GETTING UNIFORM ION DENSITY ON TARGET IN HIGH-ENERGY BEAM LINE OF CYCLOTRON U-400M WITH TWO

I. Ivanenko#, I. Kalagin, V. Kazacha, N. Kazarinov, JINR, Dubna, Moscow Region, 141980, Russia

Abstract

Formation of a uniform ion distribution in the existing beam line of U400M cyclotron with the help of octupole magnets has been studied. The simulation was performed for $^{40}Ar^{17+}$ ions with energy of 41.3 MeV/amu. The required level of beam non-uniformity on the target with diameter of 60 mm is ±7.5%. Two octupoles with static magnetic fields have been used to achieve the desired uniformity of the beam density in both coordinates simultaneously. The results of calculations are presented. This method of improving the uniformity of the beam will be implemented soon at Flerov laboratory of JINR.

INTRODUCTION

The high energy beam line of the U-400M cyclotron is intended for the irradiation of the microchips by the flow of accelerated heavy ions for determination of the possible damages by radiation. This requires the non-uniformity of density of irradiation on target is not worse than 7.5%. Various methods are used to obtain a high uniformity of the ion density distribution on the target. A simple method is to send the beam from an accelerator through a thin scattering metal foil [1]. The multiple beam scattering results in approximately Gaussian angular distribution of the particles. The target is irradiated by the particles being on flat top of a Gaussian distribution.

The possibility of obtaining a uniform distribution of particles on a target by means of two magnetic scanners (horizontal and vertical ones) and the experimental implementation of this method were described in [2,3].

Sometimes a combination of electrostatic and magnetic scanners is utilized for these purposes [4].

An electrostatic lens is used also for getting the uniform particle distribution on the target in [5].

Utilization of the non-linear magnetic elements gives the possibility to refuse rather complex systems of scanning of the beam.

The scheme for obtaining a uniform distribution of the particle density on the target using the doublet of quadrupoles and one octupole was given in [6].

A method to achieve the same goal by using a pair of magnetostatic octupole lens was proposed in [7,8].

The possibility of obtaining a uniform distribution of the ions on the target in the high-energy channel of the U-400M cyclotron with the help of two magnetostatic octupoles was examined in this work.

SCHEME OF THE ION BEAM LINE

The layout of the ion beam line is represented in Fig. 1. All distances between the optical elements of the beam line, parameters of all quadrupoles and bending magnets are presented in [9].

SIMULATION RESULTS

The $^{40}Ar^{17+}$ ions with kinetic energy W of 41 Mev/amu were chosen for calculations. Table 1 shows the values of the initial Twiss's parameters $\alpha_{x,y}$, $\beta_{x,y}$ [cm], rms emittances $\varepsilon_{x,y}$ [π mm×mrad], the horizontal dispersion function η_x [cm] and its derivative η'_x calculated at the point of the beam extraction from the cyclotron [10].

Table 1: Initial Beam Parameters

α_x	β_x	α_y	β_y	ε_x	ε_y	η_x	η'_x
-17	1927	-0.3	54.3		1.5	118	1.0

It was assumed in the calculations that the relative mean-square spread of the ion longitudinal momentum was equal to 2 10^{-3}. The values of the vertical dispersion function η_y and its derivative η'_y were equal to zero.

The calculations were carried out with the following requirements:

- The quadrupole gradients were chosen so that the sizes of the beam inside the quadrupoles would not exceed 80% of their aperture.
- The values of the found gradients should not exceed the maximum values of gradients of the existing quads.
- The irradiated target is a circle with a diameter of 60 mm. The uniformity of the distribution of the ion density on the target should not exceed the value of ± 7.5%.
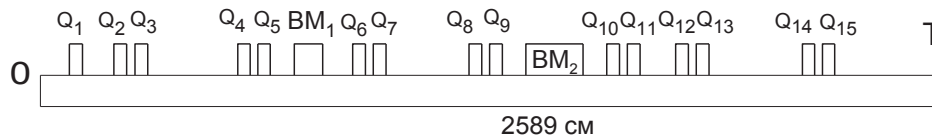

Figure 1: Layout of the high-energy beam line for ion transportation from the U-400M cyclotron. Here Q1 –Q15 are the quadrupoles, BM1 – BM2 are the bending magnets, and T is the target.

#ivan@nrmail.jinr.ru

Beam Dynamics

Beam Transport

Proposed in [7,8] method of smoothing the beam density on the target requires a creation of a ribbon beam (the size of the beam along one of the transverse coordinates is much smaller than along the other one) at the location of the octupole lenses. At that the octupole lenses have the minimal effect on the density distribution of the beam along the coordinate with a smaller size.

The horizontal (red line) and the vertical (blue line) envelopes of the ion beam along the beam line are showed in Fig. 2.
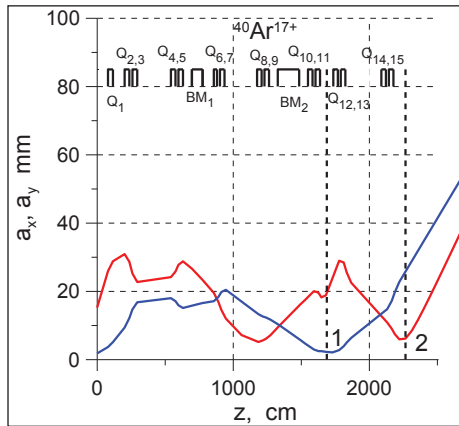

Figure 2: $^{40}Ar^{17+}$ beam envelopes. Points 1 and 2 show the location of first and second octupoles.

