AXIAL INJECTION CHANNEL OF IPHC CYCLOTRON TR24 AND POSSIBILITY OF ION BEAM BUNCHING

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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 and medical treatments. The TR24 cyclotron produced and commercialized by ACSI (Canada) delivers a 16-25 MeV proton beam with intensity from few nA up to 500 microA. The axial injection and bunching of the H- ion beam by means of multi harmonic buncher is considered in this report. The buncher may be installed in the axial injection beam line of the cyclotron. The use of a grid-less multi-harmonic buncher increases the accelerated beam current and gives an opportunity for new proton beam applications. The main parameters of the sinusoidal (one-harmonic) and multi-harmonic bunchers are evaluated.

INTRODUCTION

The beam transport and bunching of the $\mathbf{H^-}$ ion beam by means of multi-harmonic buncher which may be installed in the axial injection beam line of the TR24 [1] cyclotron is considered. Using a buncher will give an opportunity to increase the accelerated beam current. The results of the simulation in the first order of the beam optics are given in this report. The simulation of beam transport was carried out by means of 3D version of MCIB04 program code based on momentum method [2].

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

$\mathbf{H^-}$ ion beam is produced in the CUSP ion source [3] 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 10 mm and the normalized beam emittance is changing within range 0.1÷0.4 π mm×mrad. The main parameters of the $\mathbf{H^-}$ ion beam used in the simulation are contained in Table 1.

Table 1: $\mathbf{H^-}$ Beam Parameters

Parameter/notation	Value	Unit
Charge/ Z	1	
Mass number/ A	1	
Kinetic energy/ W	30	keV
Beam diameter/ d	10	mm
Beam geometric emittance / ε	50 π	mm×mrad
Ion beam current/ I	5	mA
Neutralization factor/ f	0.95	

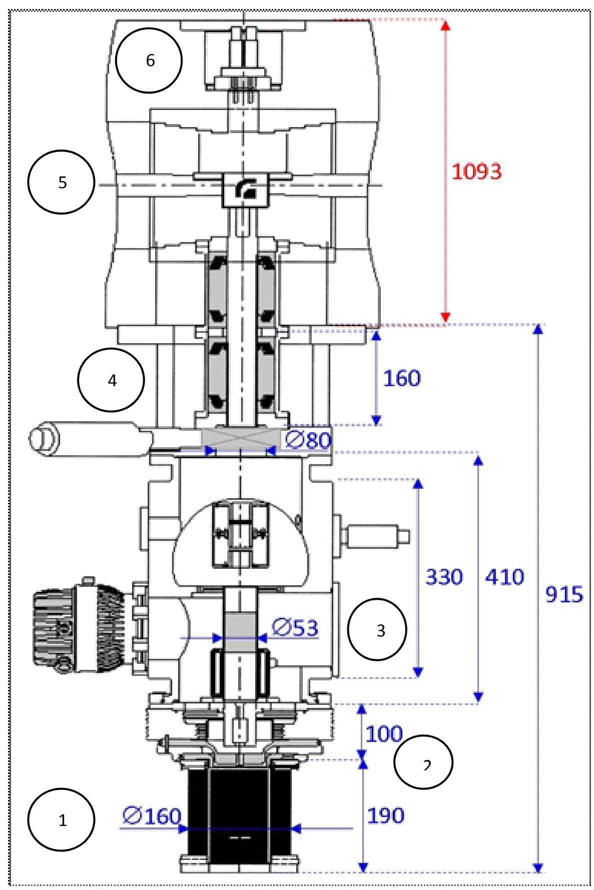

Figure 1: Axial injection beam line of TR24 cyclotron. 1 - CUSP ion source; 2 - extraction electrodes; 3 - EM steering (H/V); 4 - EM quad doublet; 5 - ES deflection; 6 - cyclotron.

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SIMPLIFIED BEAM LINE SCHEME

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

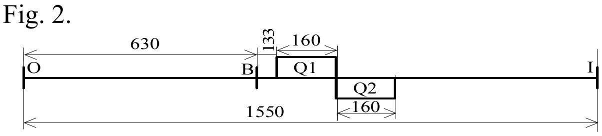

Figure 2: Beam line scheme. O – object point; I – spiral inflector; B – buncher; Q1,2 – quadrupole lenses.

