A SYSTEM FOR BEAM DIAGNOSTICS IN THE EXTERNAL BEAM TRANSPORTATION LINES OF THE DC-72 CYCLOTRON

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Abstract

The isochronous four-sector Cyclotron DC-72 will be the basic facility of the Cyclotron Center of the Slovak Republic in Bratislava. It will be used for accelerating ion beams with mass-to-charge ratio A/Z from 1 (H^-) to 7.2 ($^{129}Xe^{18+}$) with energy from 2.7 MeV/amu (A/Z=7.2) to 72 MeV (A/Z=1).

In the paper a system for external beam diagnostics is presented. It is intended for on-line data acquisition of the accelerated beam main parameters (current, position, profile, emittance and energy of the ion beams). The system allows one to provide effective tuning the acceleration regime as well as adjusting the ion beam transport lines with the ion optical systems to effective transportation the ions from the cyclotron exit to physical targets and set-ups.

INTRODUCTION

Cyclotron DC-72 represents an isochronous four-sector cyclotron. The ion beam extraction from the cyclotron will be made by means of electron stripping on a graphite foil. The ions will be extracted in two directions: A and B. Main parameters of the DC-72 cyclotron are given in Table 1, and the design parameters of ion beams are given in Table 2.

Table 1: Main parameters of the DC-72 cyclotron [1]

Pole diameter	2.6 m
Extraction radius	1.118 m
$B_{average}$ at extraction radius	1.12 – 1.51 T
Number of sectors	4
Sector angle	45°
Number of Dees	2
Dee angle	42°
Frequency range	18.5÷32 MHz
Harmonic numbers	2, 3, 4, 5, 6
Ion source for H^-, D^-, $^2H^{1+}$	Multicusp
Ion source for heavy ions	ECR
Extraction	stripping foil
Emittance on the target	< 20 π mm·mrad

The main areas of using DC-72 cyclotron ion beams will be the following [1]:

- Nuclear medicine and oncology;
- Production of radioisotopes for oncology (^{123}I, ^{81}Rb/ ^{81m}Kr, ^{67}Ga, ^{111}In, ^{201}Tl);
- Production of very short living radioisotopes for positron emission tomography (^{11}C, ^{13}N, ^{15}O, ^{18}F);
- Proton therapy of eye;
- Fast neutron therapy (FNT) and boron neutron capture therapy (BNCT);
- Metrology of ionizing radiation;
- Fundamental research;
- Applied research and development programs, surface treatment of metallic and other materials;
- Nuclear physics and techniques;
- Nuclear structure and reaction kinematics studies;
- Educational programs for students of nuclear physics and related fields.

Table 2: The design parameters of DC-72 ion beams [1]

Ch.	Technology and set-ups	Ion beam	Energy [MeV/u]	Intensity [eμA]
1	^{123}I production	p	30	50
2	^{87}Rb production	p	30	30
3	^{67}Ga, ^{201}Tl, ^{111}In prod.	p	30	100
4	Proton therapy	p	72	0.05
5	Fast neutron therapy	p	66–72	30–35
6	Applied research	Li–Xe	2.8–2.7	5–1
7	Mass-spectrometry	C–Kr	8.6–2.8	20–2
8	Physical research	Li–Xe	2.8–2.7	5–1

EXTERNAL BEAMS DIAGNOSTICS

Beam intensity measurement

The ion beam intensities at the cyclotron extraction region and in the beam transportation lines are the main parameters. The beam current measurements will be realized by special Faraday Cups (FC) (20 pieces). The sketch of FC is shown in Fig.1. At the FC design, we paid special attention to problem of FC cup radioactive activation and choice of the appropriate material. Also, we spent some time to calculate the 3D temperature distribution in the cup. From the point of view of minimal activation, the cup of FC will be made of aluminum. To satisfy the temperature condition the cup has a water-cooling system [2]. The accelerated particles are absorbed in the cup and the integrated electrical charge creates an electrical current that is measured by a current-to-voltage converter (LOG104) and than converted to a digital signal by the A/D converter (MCP3201). After all, the current value will be shown at the console in the cyclotron control room.

To eliminate the influence of secondary electrons emission on the current measurement accuracy we use a transversal magnetic field created by CoSm permanent magnets that surround the cup. The calculation results of the magnetic field distribution are presented in [2].

