

FOIL STRIPPING EXTRACTION SYSTEMS OF THE VINCY CYCLOTRON

J. Ristić-Đurović, P. Beličev, I. Draganić, Lj. Vukosavljević, Đ. Košutić, N. Nešković, S. Ćirković,
A. Dobrosavljević, Laboratory of Physics, Vinča Institute of Nuclear Sciences,
Belgrade, Serbia and Montenegro

A. S. Vorozhtsov, S. B. Vorozhtsov, Dzheleпов Laboratory of Nuclear Problems, Joint Institute for
Nuclear Research, Dubna, Russia

Abstract

The VINCY Cyclotron, the main part of the TESLA Accelerator Installation, has two foil stripping extraction systems – the back and front ion beam extraction systems. The former system enables the extraction of H^+ ion beams at the back side of the machine, and their transport down to the target stations for production of radioisotopes in the shielding vault of the machine. The latter system enables the extraction of light and low charge state heavy ion beams, and their transport down to the channels for production of radioisotopes and for radiation research. We shall describe the two systems and show some of the results of calculations of the transport of the ion beams through the extraction region.

INTRODUCTION

The fast track phase of construction of the TESLA Accelerator Installation is focused on routine production of radioisotope ^{18}F and radiopharmaceutical ^{18}FDG with the VINCY Cyclotron, the main part of the facility [1]. The radiopharmaceutical will be used for positron emission tomography. The production will be going on in the shielding vault of the machine. The next phase of construction of the facility will be focused on routine and experimental production of radioisotopes and radiopharmaceuticals, and on research in radiation physics, chemistry and biology.

The machine has two foil stripping extraction systems – the back and front ion beam extraction systems. The former system enables the extraction of H^+ ion beams at the back side of the machine using the stripping foil technique, and their transport down to the target stations for production of radioisotopes in the shielding vault of the machine. It will be used first to extract the 15 MeV H^+ ion beam obtained from the H^- accelerated beam, and to transport it to the target station for production of radioisotope ^{18}F . The latter system enables the extraction of light and low charge state heavy ion beams, and their transport down to the channels for production of radioisotopes and for radiation research.

The test ion beam of the back extraction system is (a) 15 MeV H^+ beam obtained from the H^- accelerated beam while the test beams of the front extraction system are: (b) the 65 MeV H^+ beam obtained from the H^- beam, (c) the 30 MeV H^+ beam obtained from the H_2^+ beam, (d) the 28 MeV $^4He^{2+}$ beam obtained from the $^4He^+$ beam, and (e) the 120 MeV $^{40}Ar^{15+}$ beam obtained from the $^{40}Ar^{6+}$ beam.

The H^- , H_2^+ and $^4He^+$ ion beams will be produced with the pVINIS Ion Source, which is a volume positive or negative light ion source, and the $^{40}Ar^{6+}$ beam with the nVINIS Ion Source, which is an electron cyclotron resonance heavy ion source. The calculations of dynamics of the ion beams in the extraction region were performed using the VINDY computer code package [2, 3] and the TRANSPORT code. The magnetic fields were obtained by combining the isochronous fields inside the machine and the corresponding measured stray fields matched with the isochronous fields.

BACK ION BEAM EXTRACTION SYSTEM

The main requirement for designing of the back extraction system was that the dimensions of the ion beam spot, i.e., the full-widths-at-half-maximum of the beam current distribution, in the entrance plane of the target were in the range of 12-15 mm. The back extraction system includes a dipole and quadrupole magnet – BFM1, and a quadrupole magnet – FM1. It also includes an irradiation chamber – IC, enabling one to attach two target stations – TS1 and TS2, for production of radioisotopes ^{18}F and, e.g., ^{124}I , respectively. The latter radioisotope is a positron emitter, as the former one. The scheme of the system is given in Fig. 1.

The initial parameters of the 15 MeV H^+ ion beam, i.e., its parameters in the plane of the stripping foil (SF1), are: the horizontal emittance $\epsilon_h = 5\pi\text{-mm-mrad}$, the vertical emittance $\epsilon_v = 5\pi\text{-mm-mrad}$, the maximal horizontal half-width $h_m = 1\text{ mm}$, the maximal vertical half-width $v_m = 5\text{ mm}$, the maximal horizontal half-angle $h'_m = 5\text{ mrad}$, the maximal vertical half-angle $v'_m = 1\text{ mrad}$, and the relative energy spread $\Delta E/E = \pm 3\%$. The intersection of the central ion trajectory with the plane of SF1 is designated by A1. It is assumed that the ion beam has initially a double waist. The isochronous magnetic field corresponds to the ion energy of 65 MeV at the radius of 840 mm. The final parameters of the ion beam are those in the entrance plane of the target.

