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CONCEPTUAL DESIGN OF FLNR JINR RADIATION FACILITY BASED ON DC130 CYCLOTRON

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Abstract

Flerov Laboratory of Nuclear Reaction of Joint Institute for Nuclear Research begins the works under the conceptual design of radiation facility based on the DC130 cyclotron. The facility is intended for SEE testing of microchip, for production of track membranes and for solving of applied physics problems. The DC130 cyclotron will accelerate the heavy ions with mass-to-charge ratio A/Z of the range from 5 to 8 up to fixed energies 2 and 4.5 MeV per unit mass. The intensity of the accelerated ions will be about 1 pμA for lighter ions (A from 20 to 86) and about 0.1 pμA for heavier ions (A from 132 to 209). The injection into cyclotron will be realized from DECRIS-SC the external superconducting ECR ion source. The main magnet and acceleration system of DC130 is based on the U200 cyclotron ones that now is under reconstruction. The conceptual design parameters of the various systems of the cyclotron and the set of experimental beam lines are presented in this report.

INTRODUCTION

The irradiation facility will be used for Single Event Effect testing of microchips by means of ion beams (^{16}O, ^{20}Ne, ^{40}Ar, ^{56}Fe, ^{84,86}Kr, ^{132}Xe, ^{197}Au and ^{209}Bi) with energy of 4.5 MeV per unit mass and having mass-to-charge ratio A/Z in the range from 5.0 to 5.5. Besides the research works on radiation physics, radiation resistance of materials and the production of track membranes will be carrying out by using the ion beams with energy of about 2 MeV per unit mass and A/Z ratio in the range from 7.58 to 8.0. The facility is based on DC130 isochronous cyclotron.

The working diagram of DC130 cyclotron is shown in Fig. 1. The acceleration of ion beam in the cyclotron will be performed at constant frequency f = 10.622 MHz of the RF-accelerating system for two different harmonic numbers h. The harmonic number h = 2 corresponds to the ion beam energy W = 4.5 MeV/u and value h = 3 corresponds to W = 1.993 Mev/u. The intensity of the accelerated ions will be about 1 pμA for lighter ions (A $\leq$ 86) and about 0.1 pμA for heavier ions (A $\geq$ 132).

The design is based on existing systems of IC100 (Fig. 2) and U200 (Fig. 3) cyclotrons [1].

The axial injection system and beam line for track membranes production will be adapted from the existing IC100 cyclotron systems.

In the frame of reconstruction of U200 to DC130 it is planned to upgrade the cyclotron magnetic structure, replace the magnet main coil and renovate RF system. Other systems: beam extraction, vacuum, cooling, control electronics will be new.

The experience of working at U400, U400M cyclotrons [2] will be used during developing the experimental channels for SEE testing of microchips.

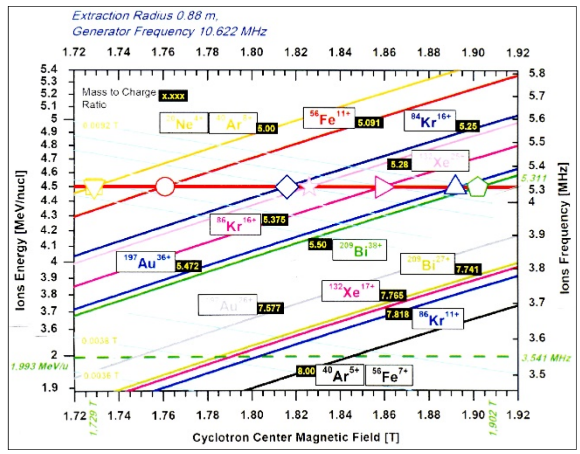

Figure 1: Working diagram of DC130 cyclotron.

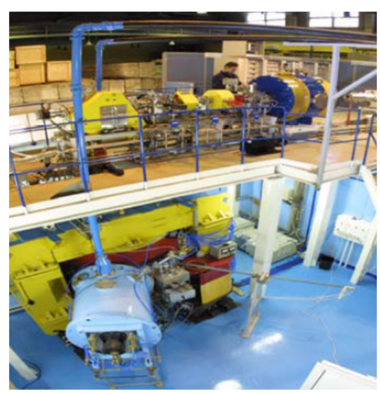

Figure 2: Layout of IC100 cyclotron.

Figure 3: Layout of U200 cyclotron.

