FOCUSING AND BUNCHING OF ION BEAM IN AXIAL INJECTION CHANNEL OF IPHC CYCLOTRON TR24

N. Kazarinov[#], I. Ivanenko, JINR, Dubna, Russia

F. Osswald, T. Adam, E. Traykov, IPHC/IN2P3/CNRS, University of Strasbourg, Strasbourg, France

Abstract

The CYRCé cyclotron (CYclotron pour la ReCherche et l'Enseignement) is used at IPHC (Institut Pluridisciplinaire Hubert Curien) for the production of radio-isotopes for diagnostics, medical treatments and fundamental research in radiobiology. The TR24 cyclotron produced and commercialized by ACSI (Canada) delivers a 16-25 MeV proton beam with intensity from few nA up to 500 µA. The solenoidal focusing instead of existing quadrupole one is proposed in this report. The changing of the focusing elements will give the better beam matching with the acceptance of the spiral inflector of the cyclotron. The parameters of the focusing solenoid are found. Additionally, the main parameters of the bunching system are evaluated in the presence of the beam space charge. This system consists of the buncher installed in the axial injection beam line of the cyclotron. The using of the grid-less multi harmonic buncher may increase the accelerated beam current and will give the opportunity to new proton beam applications.

INTRODUCTION

The beam transport and bunching of the H^- ion beam by means of multi-harmonic buncher that may be installed in the axial injection beam line of the TR24 [1] cyclotron have been considered in paper [2]. Using a buncher will give an opportunity to increase the accelerated beam current. In this report, the solenoidal focusing instead of the quadrupole one was calculated. The influence of the space charge on the beam bunching was evaluated also. The simulation of beam transport was carried out by means of 3D version of MCIB04 program code based on momentum method [3].

BEAM LINE LAYOUT

The scheme of the beam line and the approximate length of the optical elements are shown in Fig.1. This scheme was the basis for simulation of the dynamics of the ion beam.

H^- ION BEAM PARAMETERS

H^- ion beam is produced in the CUSP ion source [4] with kinetic energy of 30 keV. The beam emittance is strongly dependent on beam current. For H- ion beam currents varying from 1 mA to 5 mA the initial beam diameter is equal to 1 cm and the normalized beam emittance is changing within range 0.1÷0.4 π mm×mrad.

#nyk@jinr.ru

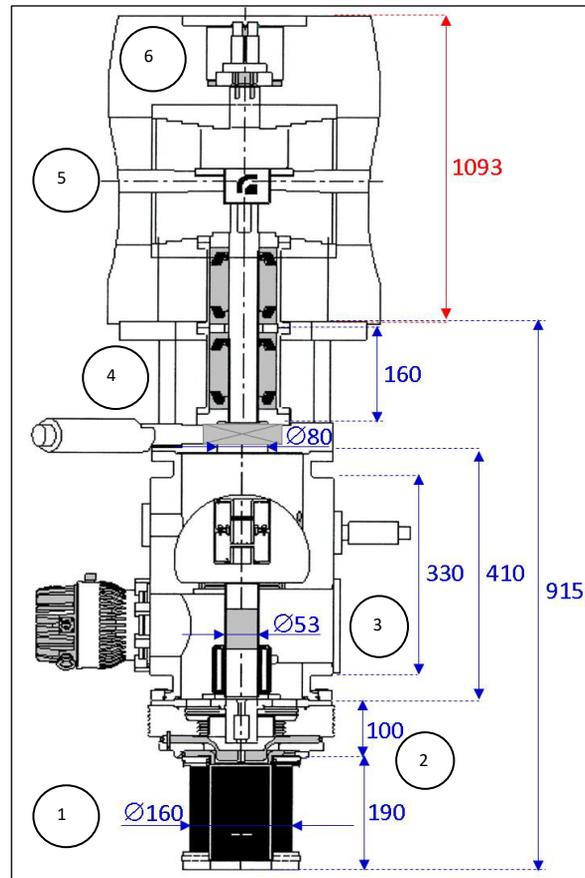The main parameters of the H^- ion beam used in the simulation are contained in Table 1.

Figure1: Axial injection beam line of TR24 cyclotron. 1 - CUSP ion source; 2 - extraction electrodes; 3 - EM steering (H/V); 4 - EM quad doublet; 5 - ES deflection; 6 – cyclotron. Dimensions – mm.

Table 1: H^- Beam Parameters

Parameter/notation	Value	Unit
Charge/ Z	1	
Mass number/ A	1	
Kinetic energy/ W	30	keV
Beam diameter/ d	1	cm
Beam emittance/ ε	50 π	mm×mrad
Ion beam current/ I	5	mA
Neutralization factor/ f	0.3-0.95	

SIMPLIFIED BEAM LINE SCHEME

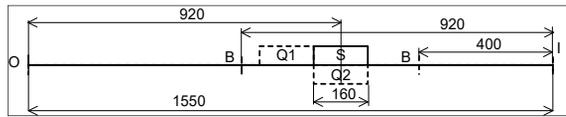The simplified scheme of the beam line is shown in Fig.2.