The calculation using the VINDY code package was performed from point A1 down to point B1, lying on the transport line axis, between BFM1 and FM1, at the distance from the origin of 2,200 mm. It showed that the initial radial position of SF1 had to be 421 mm, and that the maximal magnetic induction and the maximal magnetic induction gradient at the central point of BFM1

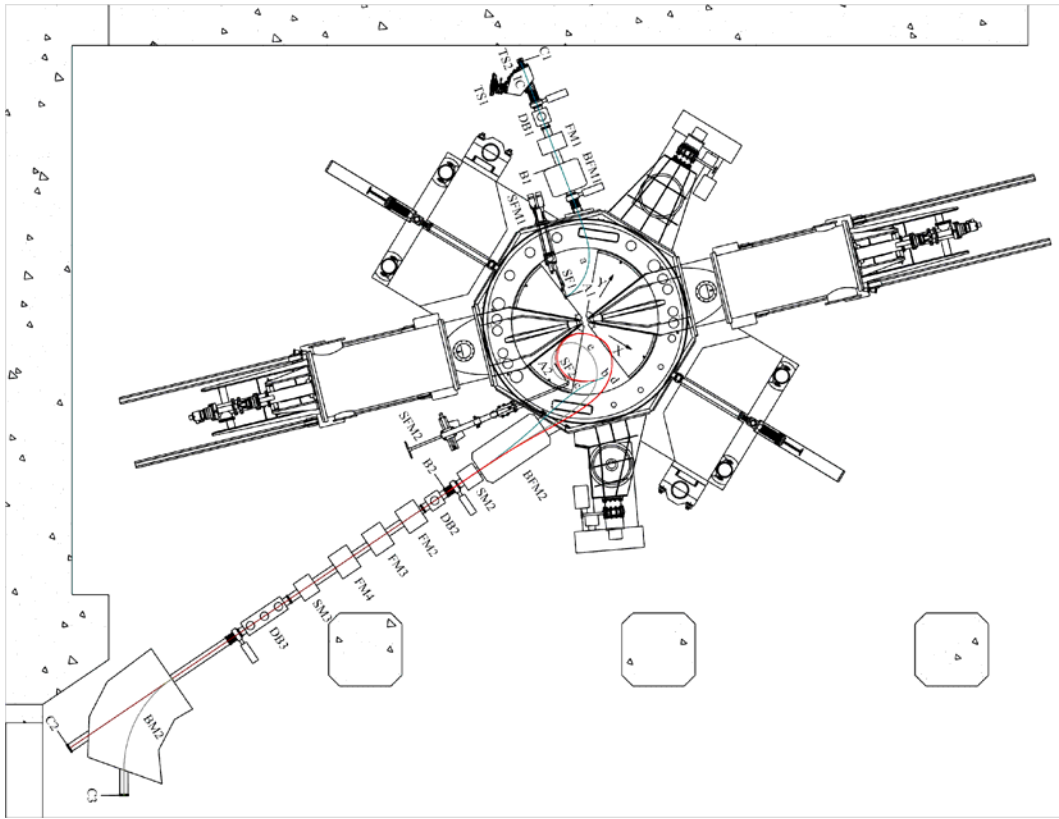


Figure 1: The schemes of the back and front ion beam extraction systems: SF1, SF2 – stripping foils; SFM1, SFM2 – stripping foil positioning mechanisms; BFM1, BFM2 – dipole and quadrupole magnets; FM1, FM2, FM3, FM4 – quadrupole magnets; BM2 – bending magnet; SM2, SM3 – steering magnets; DB1, DB2, DB3 – diagnostic boxes; IC – irradiation chamber; TS1, TS2 – target stations. The central trajectories of the test ion beams are shown too.