The object point O is placed at the edge of the CUSP source (see Fig. 1).

LONGITUDINAL MAGNETIC FIELD

The distribution of the longitudinal magnetic field B in the injection channel has been defined by scaling of the field of the cyclotron IC-100 (pole diameter 1 m) [4]. The scaling factor is equal to ratio of the pole diameters of the cyclotron magnets. The plot of this distribution is shown in Fig. 3.

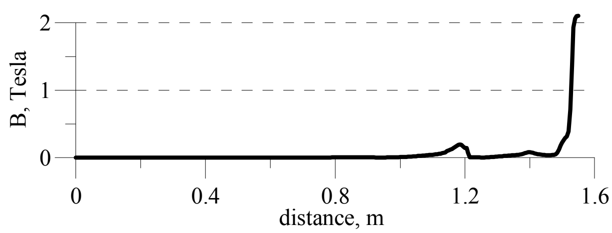

Figure 3: Longitudinal magnetic field.

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 was equal (fixed) to 95% and assumed to no change along the beam line.

BEAM TRANSPORT

The gradients of quadrupoles lenses were fitted to minimize the amplitude of the beam envelopes oscillation at the entrance of the spiral inflector for both degrees of freedom. The fitted values of the quadrupoles coefficients are equal to K1[Q1]=31.1 m^{-2} and K1[Q2]=29.9 m^{-2}.

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

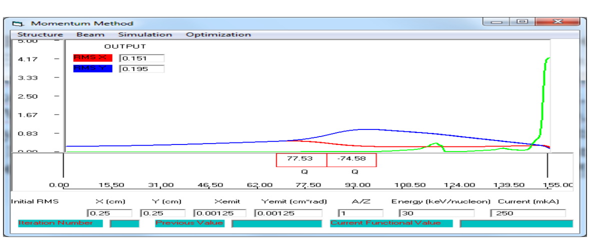

Figure 4: User interface of MCIB04 program (3D momentum method version) with beam envelopes and longitudinal B-field distribution.

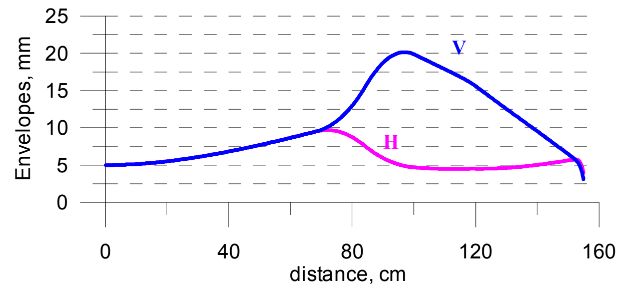

Figure 5: Horizontal (H) and vertical(V) $\mathbf{H}^{-}$ ion beam envelopes.

As may be seen from Fig. 5 the beam matching is not very good. The beam dimensions are sufficiently greater than matched beam radius which is approximately equal to 1 mm. This is explained by the use of the quadrupole lenses for beam focusing. The solenoid focusing is more convenient for the axial injection channel.

BEAM BUNCHING

The beam bunching may be realized by sinusoidal (one-harmonic) or multi-harmonic buncher B installed before quadrupole Q1 (see Fig. 2) at the distance of 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 modulation of momentum $\delta = \Delta p / p$ in the general case is defined as follows:

$$\delta = -\frac{eU_1}{2W} \sum_{n=1}^{N} \frac{U_n}{U_1} Sin \frac{2\pi n}{\lambda} z \qquad (1)$$

Here z – is the deviation of longitudinal coordinate of ions from the beam center of mass; n – harmonic number of the buncher; N – full number of the harmonic; λ – spatial period of modulation of the longitudinal density of the beam; U_n – effective voltage of the n-th harmonic of the spatial distribution $E(z)$ of the electric field of the buncher. In the symmetric case the voltage U_n is expressed by formula:

$$U_n = \int_{-\infty}^{\infty} E(z) Cos \frac{2\pi n}{\lambda} z dz \qquad (2)$$

The plot of function $E(z)$ for the one-gap buncher (symmetric case) is shown in Fig. 6.