Figure 2: Beam line scheme. O – object point; I – spiral inflector; B – buncher; Q1,2 – existing quadrupole lenses; S – solenoid. Dimensions – mm.

The object point O is placed at the edge of the CUSP source (see Fig.1). The solenoidal lens S is installed at the place of the second existing quadrupole lens Q2. The two possible placements of the buncher are shown also.

BEAM NEUTRALIZATION

The beam current from CUSP ion source may achieve up to 5 mA. The transport of the beam with a big current is impossible without reasonable assumption about beam space charge neutralization. In the simulation the neutralization factor had a different values in the space before f_n (for the non-bunched beam) and after f_b the buncher (for the bunched beam): $f_n = 95\%$; $f_b = (30 \div 95)\%$.

FOCUSING SOLENOID

The POISSON/SUPERFISH [5] computational model of the solenoid and on-axis magnetic field distribution are shown in Fig.3
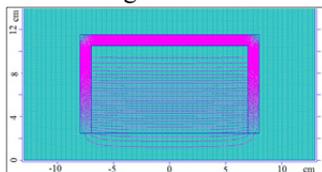

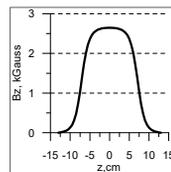Figure 3a: Solenoid computational model.

Figure 3b: Magnetic field distribution.

The parameters of the focusing solenoid are contained in Table 2.

Table 2. Solenoid Parameters

Overall length, cm	16
Overall diameter, cm	23
Screen width, cm	1
Winding dimension(hor.×vert.), cm	14×8
Number of turn	14×8=112
Diameter of aperture, cm	5
Maximum induction, kGauss	2.96
Maximum current, A	300
Power supply, kW	1.1

BEAM TRANSPORT

The maximal magnetic field induction of the solenoidal lens B_m or gradients of the quadrupole lenses were fitted to minimize the amplitude of beam envelopes oscillation at the entrance of the spiral inflector for both degrees of freedom. The fitted value of B_m is approximately equal to 2.3 kGauss.

The results of simulation of beam transport through the axial injection beam line are shown in Fig.4-5.
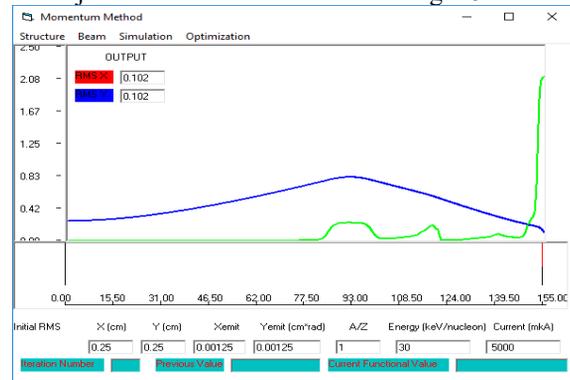

Figure 4: User interface of MCIB04 program (3D momentum method version) with RMS beam envelopes and longitudinal magnetic field distribution.
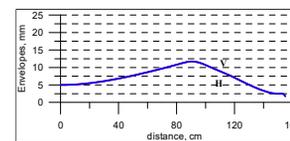

Figure 5a. Horizontal (H) and vertical (V) **H⁻** ion beam envelopes (2σ) in the case of solenoidal focusing.
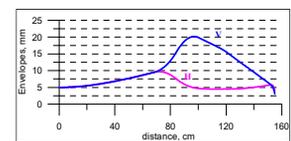
Figure 5b. Horizontal (H) and vertical (V) **H⁻** ion beam envelopes (2σ) in the case of quads focusing.

As may be seen from Fig.5 the beam matching is sufficiently better in the case of the solenoidal focusing. The beam dimensions are rather close to the matched beam radius that is approximately equal to 1 mm. Therefore, the solenoidal focusing is more convenient for the axial injection channel.

BEAM BUNCHING AND SPACE CHARGE

The beam bunching may be realized by multi-harmonic buncher B installed before quadrupole Q1 (see Fig.2) at the distance $L_B = 92$ cm from median plane of cyclotron. The electric field in the buncher produces the modulation of the longitudinal momentum of the ions. After the drift space, this modulation gives the longitudinal modulation of the ion beam density. The grid-less four-harmonic buncher has been successfully used at ATLAS facility [6].

