FRONT EXTRACTION SYSTEM OF THE VINCY CYCLOTRON

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Abstract

The front extraction system of the VINCY Cyclotron, the main part of the TESLA Accelerator Installation, enables extraction of the light ion beams and low charge state heavy beams at the front side of the machine. It is based on the stripping foil technique. The system will be used to extract, e.g., the 65 MeV H^+ beam, the 32 MeV H^+ beam, the 28 MeV $^4He^{2+}$ beam and the 120 MeV $^{40}Ar^{15+}$ beam. It will be also used to extract the 105 MeV $^{12}C^{6+}$ beam and the 315 MeV $^{84}Kr^{28+}$ beam. We shall present some of the results of calculations of the dynamics of these beams in the extraction region of the machine, obtained using the VINDY computer code. The results of calculations of the transport of these beams towards the high energy experimental channels of the facility, obtained using the TRANSPORT computer code, will be shown too. Besides, we shall present the elements of the conceptual design of the system and the extraction transport line.

INTRODUCTION

Ion beam extraction from the VINCY Cyclotron will be performed using the stripping foil technique. There will be two extraction systems, placed on the two opposite sides of the machine – the front and back extraction systems. The front extraction system will be used to extract different light beams and low charge state heavy beams, and transport them towards the high energy experimental channels of the TESLA Accelerator Installation. The first three of these channels will be the channel for production of radionuclides, the channel for proton therapy, and the channel for radiation research [1].

Two ion sources are coupled to the (axial) injection transport line of the machine. The H^-, H_2^+ and $^4He^+$ beams will be produced by the pVINIS Ion Source, being a multicusp source. The multiply charged heavy beams like $^{12}C^{3+}$, $^{40}Ar^{6+}$ and $^{84}Kr^{14+}$ will be generated by the nVINIS Ion Source, which is an ECR source. After being injected in the machine, these beams will be accelerated and extracted from it by the stripping foil technique. An ion that passes through the stripping foil loses some of its electrons, and changes its charge. In the magnetic field this leads to a change of the radius of curvature of the ion trajectory. These effects are used to extract the ion from the machine. An H^- ion loses both electrons, becomes an H^+ ion, changes its direction of rotation, and comes out of the machine. A multiply charged heavy ion loses several electrons, becomes a higher charge state ion, changes the radius of curvature of its trajectory, makes one or more loops inside the machine, and comes out of it. The stripping foil is placed in such a way to direct the ion properly out of the machine. At the exit from the machine the beam is bent and focused by two magnetic elements in order to be accepted fully by the extraction transport line.

The test beams used in designing the front extraction system are given in Table 1. Calculations of the dynamics of these beams in the extraction region of the machine were performed using the VINDY computer code [2]. The TRANSPORT computer code was used for calculations of the beam transport towards the high energy experimental channels.

Table 1: Test ion beams

Accelerated test ion (before the foil)	Extracted test ion (after the foil)	Energy (MeV)
H^-	H^+	65
H_2^+	H^+	32
$^4He^+$	$^4He^{2+}$	28
$^{40}Ar^{6+}$	$^{40}Ar^{15+}$	120
$^{12}C^{3+}$	$^{12}C^{6+}$	105
$^{84}Kr^{14+}$	$^{84}Kr^{28+}$	315

DESIGN OF THE FRONT EXTRACTION SYSTEM

The main requirements in conceptual designing the front extraction system were: (1) to extract the test beams from the machine efficiently, (2) to bend the test beams towards the extraction transport line accurately, and (3) to focus the test beams to be accepted fully by the extraction transport line, which includes the DN 100 vacuum tubes.