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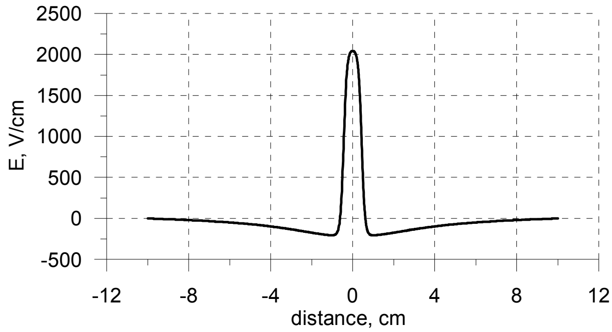

Figure 6: The distribution $E(z)$ for one-gap buncher.

The optimum value of ratio U_n/U_1 defined by achievement of the maximum of the bunching efficiency is equal to:

$$U_n/U_1 = (-1)^n/n \quad (3)$$

The optimum value of the effective amplitude of first harmonic U_1 is inverse proportional to the distance between buncher and median plane of the cyclotron. The grid-less four-harmonic buncher has been successfully used at ATLAS facility [5].

The bunching efficiency – 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, for various types of multi-harmonic buncher are shown in Fig. 9. The numbers at the curves correspond to full number of harmonic N in formula (1).

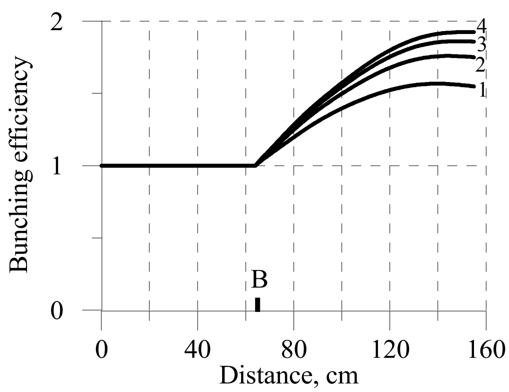

Figure 7: The bunching efficiency for various type of multi-harmonic buncher along the axial injection line. N = 1-4.

The optimum voltage amplitude of the first harmonic U_1 = 0.17 kV in the considering case.

As may be seen from Fig. 7 the bunching efficiency is increased with increasing of the full number of harmonics N. In the case of N = 4 the bunching efficiency is maximal and equal to 1.9. Therefore the accelerated beam current may be approximately in two times greater as compared with the case of absence of the bunching.

REFERENCES

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

[2] V. Aleksandrov, N. Kazarinov, and V.Shevtsov, “3D Intense Beam Dynamics Simulation Using the Moments Method”, *PEPAN Letters*, vol. 5, N7 (149), Dubna, 2008, pp.625-628K.

[3] M. 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.

[4] B. Gikal, S. Dmitriev, G. Gulbekian, P. Apel’, V. Bashevoi, S. Bogomolov, O. Borisov, V. Buzmakov, A. Cherevatenko, A. Efremov, I. Ivanenko, O. Ivanov, N. Kazarinov, M. Khabarov, I. Kolesov, V. Mironov, A. Papash, S. Patschenko, V. Skuratov, A. Tikhomirov, N. Jazvitsky. “Cyclotron based complex IC-100 for scientific and applied research”, in *Proc. 18th Int. Conf. on Cyclotrons and their Applications*, Giardini Naxos, Italy, 30 September – 5 October 2007, p.27.

[5] P.N. Ostroumov, V.N. Aseev, A. Barcikowski, B. Clifft, R. Pardo, S. I. Sharamentov, M. Sengupta, “Beam Test of a grid-less multi-harmonic buncher”, in *Proc. PAC’07*, Albuquerque, New Mexico, USA, May 2007, p. 2242.

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