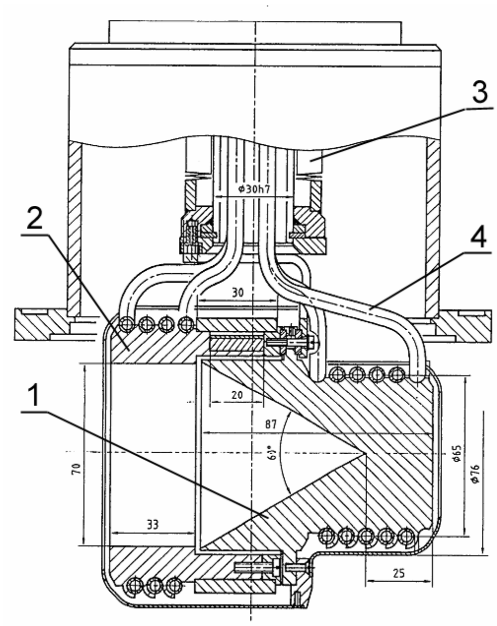

Figure 1: The sketch of the Faraday Cup, where:
1- aluminum cup, 2- aluminum diaphragm, 3- pneumatic drive, 4- cooling pipe

Beam profile and transverse position measurements

To determinate the ion beams transverse position, horizontal and vertical profile and dimensions, a rotating wire scanner will be used [3]. The scanner consists of a spiral rotating Tungsten wire, bended as a helical spiral under 45^{o}. The rotation moment is transferred to the scanner wire from the electromotor (SD-54) through magnetic coupling that provides a large number of measurement cycles. The vacuum zone is separated from the atmosphere by a motionless metal membrane. The wire position is controlled by the system from a disk with a slit and OPIC photo-interrupter (GP1A10). The scanner will be installed in the ion beam transportation lines under 45^{o} in relation to transversal axes of quadrupole lenses. The wire crosses the ion beam in two planes (horizontal and vertical) for one turn (Fig. 2).

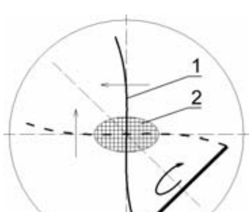

Figure 2: The scheme of the beam intersection by the scanner wire at rotating, where: 1- Tungsten wire, 2- beam cross section

The accelerated particles are absorbed in the wire and the integrated electrical charge creates an electrical current that flows through four sliding contacts, and than by LOG104 and MCP3201. Finally, the received signal is processed and the ion beam transverse position, horizontal and vertical profile in 2D pictures and beam RMS dimensions will be shown at the console in the cyclotron control room.

The basic parameters of the rotating wire scanner

- Wire diameter	1.5 mm;
- Rotation radius of a wire	45 mm;
- Revolution frequency	38.4 rpm;
- Signal processing range	0.01÷100 μA;
- Accuracy of profile measurements	< 5 %
- Maximum beam diameter	70 mm

17 pieces of the rotating wire scanner will be placed in the external beam transportation lines. The sketch of the scanner is shown in Fig.3.

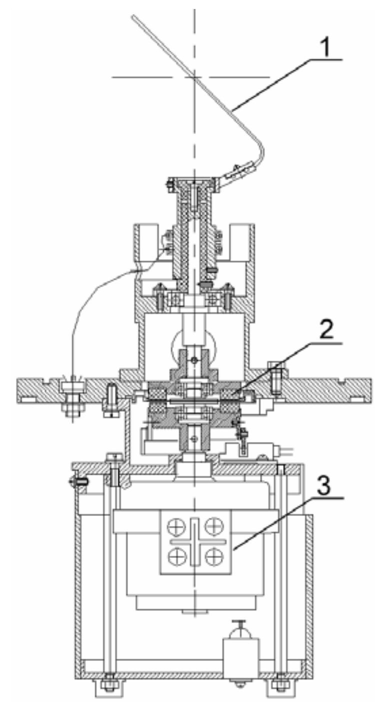

Figure 3: The sketch of the rotating wire scanner, where:
1- Tungsten wire, 2- magnetic coupling, 3- electromotor

Beam profile, transverse position and beam intensity measurements at the extraction

For measurements of ion beams transverse position, horizontal and vertical profile and dimensions at the extraction region the profile grids will be used. Profile grid consists of 30 vertical lamellas installed with the step of 11 mm, and 30 lamellas installed under 45^{o} to the horizontal plane with the step of 12 mm. The aperture of the grid itself is 350×60 mm^2, lamellas are copper plates with cross-section of 1×10 mm^2, the length of each one depends on the location. Lamellas are insulated one from another with ceramic, fixed to the water-cooled base frame.