The stripping foil technique is highly efficient, especially for light ions. For example, close to 100 % of the accelerated H^- or H_2^+ ions turn into the H^+ ions after crossing the stripping foil. This effect will help us considerably in minimizing the radiation contamination of the main chamber and the other parts of the machine. The similar situation is with the accelerated $^4He^+$ and $^{12}C^{3+}$ ions. In case of the heavier accelerated ions, the extraction efficiency is lower but still acceptable. For example, only 40 % of the accelerated $^{40}Ar^{6+}$ ions will turn into the $^{40}Ar^{15+}$ ions, and only 25 % of the accelerated $^{84}Kr^{14+}$ ions will become the $^{84}Kr^{28+}$ ions.

The scheme of the front extraction system is shown in Fig. 1. It consists of the following main parts:

- the stripping foil positioning mechanism (FM1), including the exchange chamber (EXC1);
- the extraction box (EB) with the bending magnet (BM0) and the horizontally focusing (quadrupole) magnet (QM0);

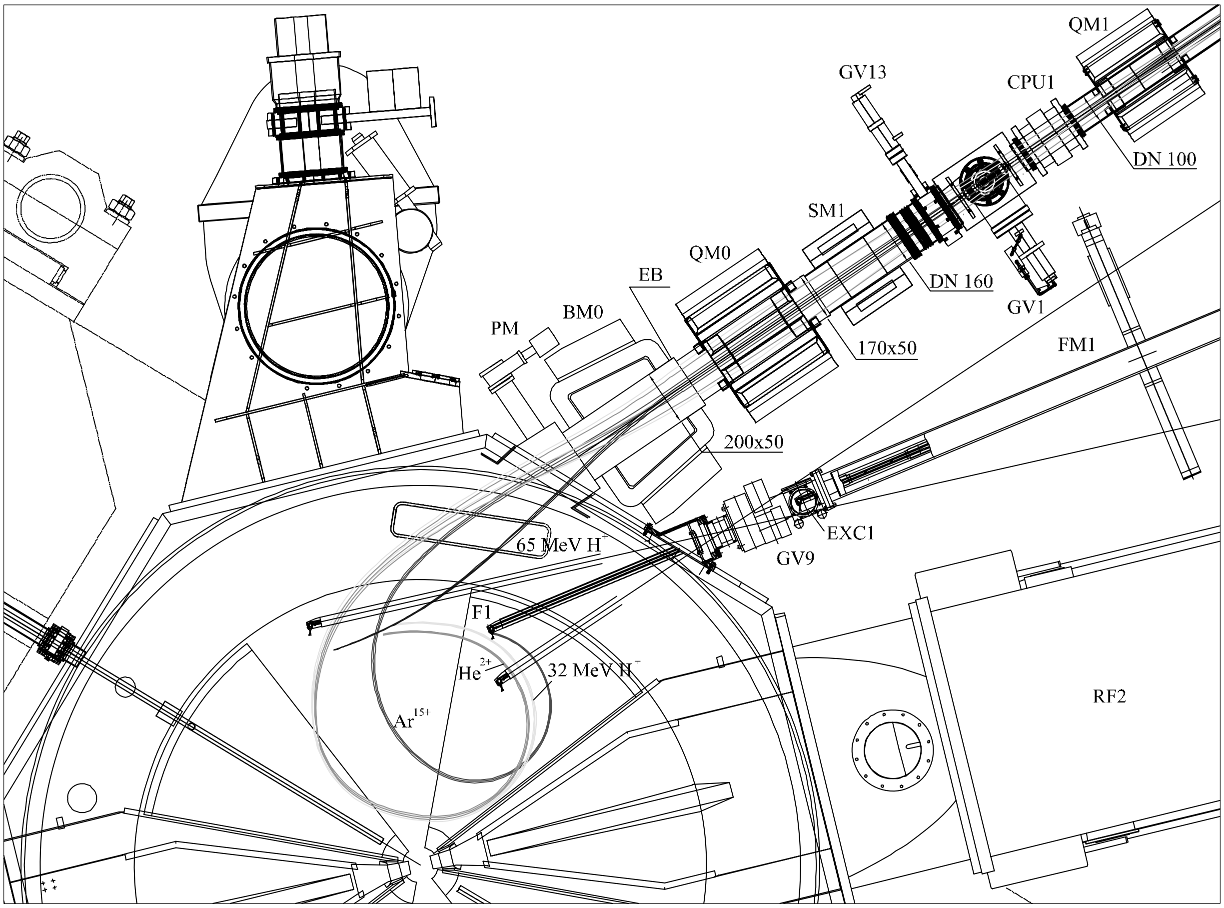

Figure 1: The scheme of the front extraction system of the VINCY Cyclotron: F1 – stripping foil, GV1, GV9 and GV13 – gate valves, EXC1 – exchange chamber, FM1 – stripping foil positioning mechanism, PM – wire grid beam position monitor, EB – extraction box, BM0 – bending magnet, QM0 – horizontally focusing magnet, SM1 – steering magnet, DB1 – diagnostic box, CPU1 – capacitive pick-up probe, QM1 – first focusing magnet, and RF2 – front resonator of the radiofrequency system of the machine.

- the extraction transport line, including three focusing (quadrupole) magnets (QM1, QM2 and QM3) and two diagnostic boxes (DB1 and DB2);
- the main bending magnet (BM1), directing the beam either towards the channel for production of radionuclides or towards the other high energy experimental channels.