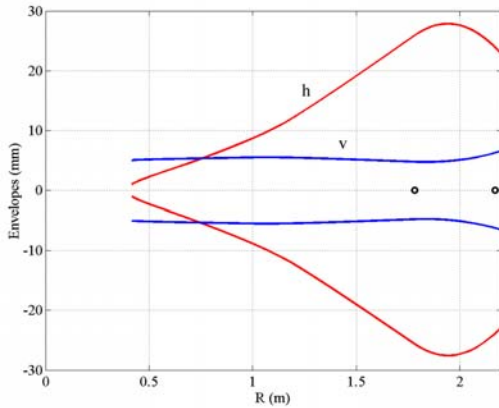


Figure 2a: The horizontal (h) and vertical (v) envelopes of the 15 MeV H^+ ion beam as a function of the distance from the origin between points A1 ($R = 421$ mm) and B1 ($R = 2,200$ mm). The central points in the entrance and exit planes of BFM1 are shown as well.

could be chosen to be ± 140 mT and 3.7 T/m, respectively. The calculation using the TRANSPORT code was performed from point B1 down to point C1, designating the intersection of the transport line axis with the entrance plane of the target. It showed that the maximal magnetic induction gradient at the central point of FM1 could be

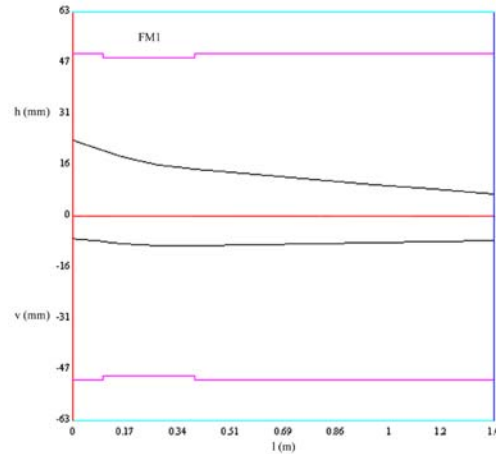


Figure 2b: The horizontal and vertical envelopes of the 15 MeV H^+ ion beam as a function of the length of the central ion trajectory between points B1 and C1.

chosen to be 4 T/m. The relevant parameters of the 15 MeV H^+ ion beam at point C1 are: the maximal horizontal half-width $h_m = 7$ mm, and the maximal vertical half-width $v_m = 7$ mm. Figures 2a and 2b show the horizontal and vertical envelopes of the ion beam between points A1 and C1.

FRONT ION BEAM EXTRACTION SYSTEM

The main requirement for designing of the front ion beam extraction system was that the characteristics of the ion beams in the final transverse planes of the transport line were adequate for their successful transport down to the targets of the channels for production of radioisotopes and for radiation research. The front extraction system includes a dipole and quadrupole magnet – BFM2, a triplet of quadrupole magnets – FM2, FM3 and FM4, and a bending magnet – BM2, enabling one to bend the ion beams directed towards the channel for production of radioisotopes towards the channel for radiation research. The scheme of the system is also given in Fig. 1.

The initial parameters of the 65 MeV H^+ ion beam, i.e., its parameters in the plane of the stripping foil (SF2), are: $\epsilon_h = 5\pi\text{-mm}\cdot\text{mrad}$, $\epsilon_v = 5\pi\text{-mm}\cdot\text{mrad}$, $h_m = 1\text{ mm}$, $v_m = 5\text{ mm}$, $h_m' = 5\text{ mrad}$, $v_m' = 1\text{ mrad}$, and $\Delta E/E = \pm 1\%$ while the initial parameters of the 30 MeV H^+ , 28 MeV ${}^4\text{He}^{2+}$ and 120 MeV ${}^{40}\text{Ar}^{15+}$ beams are: $\epsilon_h = 12\pi\text{-mm}\cdot\text{mrad}$, $\epsilon_v = 5\pi\text{-mm}\cdot\text{mrad}$, $h_m = 2\text{ mm}$, $v_m = 5\text{ mm}$, $h_m' = 6\text{ mrad}$, $v_m' = 1\text{ mrad}$, and $\Delta E/E = \pm 1\%$. The intersections of the central ion trajectories with this plane are designated by A2. It is assumed that each ion beam has initially a double waist. The isochronous magnetic fields correspond to the ion energies at the radius of 840 mm. The final parameters of the ion beams are those in the initial transverse planes of the channels for production of radioisotopes and for radiation research.