The accelerated particles are absorbed in lamellas and the integrated electrical charge creates an electrical current. After the received signal from each lamella is processed, the ion beam transverse position, horizontal and vertical profiles, and beam RMS dimensions will be shown at the cyclotron control console.

Profile grid is combined with the rectangular Faraday Cup (370×80×50 mm^3) for simultaneous measurement of ion beam intensity. The cup will be made of aluminum, and has water-cooling through embedded copper pipe.

This device will be installed in the extracting region of the cyclotron, over the radius of R~2.2 m, where there is sufficient magnetic field to eliminate the influence of secondary electrons emission on the ion beam current measurement accuracy. For moving the device to the measuring position a pneumatic drive will be used.

Beam energy measurement

The system is intended for obtaining the on-line information about ion beam energy.

The principle of energy determination is based on the measuring the ion beam bunch time-of-flight between two points (two capacitive electrodes) placed at the well-known distance to each other (TOF-method) [4]. The two pickup electrodes will be placed in the direct part of the ion beam transportation lines. The distance between pickups is 4.462 m in A direction, and 4.362 m in B one. These distances have been chosen from the point of view of tuning simplicity and possibility to make the beam energy measurement without additional commutation and tuning of channels in both directions. The today accuracy of energy measurement satisfies to the existing requirements.

In the case of necessity to develop the system and to increase the accuracy in energy determination, there are some possibilities to increase the distances up to 7.456 m, 10.124 m, 11.918 m and 14.586 m in A direction, and up to 8.576 m in B one.

In the case of the distance between two pickups is bigger than the geometrical distance between bunches, it is necessary to know the quantity of bunches between the electrodes. For this purpose it is possible to take approximate value of extracted ion beam energy. This rough estimation of beam energy can be made knowing the beam extraction radius of the accelerator and RF frequency of the accelerating field, that's why there is not necessary to use the third electrode.

The precision of the beam energy measurement depends on the error in the determination of the distance between electrodes, and on the accuracy of time-of-flight measurement.

Table 3: The energy resolution $\Delta W/W$ for TOF at the pickup distance of 4.362 m. The accuracy in the distance measurements is 1 mm, and the accuracy of time-of-flight measurements is 0.1 ns.

Particle	p	p	^{129}Xe	^{12}C
W [MeV/u]	30	72	2.7	8.6
$\beta = v/c$	0.248	0.372	0.076	0.135
f_{RF} [MHz]	22.22	31.63	19.36	22.96
Total TOF [ns]	58.70	39.12	191.5	107.8
Bunch spacing [m]	3.344	3.525	1.176	1.762
$\Delta W/W$ [%]	0.34	0.51	0.11	0.2

The electrical signals from the pickup electrodes are amplified by the high-frequency amplifiers with amplification factor of ~ 150 at 1GHz bandwidth. The amplified signals are given out to the TEKTRONIX TDS-5054 oscilloscope located in the cyclotron control room. The amplified signals will be processed, and the calculated energy will be shown at the cyclotron control console. The typical energy resolutions $\Delta W/W$ of the system are given in Table 3.

Transverse emittance measurements

The transverse emittance is one of the main parameters of charged particles ion beams. For transverse emittance measurement a gradient variation method will be used [4]. The procedure of transverse emittance measurement is based on the measurement of the beam profile width as a function of the quadrupole lens gradient. This transverse emittance measurement is possible in several places of the ion beam transportation lines by using the rotating wire scanners located at the well-known distance from the quadrupole lens. The accuracy of the transverse emittance measurements will be about 25 % that satisfies to the existing requirements. In the case of necessity to develop the system there is a possibility to use the three profiles method with rotating wire scanners without the necessity of quadrupole variation.

Aperture diaphragm

The aperture diaphragms will be used for beam size limitation, for rough estimation of the beam position in the transportation lines and for protection of the transportation line components against damage at incorrect beam adjustment.

14 aperture diaphragms will be placed in the ion beam transportation lines after the correction magnets at extraction zone, before entrances into bending magnets and in front of the last diagnostic blocks of every channel. The aperture diaphragm is a ring-shape with the inner diameter of 80 mm and thickness of 25 mm. It is made of aluminum and not water-cooled. Every diaphragm will be established in the transportation lines on isolators, and the signal from each ones will be given out at the cyclotron control console.

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