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The main parameters of DC130 cyclotron are contained in Table.1.

Table 1: DC130 Cyclotron Main Parameters

Pole (extraction) radius, m	1(0.88)	
Magnetic field, T	1.729÷1.902	
Number of sectors	4	
RF frequency, MHz	10.622	
Harmonic number	2	3
Energy, MeV/u	4.5	1.993
A/Z range	5.0÷5.5	7.577÷8.0
RF voltage, kV	50	
Number of Dees	2	
Ion extraction method	electrostatic deflector	
Deflector voltage, kV	60	

AXIAL INJECTION SYSTEM

The axial injection system of DC130 cyclotron will be adapted from the existing IC100 cyclotron one consisted of superconducting ECR ion source – DECRIS-SC [3] and transport beam line [4].

DECRIS-SC Ion Source

DECRIS-SC is 18 GHz superconducting ion source designed in Flerov Lab of JINR. It is able to produce the beams of ion from ^{22}Ne to ^{209}Bi. The ion beam currents at the source exit sufficient for the facility operation is contained in Table 2.

Table 2: Ion Beam Current Extracted from DECRIS-SC

Ion	Current, pmcA	Ion	Current, pmcA
$^{22}Ne^{4+}$	~ 50	$^{132}Xe^{23+}$	~ 4
$^{40}Ar^{7+}$	~ 30	$^{132}Xe^{24+}$	~ 4
$^{56}Fe^{10+}$	~ 4	$^{197}Au^{34+}$	~ 0.3
$^{84}Kr^{15+}$	~ 8	$^{209}Bi^{37+}$	~ 0.2

In adaptation, the distance between extraction hole of the ion source and first focusing solenoid of transport beam line will be significantly reduced to avoid the losses of the ion beam.

Axial Injection Beam Line

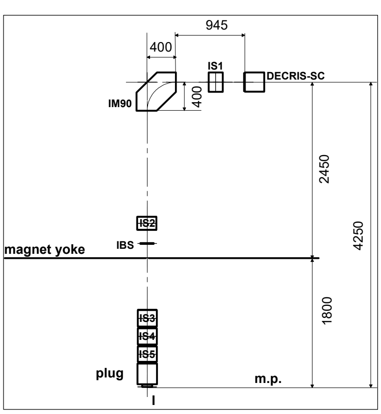

Figure 4: Scheme of the axial injection beam line.

The scheme of the beam line is shown in Fig. 4. The length of the beam line is equal to 5.423 m. The 90-degree analysing magnet IM90 separates the injected beam. The solenoidal lenses IS1-5 focus and match beam with the acceptance of the spiral inflector I for all level of the magnetic field. The sinusoidal buncher IBS increases the beam capture into acceleration. The design transport efficiency is equal to 100% for all type of the ion beam accelerated in the cyclotron. The envelopes of $^{209}Bi^{38+}$ ion beam are shown in Fig. 5. More detail information about axial injection beam line contains in report WEP2PO027 [5] at this conference.

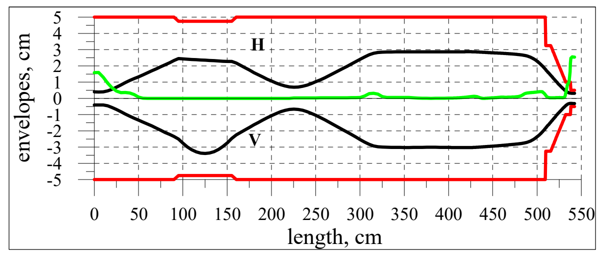

Figure 5: Horizontal (H) and vertical (V) envelopes of $^{209}Bi^{38+}$ ion beam; aperture (red line); longitudinal magnetic field (green line).

DC130 MAGNETIC SYSTEM

The magnetic system of DC130 cyclotron will be based on the existing U200 cyclotron one. The magnetic field distribution in the median plane of the DC130 cyclotron magnet has been found by means of computer simulation with 3D OPERA program code [6]. The computer model of the magnet is shown in Fig. 6. The main parameters of the magnet are contained in Table 3.