Table 1: The parameters of the test ion beams of the front ion beam extraction system at point C2

Ion beam	h_m (mm)	v_m (mm)	h_m' (mrad)	v_m' (mrad)
65 MeV H^+	17	19	0.6	1.2
30 MeV H^+	8	23	4.7	6.5
28 MeV ${}^4\text{He}^{2+}$	12	20	4.7	3.4
120 MeV ${}^{40}\text{Ar}^{15+}$	13	16	5.9	9.0

The calculations using the VINDY code package were performed from point A2 down to point B2, lying on the transport line axis, between BFM2 and FM2, at the distance from the origin of 3,000 mm. They showed that in the cases of 65 MeV H^+ , 30 MeV H^+ , 28 MeV ${}^4\text{He}^{2+}$ and 120 MeV ${}^{40}\text{Ar}^{15+}$ ion beams the initial radial positions of SF2 had to be 812, 824, 818 and 851 mm, respectively, and that the maximal magnetic induction and the maximal magnetic induction gradient at the central point of BFM2 could be chosen to be $\pm 230\text{ mT}$ and 1.1 T/m , respectively. The calculations using the TRANSPORT computer code were performed from point B2 down to points C2 and C3, designating the intersections of the transport line axis with the initial transverse planes of the channels for production of radioisotopes and for radiation research, respectively. They showed that the maximal magnetic induction gradients at the central points of FM2, FM3 and FM4 could be chosen to be 4 T/m , and that the maximal magnetic induction at the central point of BM2 could be chosen to be 1.3 T . Tables 1 and 2 contain the relevant

parameters of the ion beams at points C2 and C3, respectively.

Table 2: The parameters of the test ion beams of the front ion beam extraction system at point C3

Ion beam	h_m (mm)	v_m (mm)	h_m' (mrad)	v_m' (mrad)
65 MeV H^+	9	15	8.1	3.5
30 MeV H^+	12	15	10.1	1.7
28 MeV ${}^4\text{He}^{2+}$	15	32	7.4	2.6
120 MeV ${}^{40}\text{Ar}^{15+}$	8	5	7.7	5.8

Figures 3a and 3b show the horizontal and vertical envelopes of the 120 MeV ${}^{40}\text{Ar}^{15+}$ beam between points A2 and C3.

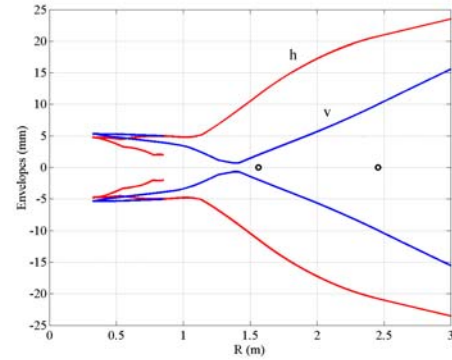


Figure 3a: The horizontal (h) and vertical (v) envelopes of the 120 MeV ${}^{40}\text{Ar}^{15+}$ ion beam as a function of the distance from the origin between points A2 ($R = 851\text{ mm}$) and B2 ($R = 3,000\text{ mm}$). The central points in the entrance and exit planes of BFM2 are shown as well.

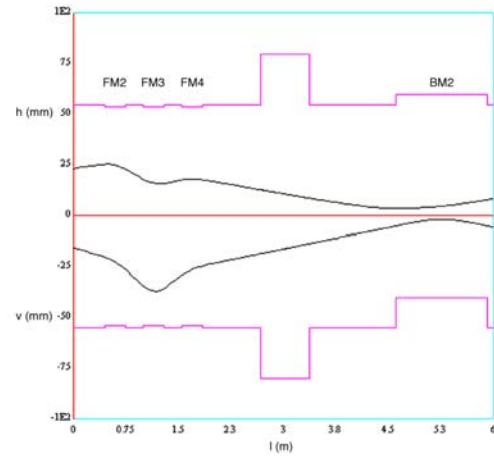


Figure 3b: The horizontal and vertical envelopes of the 120 MeV ${}^{40}\text{Ar}^{15+}$ ion beam as a function of the length of the central ion trajectory between points B2 and C3.

REFERENCES

- [1] N. Nešković et al., Nukleonika 48, Suppl. 2 (2003) S135.
- [2] J. Ristić-Đurović, Phys. Rev. ST AB 4 (2001) 123501.
- [3] J. Ristić-Đurović and S. Ćirković, Phys. Rev. ST AB 6 (2003) 033501.