The stripping foil positioning mechanism (FM1) is used for the radial and azimuthal positioning of the stripping foil (F1). Its radial and azimuthal operating ranges are 695-897 mm and 274-326 deg, respectively (in the coordinate system of the machine). In addition, it enables exchange of the stripping foil without disturbing the vacuum inside the main chamber. This is achieved by removing the stripping foil from the main chamber to the exchange chamber (EXC1). After closing the gate valve between these two chambers (GV9) and opening the venting valve of the exchange chamber, it will be possible to open the vacuum window of the exchange chamber and replace the stripping foil. The thickness of the stripping foil is 1-2 µm, its dimensions are 20×20 mm^2, and it is made of graphite. The stripping foil is placed at the end of a long supporting rod that can travel through a long bellows, enabling its maximal linear movement of 1,770 mm (see Fig. 1). A short bellows, placed between gate valve GV9 and the flange of the main chamber, enables the angular positioning of the supporting rod within ±10 deg relative to its central position. Two servo motors with absolute encoders will be used for these radial and angular movements.

Calculations of the dynamics of the test beams in the extraction region were performed using the VINDY computer code [2], with the corresponding measured isochronized magnetic field maps. These calculations enabled us to determine the optimal positions of the stripping foil and the central trajectories and envelopes of each of the test beams (see Fig. 1). They were performed from the stripping foil (F1) down to the entrance plane of the bending magnet (BM0). Figure 2 gives the horizontal and vertical envelopes of the 65 and 32 MeV H$^+$ test beams, obtained from the H$^-$ and H$_2^+$ accelerated beams, in the extraction region. The TRANSPORT computer code was used to calculate the beam transport from the entrance plane of the bending magnet (BM0) along the rest of the front extraction system, which includes the horizontally focusing magnet (QM0), three focusing magnets (QM1, QM2 and QM3) and the main bending magnet (BM1) (Fig. 1 contains only QM1).