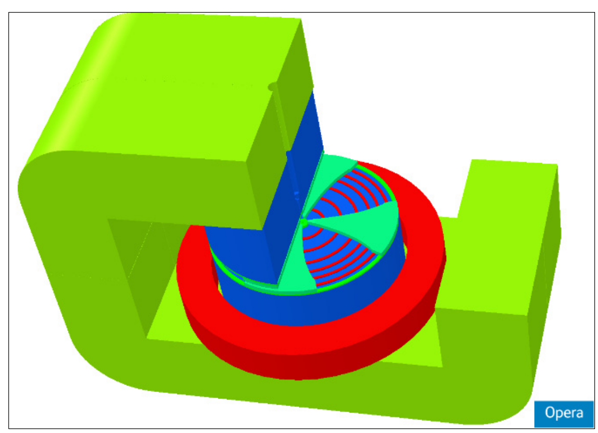

Figure 6: Computational model of cyclotron magnet.

Table 3: DC130 Cyclotron Magnet Main Parameters

Size of the magnet, mm	5000×2100×3600
Diameter of the pole, mm	2000
Distance between the poles, mm	160
Number of the sectors pairs	4
Sector angular extent (spirality)	43° (0°)
Sector height, mm	45

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Distance between the sectors (magnet aperture), mm	30
Distance between the sector and pole (for correcting coils), mm	20
Number of radial coils	6
Maximal power, kW	≈ 300

The operation mode change will be implemented only by variation the level of the magnetic field in the range from 1.729T to 1.902T and its isochronous distribution will be formed operationally by means of six radial correcting coils. The real magnetic field and isochronous ones radial distributions for three operation modes are shown in Fig. 7. At the middle level (red lines) the formation of the magnetic field has been made by shaping of the sector height from the pole side. In accordance with magnetic field distribution, each radial coils should be capable to produce ± 600Gs of correction magnetic field. The estimated current of the coil is equal to 15000 At. We consider the possibility of reducing the range of the magnetic field of the cyclotron and, as a consequence, the magnitude of the coil current.

The detail information about magnetic system of DC130 cyclotron contains in report THPWWC03 [7] at this conference.

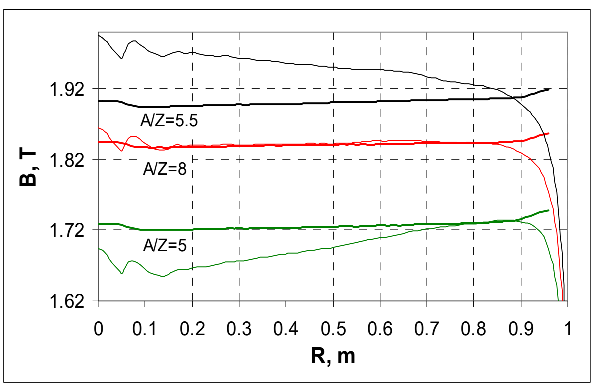

Figure 7: Magnetic field radial distributions.

RF SYSTEM

The working frequency of RF system is constant and equal to 10.622 MHz. The scheme of RF-resonator is shown in Fig. 8. The dashed line designates the placement of the ground plate. Two generators are used for independent feed of two RF resonators.

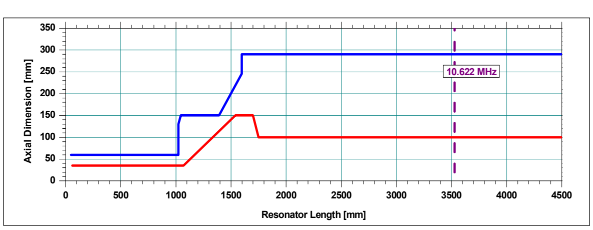

Figure 8: Scheme of RF-resonator.

The feedback system ensures precise tuning of RF phase and amplitude at both dees independently. The evaluated power of each RF generator is equal to 11.5 kW.

BEAM EXTRACTION SYSTEM

The scheme of beam extraction system of DC130 cyclotron is shown in Fig. 9. The dashed line is the cyclotron orbit corresponding to average radius of 88 cm. The red line is extraction orbit ending in the object point of the experimental beam lines. The beam extraction system includes the electrostatic deflector ESD and two magneto static channel MC1,2. In accordance with results of simulation, the maximum voltage at the deflector ESD is equal to 60 kV. The magnetic field gradients in MC1,2 channels are equals to 25 T/m and 8 T/m correspondingly.

