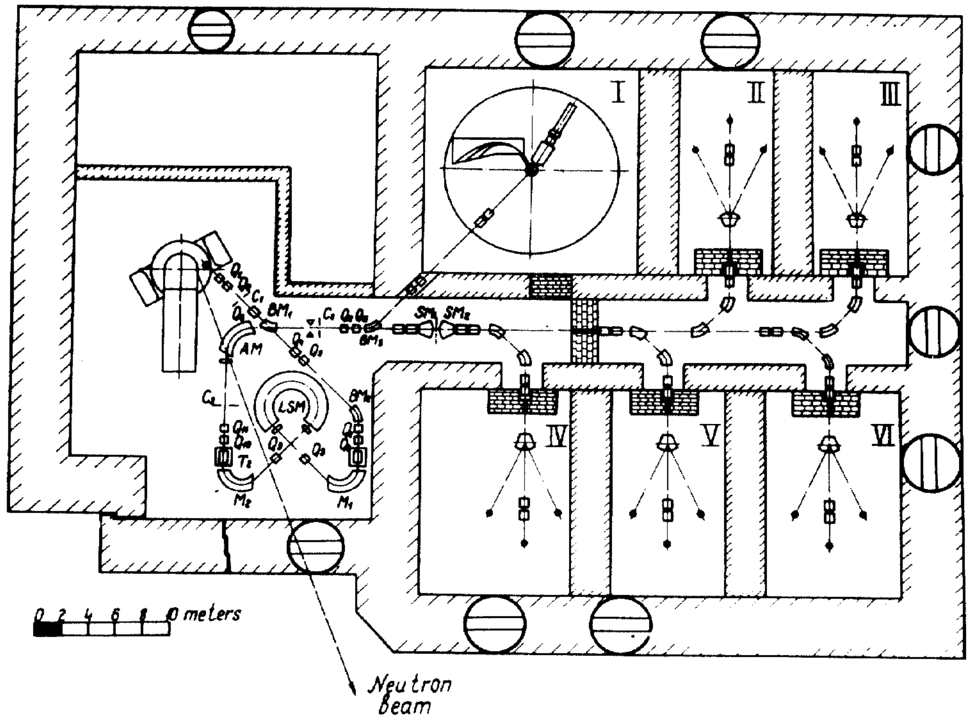

Fig.4. Beam layout and external monochromatization system. Dotted line is the direction of neutron beam.

3. NEUTRON PULSE SOURCE MODE

At designing the conversion of Kiev isochronous cyclotron into the mode of neutron pulse source the circuit of Karlsruhe cyclotron was takenas a prototype[7]. The obtaining of current pulses with duration about 1 ncek at pulse rate 1÷100 kHZ is provided by the new initial optics. The internal deflector (fig.5) forms a pulse set of (25-100) beam bunch pulses, deflecting other pulses in the vertical direction on the water-cooled stopper. A pulse train has radius (86-100)cm, where an external deflector is installed. At the same time the deflector spills them on the internal neutron target. In the mode of neutron pulse source the neutron flow of 3.10^{18} sec^{-1} is supposed at pulse duration equal to 2 nsec and pulse rate controlled between 1-100 kHZ.

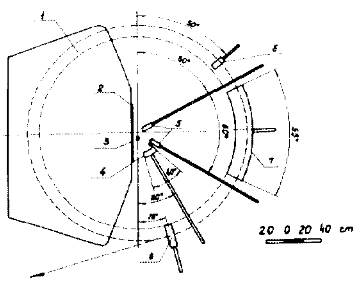

Fig.5
The scheme of dropping of a set of orbits on the internal target for obtaining of a short neutron pulse:
1 - dropped orbit region;
2 - puller; 3 - ion source;
4 - internal deflector with stopper; 5 - collimators;
6 - limiting frame;
7 - external deflector;
8 - generating target.

The neutron beam is transported from the target to the radiation detectors through three forevacuum neutron tubes. The angle between axes of the lateral beams is 3.5°.

The length of drift bases of the lateral channels is 100 m and of the central channel is 180 m. It is possible to increase the drift base up to 400 m.

4. HEAVY ION ACCELERATION

The accelerator has the heavy ion source[8]. It differs by a cathode unit from the light ion source, which consists of a tungsten cube with 7x7 mm cross section, heated by electron bombardment. The heavy ion source is inserted into the chamber over the radius. It can operate in DC and pulse modes.

The source of multicharged ions[9] is being tested with supplying of working material into gas discharge chamber by means of its evaporation by the electron beam. Electron beam evaporation allows to exclude the ballast gas from the discharge chamber of the source and the vacuum chamber of the accelerator.

The magnetic field and the adjustment range of the cyclotron accelerating system at the maximum radius 103 cm allow to obtain heavy ions up to 140 Z2/A MeV, which is higher the Coulomb barrier for eight-charged argon ions or four-charged neon ions. The ions heavier than argon cannot be accelerated to the required energy directly in the isochronous cyclotron, as the value of the specific ion charge is still small[10]. The ions heavier than argon are supposed to be accelerated in the cyclotron after preacceleration up to the energy about 1 MeV/nucleon in the tandem-generator ЭГП-20(10 MV on the conductor) and after stripping at the solid stripper inside the cyclotron.

Such an arrangement is being investigated in detail.

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DISCUSSION

KIM: You are proposing an energy spread of 2×10^{-4} with 20 μA current. I would like to know more about the method you propose.

LINEV: Dr. Basargin's active monochromatization system will be used. The longitudinal momentum particle separation is achieved with the 270 deg magnet. The RF field of cavity is used for the energy spread compensation. About this proposal there was a report at the Cyclotron Conference in Oxford (1970).