Figure 3 represents the end part of the beam line with two installed octupoles O_1 and O_2. Starting point of this beam line section is at the entrance to the first octupole lens (point 1 in Fig. 2).
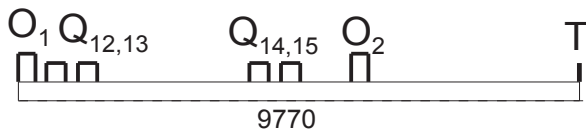

Figure 3: End part of the beam line.

Table 2 shows the distances between the centres of the optical elements in the end part of the beam line (see Fig. 3).

Table 2: Structure of the End Part of the Beam Line

Elements	Interval, cm
$O_1 - Q_{12}$	50.5
$Q_{12} - Q_{13}$	55
$Q_{13} - Q_{14}$	181
$Q_{14} - Q_{15}$	55
$Q_{15} - O_2$	105.5
$O_2 - T$	382.3

Simulation of the end part of the beam line with two octupoles was carried out by the method of large particles. Using a special program code 10^6 particles were placed in a phase space ($x, x', z, z', \Delta p / p$) so that they had the Gaussian distribution, and all second order moments corresponded to the beam characteristics defined at point 1 (see Fig. 2). Table 3 lists the parameters of the ion beam, necessary for calculation of the end part of the beam line with two octupoles.

Table 3: Beam Parameters at Starting Point of the End Part of the Beam Line

α_x	β_x	α_y	β_y	ε_x	ε_y	η_x	η'_x
-21	4902	-.22	74.2	2.8	1.5	140	-1.2

Figure 4 shows the form of the calculated particle distribution in a plane (x, y) at the octupole lens Q_1 input.
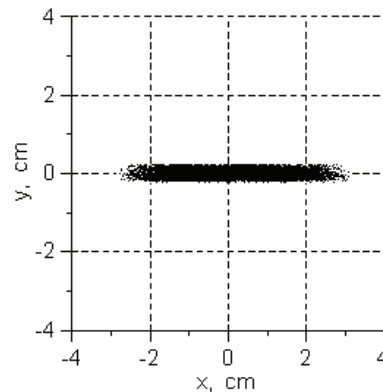

Figure 4: Distribution of ions at first octupole.

Figure 5 shows the form of the calculated particle distribution in the same plane at the octupole lens Q_2 input.
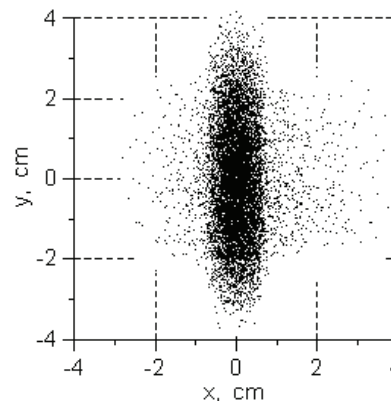

Figure 5: Distribution of ions at the second octupole.

Beam Dynamics

Beam Transport

The horizontal beam size is in ~ 10 times greater than the vertical one at the entrance of first octupole lens O1. This allows using octupole lens O1 for getting of the uniform distribution along the horizontal axes without changing of vertical distribution. The vertical size is in ~ 4.5 greater then horizontal one at the entrance of the second octupole lens O2. This allows using octupole lens O2 for getting of the uniform distribution along the vertical axes without changing of horizontal distribution.

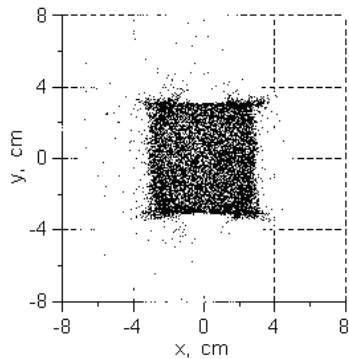Figure 6 shows the calculated distribution of the particles on the target.

Figure 6: Distribution of ions on the target.

Figure 7 represents the resulting distribution of the particle density on the target along the horizontal (curve 1) and along the vertical (curve 2).
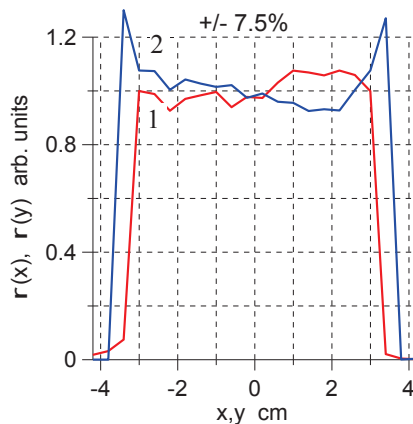

Figure 7: Distribution of the ion density on the target along the horizontal (curve 1) and along the vertical (curve 2).

CONCLUSION

The carried out calculations have shown that the density distribution of the beam with the desired level of uniformity of ± 7.5% on the target with diameter of 60 mm can be obtained in the high energy beam line of U400M cyclotron with the help of two magnetostatic octupoles.

The beam losses outside the target in this case are ~ 40%.

Octupoles parameters:
- the bore diameter of the octupoles is equal to 100 mm;
- the effective length of the octupoles is equal to 300 mm;
- the value of the magnetic field at the pole of first octupole is equal to –1000 Gs;
- the magnitude of the magnetic field at the pole of second octupole is equal to +625 Gs.

All results were obtained under the assumption that the density of the ion beam has the Gaussian distribution, and the beam moves without displacement from the axis of the beam line.

Possible misalignments of the beam axis can be offset by using of two sextupoles [7]. The first one is located near O1 and the second one is placed near O2.

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