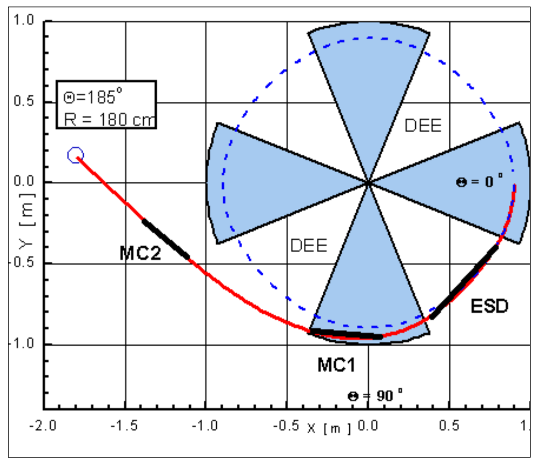

Figure 9: Scheme of DC130 extraction system.

VACUUM SYSTEM

In the axial injection beam line, the allowable average pressure of the residual gas is $1.5 \cdot 10^{-7}$ Torr. Such pressure can be provided using two turbomolecular and two cryopumps with a total pumping speed of 1600 l/s. The ion losses due to charge exchange process in the beam line is less than 15%.

The vacuum system of the DC130 cyclotron should provide the average residual gas pressure in the vacuum chamber at the level $7 \cdot 10^{-8}$ Torr. This level of pressure will be achieved with the help of turbomolecular and cryopumps with a total pumping speed of 15000 l/s.

OTHER SYSTEMS

The water-cooling and control systems will be upgraded.

EXPERIMENTAL BEAM LINES

The set of the experimental beam lines includes Track Membrane line, SEE testing line and Radiation Physics line. The scheme of the experimental beam lines is shown in Fig. 10. The common part of the channel consists of extraction bending magnet, the quadrupole lens triplet and

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commutating magnet. The center of the extraction bending magnet is an object point for all beam line.

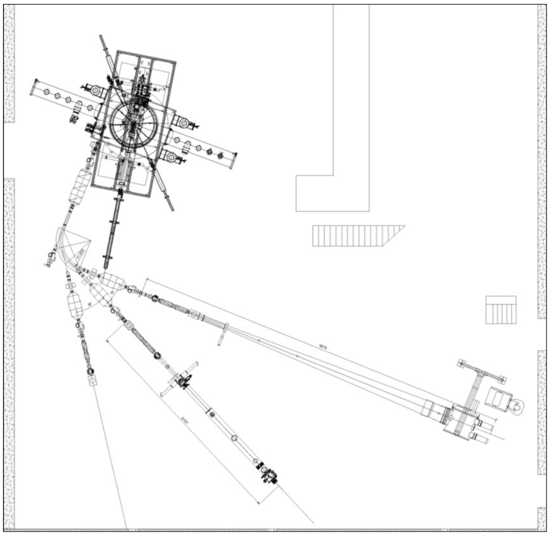

Figure 10: Scheme of experimental beam lines. From left to right: RP line; SEE testing line; TM line.

Radiation Physics Beam Line

RP line has a focusing quadrupole triplet and electromagnetic two-coordinate beam scanning system provides the homogeneous ion distribution at the irradiated surface.

SEE Testing Beam Line

During developing the experimental channels for SEE testing of microchips, we will use the experience of working at U400, U400M cyclotrons [2]. The lower energy SEE testing beam line of U400M cyclotron will be adapted to ion beam parameters of irradiation facility. This beam line contains: ion beam transportation system, beam monitoring system, energy measurement system and user vacuum test chamber with a mounting and positioning assembly to hold the sample in the irradiation field. The layout of the experimental set up is given in Fig. 11.

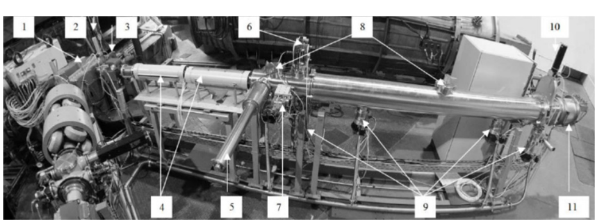

Figure 11: Layout of U400M SEE testing set up [2].

The beam leading line is separated from a bending magnet (1) by vacuum gate valve (2). The two-coordinate steering magnet (3) guides the beam through variable size diaphragm placed in entrance of the 50 Hz two-plane magnetic scanning system (4). This system provides exposure over the target area 200x200 mm^2 with inhomogeneity less than 30% in the flux range of 1÷10^5 particles/(cm^{2}s).