Using of the buncher will give opportunity to double the accelerated beam current in the case $f_n = f_b = 95\%$ and quadrupole focusing of the beam [2]. In fact, the neutralization of the space charge of the beam is not the same for non-bunched and bunched beams. For the non-bunched beam, the neutralization factor f_n is close to 100% and the value $f_n = 95\%$ is a rather good

approximation. However, for the bunched beam the neutralization factor f_b may significantly differ from 100%.

Let define the bunching efficiency as the ratio of the number of ions within phase interval 20 degrees of RF field of the cyclotron for bunched beam and non-bunched beam. The dependence of the bunching efficiency on length after the buncher for various values of the bunched beam neutralization factor f_b is shown in Fig.6.
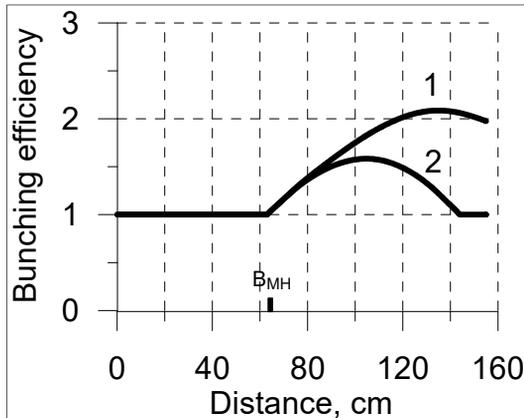

Figure 6: Bunching efficiency. L_B = 92 cm. Curve 1 – f_b = 95%; Curve 2 – f_b = 80%.

As may be seen from Fig.6 the bunching efficiency decreases with decreasing of the neutralization factor of the bunched beam f_b and for $f_b \geq 80\%$ the use of the buncher becomes non-effective because of the space charge debunching forces.

The decreasing of the length of bunching L_B leads to decreasing of the lower limit of the neutralization factor f_b.

The dependence of the bunching efficiency on length after the buncher placed at the distance L_B = 40 cm from median plane of cyclotron for various values of the bunched beam neutralization factor f_b is shown in Fig.7.

Comparison of Fig. 6,7 shows that the decreasing of the length of bunching L_B leads to increasing of the bunching efficiency (for the same neutralization factor of the bunched beam f_b). The accelerated beam current may be approximately doubled (L_B = 92 cm) or tripled (L_B = 40 cm) in the case of big neutralization of the bunched beam (f_b = 95%). The lower limit of the neutralization of

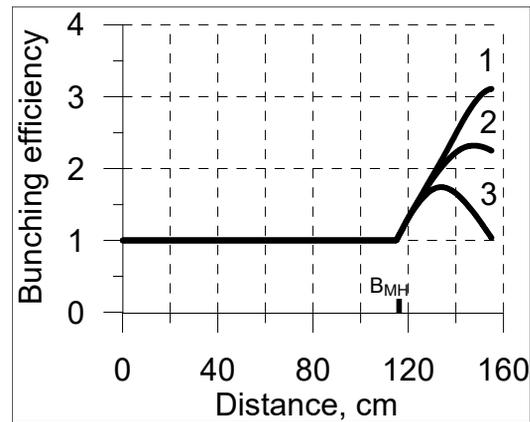bunched beam when the beam bunching becomes non-effective is smaller for L_B = 40 cm and equal to f_n = 30%.

Figure 7: Bunching efficiency. L_B = 40 cm. Curve 1 – f_b = 95%; Curve 2 – f_b = 80%; Curve 3 – f_b = 30% .

REFERENCES

[1] Advanced Cyclotron Systems Inc., http://www.advancedcyclotron.com/cyclotron-solutions/tr24

[2] N.Kazarinov, I.Ivanenko, F.Osswald,"Axial Injection Channel of IPHC Cyclotron TR24 and Possibility of Ion Beam Bunching", in *Proc. 21st International Conference on Cyclotrons and Their Application*, September 11-16, Zurich, Switzerland, pp.224-226.

[3] V.Aleksandrov, N.Kazarinov,V.Shevtsov. 3D Intense Beam Dynamics Simulation Using the Moments Method, *PEPAN Letters*, v5, N7(149), Dubna, 2008, pp.625-628.

[4] K. Jayamanna, M. McDonald, P.W. Schmor, D. H. Yuan, "The TRIUMF Compact DC H-/D- Ion Source", in *Proc. EPAC'90*, 12-16 June 1990, Nice, France, pp.647-649.

[5] "Reference Manual for the POISSON/SUPERFISH Group of Codes", Los Alamos National Laboratory Report LA-UR-87-126, 1987.

[6] P.N. Ostroumov *et al.*, "Beam test of a grid-less multi-harmonic buncher", in *Proc. PAC'07*, Albuquerque, New Mexico, USA, 2007, p.2242.