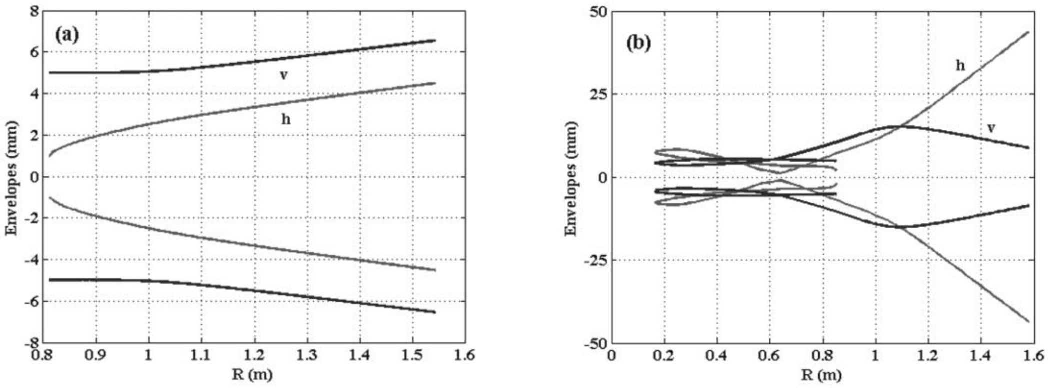

Figure 2: The horizontal (h) and vertical (v) envelopes of (a) the 65 MeV H^+ test ion beam, and (b) the 32 MeV H^+ test beam as functions of the distance from the center of the machine. They are given from the stripping foil (F1) to the entrance plane of the bending magnet (BM0).

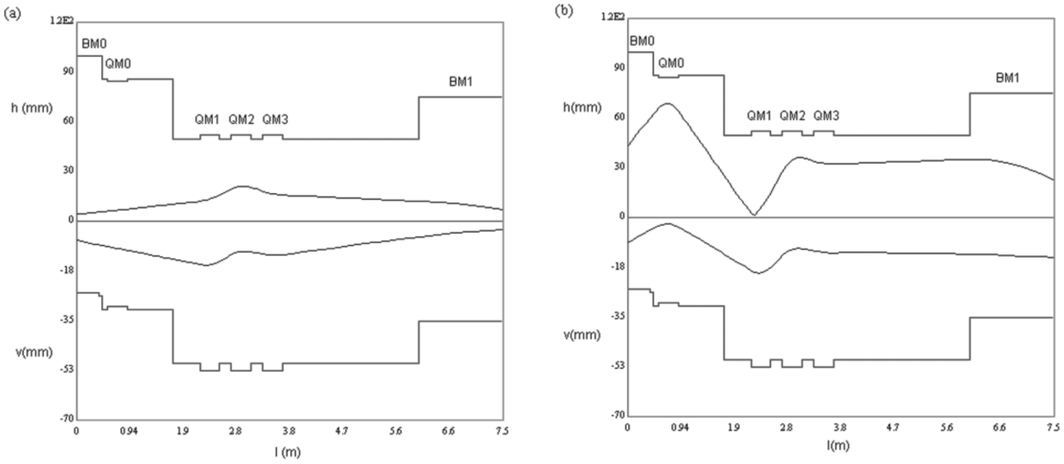

Figure 3: The horizontal (h) and vertical (v) envelopes of (a) the 65 MeV H^+ test ion beam, and (b) the 32 MeV H^+ test beam along the front extraction system. They are given from the entrance plane of the bending magnet (BM0) to the exit plane of the main bending magnet (BM1).

Figure 3 shows the horizontal and vertical envelopes of the 65 and 32 MeV H^+ test beams along the system. The resulting maximal magnetic induction of the bending magnet is 730 mT and its maximal bending angle is ±13 deg relative to the axis. The required maximal magnetic induction gradient of the horizontally focusing magnet is 3 T/m. However, we have decided to use for this purpose a standard quadrupole magnet of the maximal magnetic induction gradient of 5 T/m.

CONCLUSIONS

We have successfully finished conceptual designing the front extraction system. The basic parameters of all its parts have been determined, with all the test beams accepted fully by the DN 100 vacuum tubes of the extraction transport line. Thus, we have decreased the price of fabrication of this part of the machine relative to the prices of its previous versions [3]. The extraction box (EXC1) has a rectangular shape, and ends after the horizontally focusing magnet (QM0) with a DN 160 flange. The bending magnet (BM0) has a special shape, in accordance with the shape of the extraction box, while the horizontally focusing magnet is a standard quadrupole magnet. The extraction transport line contains the standard focusing magnets (QM1, QM2 and QM3), with the DN 100 vacuum tubes. The stripping foil positioning mechanism (FM1) enables quick and easy exchange of the stripping foil (F1) without disturbing the vacuum inside the main chamber.

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