The degrader (5) with tantalum foils of various thickness gives possibility to choose appropriate ion energy and the Linear Energy Transfer function (LET) value.

Diagnostic elements such as Faraday cup (6) and luminophor screen (7) are used during beam tuning at high intensity.

Energy of particles passed through the foils as well as initial ion energy is measured by Time-Of-Flight (TOF) method with the help of two pick up electrodes (8).

The vacuum system of the beam line consist of three turbo molecular pumps (9). The vacuum gate valve (10) separates from the ion transport line the user target chamber (11) that is equipped with own vacuum system. This system is fast enough to pump down the chamber in less than 10 minutes.

The outer and inner view of user target chamber are given in Fig. 12.

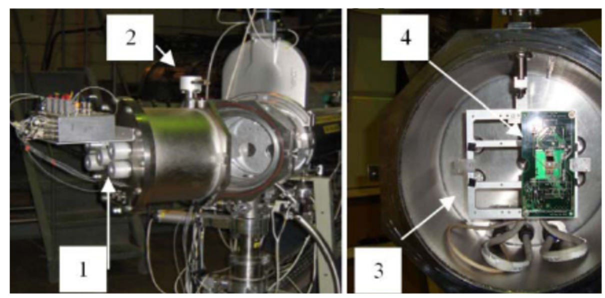

Figure 12: Outer (left) and inner (right) view of user target chamber.

The chamber has inner diameter of 28 cm and depth of 30 cm. The beam diagnostic elements (1) and user connectors are placing on the end flange of the chamber. Testing targets (4) are mounting on the frame (3) that can be tilted to the ion beam direction within 0÷75 degrees by using turning gear (2).

Track Membrane Beam Line

The beam line for track membranes production will be adapted from the existing IC100 cyclotron one [4]. The experience of creating TM beam line for DC110 cyclotron [8] will be used also. The TM beam line of IC100 and DC110 cyclotrons are shown in Fig. 13 and 14.

Figure 13: TM beam line of IC100 cyclotron [4].

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TM beam line consists of an initial constant aperture section with diameter of 100 mm and the special channel, made in the form of a rectangle expanding to an area of 300 x 700 mm^2.

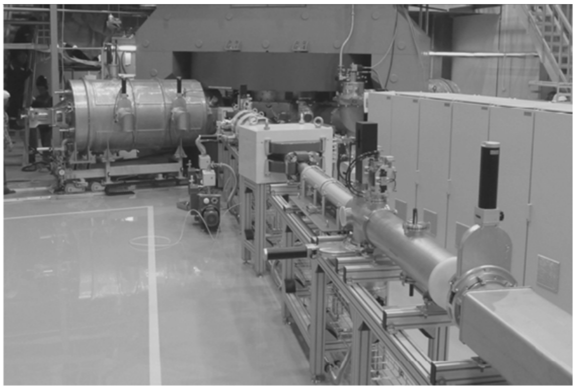

Figure 14: TM beam line of DC110 cyclotron [8].

The optical system of the channel consists of a triplet of quadrupole lenses, correcting magnets, and a scanning system for the ion beam. A horizontal scanner is based on a bending magnet supplied by a saw tooth current. Vertical scanner may be performed as electrostatic deflector [8] or alternatively as the horizontal one [2]. The working frequency of horizontal scanner is equal to 100 Hz. The electrical vertical scanner has frequency 2 kHz.

Control, blocking of the scanning system and monitoring of it parameters are the part of accelerator control system. Faraday Cups and profiler are installed in the diagnostic boxes for monitoring the beam parameters.

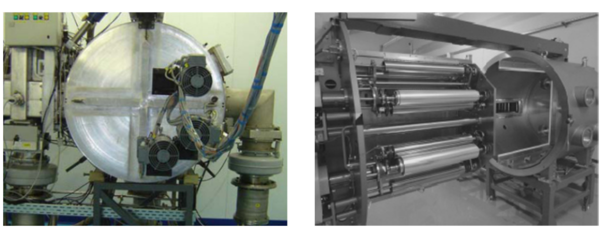

Figure 15: Film irradiation device of IC100 [4] (left) and DC110 [8] (right) cyclotrons.

TM beam line is equipped with a specialized device (see Fig. 15) intended for heavy ion irradiation of polymer film moving in the irradiated zone.

The vacuum system of TM beam line should provide the average residual gas pressure at the level $5 \cdot 10^{-6}$ Torr.

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